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Not just phonology: a longitudinal study of dyslexia subtypes based on the distinction between reading accuracy and reading rate

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Introduction: Previous cross-sectional investigations by Shany and colleagues have provided evidence of double dissociation among dyslexics between word reading accuracy and (pure) word reading rate. A rate-disabled subtype (with intact reading accuracy) evinced deficits only in rapid naming (RAN); An accuracy-disabled subtype (with intact reading rate) showed deficits in phonological awareness (PA) and morphological awareness (MA) but not RAN.

Method: The present longitudinal study followed 639 Palestinian Arabic-speaking children from preschool to Grade 1 with the aim of determining (1) whether a dissociation between PA C MA and RAN is apparent among pre-literate preschoolers, (2) whether the PA C MA-disabled subgroup constitutes a mild form of Developmental Language Disorder (DLD), (3) whether our three disabled subgroups (PA C MA-only, RAN-only, and PA C MA-plus-RAN) can be differentiated on preschool early literacy measures and, (4) whether the three at-risk subgroups develop into selectively rate-disabled, accuracy-disabled, or doubly-disabled (accuracy C rate) readers in Grade 1?

Results: Our findings confirmed the existence of two distinct selectively disabled/at-risk subgroups in preschool: a RAN-only subgroup with intact PA and MA and a PA C MA subgroup with broad impairments across language measures but intact RAN. Grade 1 reading data also confirmed that the RAN-disabled subgroup became slow but accurate readers, whereas the PA C MA subgroup developed into inaccurate and slow readers.

Discussion: Our study indicates partial dissociation between early dyslexia subtypes, each displaying distinct and non-overlapping cognitive-linguistic profiles in preschool. The study also revealed a strong association between reading accuracy and reading rate among beginning readers. This study emphasizes the importance of considering heterogeneity in reading outcomes as well as multiple oral language skills beyond the well-documented role of PA.

KEYWORDS
dyslexia, subtypes, Arabic, prediction, longitudinal study, phonological awareness, morphological awareness, RAN

1 Introduction

A sizeable body of research has endeavored to subtype struggling readers with the goal of creating effective interventions for each profile (Norton and Wolf, 2012).

One of the most influential typologies emerged from the Coltheart/Baron dual-route model of word reading (Castles and Coltheart, 1993; Coltheart et al., 1993, 2001). According to this model, no single procedure yields correct pronunciations of both non-words and exception words in English: Non-words such as *slint* can only be correctly pronounced via grapheme-phoneme correspondence rules, the "non-lexical" route, whereas exception words such as *knight* can only be read through the "lexical" route. The model classifies selective impairments in reading exception words as "surface dyslexia," while selective impairments in reading non-words is classified as "phonological dyslexia." However, the applicability of the dual-route framework is questionable in transparent orthographies in which most words have regular grapheme-phoneme correspondences, and irregular words are rare (Ziegler and Goswami, 2005). In such orthographies, which are the global norm (Daniels and Bright, 1996; Aaron and Joshi, 2006), accuracy levels approach ceiling by the end of Grade 1 (Seymour et al., 2003). Consequently, fluency and speed are often the more discriminating measures of reading difficulty. Indeed, various studies conducted in Dutch (Yap and van der Leij, 1993), Finnish (Lyytinen et al., 2004), German (Wimmer, 1993), Greek (Porpodas, 2006), Hungarian (Csepe, 2006), Hebrew (Breznitz, 1997; Share and Levin, 1999), Italian (Zoccolotti et al., 1999), and Norwegian (Lundberg and Høien, 1990) showed that many dyslexics attain high levels of reading accuracy but remain slow.

The emphasis on reading rate and fluency in research in transparent orthographies, together with the recognition of the importance of reading fluency since the landmark publication of the National Reading Panel Report (2000), has helped refine the definition of dyslexia on both sides of the Atlantic by giving attention to both word reading speed and accuracy. DSM-5 (2013) defines learning disability in reading as "*inaccurate or slow and effortful word reading*" (see also the British Psychological Association, 1999). DSM-5 not only explicitly refers to two dimensions of word reading difficulty—accuracy and rate, but also implies the possibility of dissociation between these two dimensions. This suggests that the distinction between difficulties in reading rate vs. reading accuracy may be a fruitful avenue for subtyping investigations and, furthermore, one that may have universal applicability.

In a series of pioneering studies exploring subtypes of dyslexia based on accuracy/rate criteria, Lovett (1984a,b, 1987) classified a clinical sample of children into two subtypes: accuracy-disabled or rate-disabled. However, Lovett did not establish a true double dissociation between the accuracy-only and rate-only subtypes, as no rate criterion was specified for the accuracy subgroup who were both inaccurate *and* slow readers. Leinonen et al. (2001) also explored accuracy vs. rate subtypes among Finnish reading-disabled adults. They identified a rate-only disabled ("hesitant") subgroup in addition to an accuracy-only ("hasty") subgroup, but both subgroups were below average on both rate and accuracy and, therefore, cannot be considered "hard" or "true" subtypes in the sense of intact performance on one dimension, co-occurring with impaired performance on the other (see Stanovich and Siegel, 1994).

Recently, Shany et al. reported true double dissociation between pure rate and accuracy in Hebrew (Shany and Breznitz, 2011; Shany and Share, 2011) and in Arabic (Shany et al., 2023), suggesting that rate-disabled dyslexics have a selective deficit in reading rate while maintaining normal reading accuracy. Accuracy-disabled dyslexics, on the other hand, were found to have impaired reading accuracy with normal levels of reading speed, and doubly-disabled dyslexics impairments in both accuracy and rate. Furthermore, all three studies showed that the two singly disabled subgroups displayed distinct cognitive-linguistic profiles. The rate-disabled subtype exhibited slow performance on RAN alone, whereas the accuracy-disabled subtype showed poor performance on phonological awareness (PA), morphological awareness (MA), and to a lesser degree, several additional verbal-linguistic measures (vocabulary, syntax, and verbal memory), but not on RAN. For instance, in the fourth-grade Hebrew study (Shany and Share, 2011), participants in the accuracy-disability subgroup evinced statistically significant deficits on three measures of morphological knowledge, verbal fluency, and verbal memory but not on working memory or a measure of syntax (pronominal reference). On the other hand, Shany et al.'s (2023) Arabic study found significant deficits in morphology and vocabulary but not in syntax. We thus examine the flip side of this issue by asking whether preschoolers with the same constellation of deficits—PA and MA, demonstrated weaknesses in these other non-phonological aspects of language processing.

The broad profile of linguistic deficits in Shany's accuracy-disabled subtype raises the question of whether this subgroup can be classified as cases of Developmental Language Disorder (or DLD, formerly SLI). Examining this subgroup on a case-by-case basis, Shany et al. (2023) concluded that although the label of DLD was not applicable; the accuracy-disabled subtype, on the whole, can be characterized as having broad linguistic weaknesses in multiple domains relevant to word-level processing, namely, phonology, morphology, and lexicon.

Note that Shany's rate/accuracy typology is congruent with ample research in shallow orthographies suggesting that PA is primarily related to reading accuracy (Elbeheri and Everatt, 2007; Puolakanaho et al., 2007; Saiegh-Haddad and Geva, 2008; Rakhlin et al., 2014; Protopapas, 2017), whereas Rapid Automatized Naming (RAN) measured in tasks requiring rapid serial naming of familiar symbols such as digits, letters, colors, and objects, is more strongly related to reading speed (Bowers and Swanson, 1991; Wolf and Bowers, 1999; Kirby et al., 2003; Saiegh-Haddad, 2005; Breznitz, 2006; Taibah and Haynes, 2011; Landerl et al., 2019; Tibi and Kirby, 2019). A large body of evidence now shows that RAN plays an important role in reading disabilities, distinct from that of PA (e.g., Cornwall, 1992; Cutting and Denckla, 2001; Wolf et al., 2002; Kirby et al., 2003; Georgiou et al., 2012). Furthermore, RAN and PA have been found to have distinct genetic etiology with both shared and unique genes (Naples et al., 2009).

The distinctive pattern of cognitive deficits emerging in Shany's subtyping studies bears a striking resemblance to the Double-Deficit Hypothesis of Wolf and Bowers (1999). However, it is essential to note two fundamental differences between these two approaches. First, Shany classifies dyslexics on the basis of their *reading* profiles, specifically word reading accuracy and (pure) rate, whereas Wolf and Bowers (1999) Double-Deficit approach classifies subtypes according to the *cognitive* profiles, namely, PA and RAN. Second, the Double-Deficit hypothesis only focuses on PA, whereas Shany includes morphological deficits alongside phonological deficits. This better aligns with contemporary research indicating (i) a central role for morphology in reading development and reading difficulties (Kirby and Bowers, 2018; Berthiaume et al., 2019; Levesque et al., 2021; Hasenäcker et al., 2023; Rastle, 2023) and (ii) a growing consensus that the roots of many reading difficulties including dyslexia can be found in broader linguistic deficiencies and not just phonology (Catts, 1996; Catts and Kamhi, 2005; Scarborough, 2005; Adlof and Hogan, 2018; Snowling and Hulme, 2021).

Since our study was undertaken among native speakers of Arabic, we provide a brief overview of the Arabic language, writing system, and curriculum. While most of the research has been conducted in English and a handful of Western European languages, all written in Roman Alphabet; it is important to consider other non-European languages and non-alphabetic orthographies. Arabic is a particularly valuable case study owing to its unique linguistic and orthographic features, including diglossia, multiple visual-orthographic features, and non-concatenative morphology.

1.1 The Arabic language and orthography

Arabic is the sixth most spoken language in the world (Eberhard et al., 2023). It is a Semitic language spoken by ∼274 million people globally and is also an official language in 25 states (Eberhard et al., 2023). It has been suggested that the development of Arabic word reading is influenced by three critical language and orthographic features: diglossia, morphological structure, and orthographic complexity (Daniels and Share, 2018; Saiegh-Haddad, 2018). Diglossia is a sociolinguistic phenomenon in which two varieties of a language—in the present context, Spoken Arabic (SA) and Modern Standard Arabic (MSA) coexist and are used by the same speakers for different purposes (Ferguson, 1959; Maamouri, 1998; Saiegh-Haddad, 2012; Myhill, 2014). Spoken Arabic, which is actually a host of spoken (regional and national) dialects, is used for daily communication, whereas MSA is used for formal communication and is uniform across the entire Arabic world. The linguistic distance between spoken Arabic and MSA poses a serious obstacle for novice readers as they must learn to read many words that are not the same as the spoken words with which they are familiar (Saiegh-Haddad, 2018). Hence, despite the high degree of decipherability (decodability) that is offered by the transparent (fully voweled, *mashkoul*) Arabic script that beginners learn to read, accurate reading is not necessarily sufficient for lexical identification owing to diglossia. Consequently, from a very early age, Arabic-speaking children intuitively gravitate toward larger grain size units (i.e., morphological units) to facilitate lexical access (Shalhoub-Awwad and Leikin, 2016). This tendency is enhanced by the prevalence of a rich morphology based on non-concatenative word-building procedures (Holes, 2004), which contrasts sharply with the concatenative (stem + suffix) procedures that dominate word formation in Indo-European languages such as English. Most Arabic content words (all verbs and most nouns and adjectives) consist of two non-concatenated, interwoven derivational morphemes, a root, and a word pattern (Saiegh-Haddad and Henkin-Roitfarb, 2014). The root is a discontinuous and unpronounceable bound morpheme, usually represented by three consonants, conveying the core semantic meaning of the word. The word pattern, however, is a fixed phonological-prosodic template that is also a discontinuous, unpronounceable bound morpheme with slots for the root consonants and which carries categorial meaning and morphosyntactic information. It also determines many of the phonological characteristics of the surface form (vocalic, syllabic, and prosodic structures) (Boudelaa and Marslen-Wilson, 2015). This non-linear root-and-word pattern word-formation system is transparently represented orthographically and plays a central role in the organization of the Arabic mental lexicon (Boudelaa, 2014). Numerous studies have consistently highlighted the role of morphological awareness in word recognition and spelling development (e.g., Saiegh-Haddad, 2013; Taha and Saiegh-Haddad, 2017; Tibi and Kirby, 2017; Tibi et al., 2020). Additionally, recent research supports the early emergence of derivational morphological processing in reading (e.g., Shalhoub-Awwad and Leikin, 2016; Shalhoub-Awwad, 2020, 2022).

Visual-orthographic complexity is another feature that is thought to be another major source of difficulties in learning to read and write Arabic prolonging acquisition compared to other languages (Ibrahim et al., 2002; Abu Ahmad et al., 2014; Eviatar and Ibrahim, 2014; Yassin et al., 2020). Unlike alphabetic writing systems, in which consonants and vowels have equivalent status, the Arabic abjad has two sets of graphic signs: horizontally arrayed consonantal letters and vertically arrayed extra-linear diacritic-like signs which appear primarily above but, at times, below the letters. Extensive ligaturing[1] and allography[2] are further complications challenging the novice reader/writer (Daniels and Share, 2018; Yassin et al., 2020).

1.2 The preschool and first-grade literacy curriculum in Israel

The preschool educational system (Kindergarten and pre-kindergarten) in Israel is physically and institutionally separate from the elementary school system. Elementary schooling only begins in Grade 1 when formal reading instruction commences, hence almost all Arabic-speaking children enter school (Grade 1) as non-readers (Saiegh-Haddad and Everatt, 2017). These two systems also employ separate curricula: one focusing on literacy preparation for preschool-aged children (three to 5 years old), and another addressing Arabic language education for elementary school students in Grades one through six (Ministry of Education, 2009). The curriculum for literacy preparation in preschool (3- to 5-year-olds)—*Foundations of Reading and Writing in Arabic as a Mother Tongue: A Preschool Curriculum (Ministry of Education, 2008)* aims to enhance the development of early literacy with special focus on the basic components that prepare children for reading and writing at school. The curriculum delineates precise objectives for each age group (three to 6 years old) and underscores the necessity for explicit instruction of five language and literacy components, including phonological awareness, morphological awareness, letter knowledge, print concepts, and lexical knowledge. However, the curriculum does not provide any specific guidance

1 The majority of the letters in a word are connected to the adjacent letters, creating a word that forms a single unbroken graphic unit. Thus, three types of words are possible: a fully connected word بيت *bayt "home"*, a partly connected word مولود *mawlu:d* "born" and an entirely unconnected word ورود *wuru:d* "roses" (Yassin et al., 2020).

2 The variability of letter forms. This variability depends on two factors: first, the letter's position in the word-initial, medial, or final—and second, whether or not it connects to the letter that precedes it. Together, letter position and ligaturing create the allographic variants.

or activities that foster rapid automatized naming abilities. As for the PA component, children are expected to develop an awareness of rhymes, syllables, sub-syllabic units like consonant-vowel (CV units), and phonemes (consonants) through diverse activities, including comparison, isolation, segmentation, blending, and deletion. In terms of MA, children between 4 and 6 years of age are expected to use common nominal patterns in different words, such as the patterns of professions/occupations: CaCCa:C (e.g., /ṭˤabbax/"cook"), instruments: miCCa:C (e.g., *mifta:h* "key"), miCCaCa (e.g., *miknasat-un* "sweeper"), Ca:Cu:C (e.g., *ha:su:b* "computer") and places: maCCaC (e.g., *maktab* "office"), maCCaCa (e.g., *madrasat-un* 'school'). At 3–6 years of age, children are expected to use passive participles *ʔism-l'mafʕu:l* such as maCCu:C (e.g., *maktu:b* "written/letter") (Shalhoub-Awwad and Khamis-Jubran, 2021). In addition, kindergarten children are expected to gradually build their vocabulary knowledge through exposure to a rich language environment, interactive learning experiences, and explicit vocabulary instruction provided by teachers and caregivers. This goal is promoted by involving children in tasks like organizing and categorizing objects or images and by introducing word families for them to utilize. As for reading, the curriculum's objective "is not to teach children the decoding of words and texts or the writing of texts using conventional spelling" p. 10, but rather facilitate the acquisition of reading and writing at school (Saiegh-Haddad and Everatt, 2017). Preschool children are expected to develop basic sight word recognition by recognizing and reading common sight words encountered in books, classroom materials, and environmental print. Secondly, they are encouraged to attempt reading new words, often by engaging with storybooks and identifying repeated words. In grade one, however, systematic reading instruction is based on a phonic approach. The curriculum places a strong emphasis on developing rapid and accurate decoding skills for decontextualized words. Effective, targeted teaching and ample practice in word decoding is aimed to promote significant levels of accuracy by the end of first grade. Children are also expected to master all the Arabic letters in their various allographic forms (positional variants), along with diacritic-like signs (*tashkil*) indicating three short vowels, consonant doubling, and vowel nullification. They are also expected to be able to read simple texts accurately and spell orthographically shallow content words, high-frequency function words like pronouns and prepositions.

To sum up, beginning in Grade 1, systematic phonics-based methods are used to teach children to read and write a non-concatenative root-and-pattern language written in an orthography that, although nominally transparent in terms of letter-sound correspondence, confronts the novice with a variety of unique challenges.

1.3 The present study

All three Shany studies cited above were cross-sectional and focused on children either in Grade 4 or adults who had already been taught to read. This raises the question of whether the distinct cognitive-linguistic profiles identified in these studies are causes or consequences of reading disability. Particularly noteworthy is the accuracy-disabled subtype, which exhibited notable deficiencies primarily in PA and MA both of which have reciprocal relationships with literacy achievement

Limited exposure to written materials might have resulted in missed opportunities to enhance their linguistic and metalinguistic abilities (Stanovich et al., 1997). Thus, it is important to explore the predictive value of these unique cognitive-linguistic profiles before formal reading instruction commences. The present longitudinal study addresses the cause-vs.-consequence issue in the context of a longitudinal study launched prior to the onset of reading instruction, thereby providing cleaner and more robust evidence concerning the directionality of influence and the causal- predictive status of the cognitive-linguistic deficits shown by older fourth-grade readers in our previous studies in Hebrew (Shany and Share, 2011) and Arabic (Shany et al., 2023). Moreover, the early identification of the sources of later reading difficulties will lay the foundations for developing effective tools for diagnosis and intervention. This issue has special significance since distinct cognitive-linguistic and reading profiles among dyslexic subtypes calls for different interventions.

The present longitudinal study addressed questions: (1) Is a dissociation between PA + MA and RAN apparent in kindergarten? (2) Does the PA + MA-disabled subgroup constitute a mild form of Developmental Language Disorder (DLD)? (3) Can the three disabled subgroups be differentiated on early preschool literacy abilities? (4) Will kindergartners who show selective deficits in RAN or PA + MA develop into selectively rate-disabled and accuracy-disabled readers, respectively, in Grade 1? and the doubly disabled subgroup become accuracy *and* rate disabled readers in first grade? We anticipated double dissociation between the PA + MA and RAN subgroups in kindergarten, expecting that the PA + MA subgroup would present a mild case of DLD by manifesting low performance in multiple language domains. Additionally, we predicted that the PA + MA and the doubly disabled subgroups would show significantly lower performance relative to the intact group and the RAN disabled subgroup on preschool literacy abilities. Finally, we predicted that a selective deficit in PA + MA would lead to an intact rate but inaccurate reading, while selective deficits in RAN would lead to intact accuracy but a slow reading rate, and the double deficiency in RAN and PA + MA would result in inaccurate and slow reading in first grade.

2 Materials and method

2.1 Design

The current study was part of a larger longitudinal study conducted at the Edmond J. Safra Brain Research Center for the Study of Learning Disabilities at the University of Haifa. Here, we focus on the data that was obtained in kindergarten and Grade 1. As already noted above, formal reading instruction in Israel only begins in Grade 1, as in most European countries.

2.2 Participants

A sample of 1,158 Palestinian Arabic-speaking children were recruited from 73 kindergartens in the north of Israel. This region contains 80% of the total Arab-speaking population in Israel and includes the four main Northern Palestinian dialects: Urban-northern, Rural-Northern, Druze, and Bedouin. Sample recruitment was based on the welfare index of schools,[3] ranging from two (medium-high) to five (low), and their proportional distribution in the population.[4]

2.2.1 The sample in the present study

Before selecting the subgroups that were the focus of the present study, we applied three criteria: firstly, we excluded 198 children who were not tested in Grade 1 owing to the school closures in March 2020 that followed the outbreak of the COVID-19 pandemic. Secondly, we excluded children who scored one standard deviation or more below the mean ($N = 137$; $M = 9.6$, $SD = 2.80$) on the Raven non-verbal intelligence test (Raven et al., 1998). Lastly, a considerable number of children made errors on the RAN tasks.[5] Consequently, we only included children who made one or zero errors thereby excluding 184 children. We reasoned that a single error on a 50-item test was unlikely to significantly alter the total naming time. After these criteria were applied, our final study sample consisted of 639 children (291 boys and 348 girls, $M_{age} =$ 5.7 years, $SD = 0.27$). This cohort was followed longitudinally from Kindergarten to March Grade 1 when testing was discontinued after the COVID-19 outbreak and school closures.

To check the possibility of bias in the reduced sample due to the elimination procedure, we compared the initial sample ($N =$ 1,158) to our reduced sample ($N = 639$) on a range of background measures including age, gender, non-verbal ability and SES. No significant differences were found between the two samples on any background measure except for the Raven which was anticipated given the elimination procedure.

2.2.2 Criteria for selection of subgroups

Subgroup selection was based on the performance of the children in kindergarten on multiple measures of PA, MA, and RAN tasks. Composite *Z*-scores were calculated for each of the three domains. The phonological composite and the morphological composite were then combined into a single phonological-morphological (PA + MA) composite score. The bivariate correlation between PA + MA and RAN composite variables in our sample ($N = 639$) was $r = 0.16^{**}$ ($p < 0.01$). This low (almost inconsequential) correlation supports the idea of dissociability between the two dimensions underlying the rate-accuracy subtyping scheme (see Table 2).

We followed conventional practice in the reading disability literature and used a 25th percentile low achievement cut-off on each measure; performance above the 35th percentile was deemed to be in the normal range (see e.g., Bowers and Wolf, 1993; Stanovich et al., 1997; Shany and Share, 2011; Shany et al., 2023). This procedure yielded four subgroups, two singly disabled, one doubly disabled, and one non-disabled "control" subgroup. Children scoring below the 25th percentile mark on the PA + MA composite but above the 35th percentile on the RAN composite were labeled *PA + MA disabled* ($N = 94$, 14.6% of the sample); children scoring below the 25th percentile mark on the RAN but above the 35th percentile on PA + MA composite z-score were labeled *RAN disabled* ($N = 93$, 14.5% of the sample); children scoring below the 25th percentile on both composite measures (PA + MA and RAN) were considered *doubly-disabled* ($N = 51$, 8% of the sample). Finally, as a control group, children scoring above the 35th percentile mark on both the RAN and PA + MA composite z-scores were labeled *non-disabled* ($N = 122$, 19% of the sample). Initial comparison of the four groups on background measures indicated significantly higher non-verbal ability scores in the RAN disabled subgroup ($M = 10.4$, $SD = 2.03$) relative to both the PA + MA disabled ($M = 9.4$, $SD = 1.85$) and the doubly-disabled subgroups ($M = 9.2$, $SD = 1.62$), $F_{(2,238)} = 8.056$, $p < 0.0001$. To eliminate this potential, confound, we reconstituted our groups by forming matched foursomes—one child from each of the four groups individually matched as closely as possible on age, gender, SES (welfare index), and Raven scores. This yielded 50 children in each of the singly disabled subgroups, 47 children in the doubly disabled subgroup, and 60 children in the control group.

2.3 Procedure

The data were collected in mid-late Kindergarten and again in mid-Grade 1. The testing took place in two-three sessions (each lasting ∼20–30 min) with a maximum time interval of 1 week. At each testing phase, all participants were individually administered a battery of linguistic, cognitive, early literacy, and (in Grade 1) reading measures. The only exception was the Raven's Matrices test, which was administered in small groups of four to five participants in Grade 1. The order of the tasks within each battery was counterbalanced across participants, but the order of the items per task was fixed. Each child was assessed in a quiet room in his/her kindergarten/school by trained Arabic-speaking testers (with a background in education, psychology, or speech pathology) who were matched according to their dialect to the child's specific dialect. To achieve maximally standardized administration procedures, all testers participated in multiple training workshops and conducted simulations.

2.4 Materials

Four types of measures were used in this study: linguistic, cognitive, early literacy, and reading. All measures were either developed from scratch by the Safra team or adapted from existing clinical or research instruments.

3 The Ministry of Education's Welfare Index is a composite comprised of several components, including the education level of the most educated parent (40%), the family's per capita income level (20%), the school "periphery" status (20%), and immigration from an underdeveloped country (20%).

4 According to the Central Bureau of Statistics (2018) the distribution of the Arab-speaking population in Israel was 73% Arabs (primarily Muslims and Christians), 17% Druze, and 10% Bedouin.

5 Of the total sample, 13% committed two or more errors on the RAN colors task and 16% on the RAN objects task.

All tasks were piloted before each testing phase of the study.

2.4.1 Kindergarten measures

2.4.1.1 *Phonological awareness*

All PA tasks were developed for this study by the Safra team. As there are no existing corpora in Arabic that provide childhood printed word frequencies, target words were chosen from children's storybooks and were piloted (with an independent sample of 50 Kindergarten children) to determine their frequencies. Only items with high frequencies (familiarity of 90% and above) were included in the tasks. Prior to administering each task, two examples were given; the first was designed to model the task by providing an explicit demonstration by the examiner of the desired manipulation. In the second example, the child was asked to provide the answer. If the child failed in this second example, two additional examples were given. In all PA tasks, the child was first required to repeat a word spoken aloud by the examiner and then perform a phonological manipulation. Feedback was provided for the examples, but not during the test phase. Each task included 12 items, and one point was awarded for each correct response.

Initial CV isolation in disyllabic words **(developed by Jabbour-Danial et al., 2019a)**

This task includes six *CV.CVC words and six CVC.CVC words.* Children were asked to isolate the initial CV, i.e., *ʔu:l dulfi:n* "say dolphin", *bkilmit dulfi:n mnismaʕ bilʔawwal* "in the word dolphin we hear at first"_____ *(du/d/ʔed).*[6] (Cronbach's alpha = 0.94, test-retest reliability = 0.83).

Initial CV isolation in monosyllabic CVC words **(developed by Jabbour-Danial et al., 2019b)**

Participants were asked to isolate the CV (sub-syllabic or "core") unit, i.e., *ʔu:l ta:j* "say crown", *bkilmit ta:j mnismaʕ bilʔawwal* "in the word crown we hear at first"_____ (*ta:/t/ʔet*). (Cronbach's alpha = 0.92, test-retest reliability = 0.91).

Initial consonant isolation in CVC words **(developed by Abu-Ahmad et al., 2019a)**

In this task, children isolated the initial consonant, i.e., *ʔu:l nu:r* "say light", *bkilmit nu:r mnismaʕ bilʔawwal* "in the word light we hear at first"______(*n*/*nu:*). (Cronbach's alpha = 0.95, test-retest reliability = 0.93).

Initial Consonant Isolation in CCVC Words **(developed by Abu-Ahmad et al., 2019b)**

Here, children were required to isolate the initial consonant in complex onset, i.e., *ʔu:l kla:b* "say dogs", *bkilmit kla:b mnismaʕ bilʔawwal* "in the word *dogs*, we hear at first"______(*k/ʔek*). (Cronbach's alpha = 0.95, test-retest reliability = 0.88).

6 Arabic letters have two names—standard and colloquial: Standard names are tri-phonemic (e.g., *da:l*; *qa:f*) with the exception *ʔalif* and *hamza*. On the other hand, the colloquial letter names are also tri-phonemic but start with a fixed (ʔɛ-) prefix and end with the target consonantal phoneme ʔɛC (e.g., *ʔɛd; ʔɛq)* (for details see Abu-Ahmad and Share, 2021).

2.4.1.2 *Morphological awareness*

Noun pluralization: dual and plural forms **(developed by Shalhoub-Awwad et al., 2019a)**

The tester presented a picture of a single object (e.g., *tuffaha* "apple") alongside either a picture of two of the same objects (for the dual form) or a picture of four of these objects (for the plural form) (e.g., *ʔarbaʕ tuffaha:t* 'four apples') and said while pointing to each picture in turn: Here, there is *tuffaha wahdi* "one apple", and "here there are four…"? (expected answer: *tuffaha:t*'apples'). The test items included the three plural forms: Sound feminine plural, sound masculine plural, and broken plural[7] (3, 3, 4 items, respectively) and the dual form in Arabic (five items). A correct answer was awarded one point for a maximum possible score of 12 (Cronbach's alpha = 0.82, test-retest reliability = 0.63).

Resultative adjective derivation **(developed by Shalhoub-Awwad et al., 2019b)**

In this task, 12 sentences were presented orally, along with a pair of pictures containing an event with its result. The children were asked to complete these sentences by deriving an adjective from a given verb. For example: They arranged (*rattabu)* the books. Now the books are (arranged) *mrattabi:n*. One point was awarded for producing the correct derivation (Cronbach's alpha = 0.76, test-retest reliability = 0.57).

Verb derivation test **(adapted from Novogrodsky and Kreiser, 2015, by Shalhoub-Awwad et al., 2019c)**

In this task, the child was required to complete 12 spoken sentences by deriving the correct form of the verb from the orally given noun. For example, *iddaha:n…* "the painter…", the expected answer is *bidhan* "paints". A demonstration sentence and a training sentence (with corrective feedback) were presented before the test began. One point was awarded if the child produced the correct derivation (Cronbach's alpha = 0.71, test-retest reliability = 0.64).

2.4.1.3 *Vocabulary*

Two expressive vocabulary tests (adapted from the Tavor Vocabulary Test, 2008, by Shalhoub-Awwad et al., 2019d) were administered to measure children's vocabulary breadth (Tavor, 2008).

Expressive vocabulary I

The child was presented with 11-line drawings of objects and required to say what s/he sees in the drawing. The targeted answer was always a noun. Each correct answer earned one point (Cronbach's alpha = 0.48, test-retest reliability = 0.91).

Expressive vocabulary II

In this task, the child was presented with 12-line drawings, and required to answer a question about the drawing (e.g., what do you see here? What is he doing? How does he feel?). The targeted answer could be either a noun, a verb, or an adjective. Each correct answer

7 Broken plurals are nouns that are inflected non-linearly as in the case of woman/women in English. For example, the singular noun *mufta:h* "key" is non-linearly inflected to the broken plural *mafa:ti:h* "keys".

earned one point (Cronbach's alpha = 0.69, test-retest reliability = 0.83).

2.4.1.4 *Syntax*

***Expressive syntax* (developed by Shalhoub-Awwad et al., 2019e)**

This test included 10 items and was administered to assess children's proficiency in sentence production. In the first six items, the children were shown pictures and asked what was happening. In the remaining four items, the children were shown pictures and asked to answer "how" questions about each picture (e.g., "How do we know that this boy has finished eating?") (Cronbach's alpha = 0.74, test-retest reliability = 0.72).

***Receptive syntax* (adapted to Arabic from the clinical evaluation of language fundamentals, CELF (Semel et al., 2000, by Shalhoub-Awwad et al., 2019f)**

This task evaluated children's capacity to understand sentences. The child heard a sentence and was asked to point to the appropriate picture out of three possibilities. The target sentences were syntactically complex, containing conjunctions, relative clauses, adjectives, negative elements, and time clauses (e.g., "The child who is being carried by his mother is clapping"). One point was given for a correct answer (Cronbach's alpha = 0.56, test-retest reliability = 0.62).

2.4.1.5 *Cognitive measures*

Non-verbal ability was assessed with *Raven's Colored Progressive Matrices* (Raven et al., 1998)

Following an explicit demonstration example, participants were asked to select the missing part of a geometric pattern from several alternatives. We administered all three sets in this test (sets A, B, and AB, odd items only, 18 items) (test-retest reliability in our pilot sample = 0.80).

Rapid automatized naming

As a considerable number of kindergarten children in the Arabic-speaking population do not know the names of many letters or digits, naming speed was assessed in kindergarten with colors and objects. Each task was composed of 50 stimuli (five stimuli repeated randomly ten times) which the child was asked to name as rapidly as possible. The pronunciation of the words (colors and objects) was identical in all four dialects. The total naming time was measured, as well as the number of errors in each test. As already noted earlier, only subjects with one or no errors were included in the analyses reported below.

***Color naming (RAN colors)* (adapted to Arabic from Denckla and Rudel, 1976, by Shalhoub-Awwad and Jabbour-Danial, 2019a)**

This task consists of five colors: *ʔahmar* "red", *ʔaxdˁar* "green", *ʔazraq* "blue", *ʔaswad* "black", *ʔasˁfar* "yellow". The choice of these specific colors was based on a study by Meir and Aasi-Khraysh (2017), who found that Arabic-speaking children at the age of 4:07–5:06 tended to name these colors faster than other colors with 95% accuracy. The total naming time was recorded, as well as the number of errors in each test (Test-retest reliability = 0.83).

***Object naming (RAN objects)* (adapted to Arabic from Denckla and Rudel, 1976 by Shalhoub-Awwad and Jabbour-Danial, 2019b)**

This task consists of five objects: *lion, ball, chair, flower*, and *clock,* found to have high familiarity (80–100%) in our pilot study. The pronunciation of the words was identical in all four dialects of the current sample (except for the word "clock", which has two variations *saʕa and seʕa,* which were not considered to affect naming speeds. The total naming time was measured, as well as the number of errors in each test (test-retest reliability = 0.63).

2.4.1.6 *Letter knowledge*

Two letter knowledge tasks were developed for the current study: *Letter Name Identification* and *Letter Name Retrieval,* which were administered in kindergarten.

***Letter name identification* (developed by Shalhoub-Awwad et al., 2019g)**

Based on our pilot study, high, medium, and low-familiarity letters were selected. The task consisted of 14 sets of four letters in the cardinal (non-ligatured) form. For each set, the child was asked to point to one of four letters that matched the standard letter name read out loud by the examiner. One example was given prior to testing. A correct answer was awarded 1 point (Cronbach's alpha = 0.83, test-retest reliability = 0.85).

***Letter name retrieval* (developed by Shalhoub-Awwad et al., 2019h)**

Fourteen high familiarity letters (above 76% recognition accuracy, M = 84.2, SD = 5.54) were presented in their cardinal form in random order on cards (one letter per card). The child was asked to pronounce the standard name of the letters. Before testing, each child received two practice sessions, and feedback was given by the examiner emphasizing the standard letter name (not the colloquial name (ʔɛC), letter sound (phoneme), or CV). Each correct answer was awarded 1 point (Cronbach's alpha = 0.89, test-retest reliability = 0.91).

2.4.1.7 *Orthographic knowledge*

Word recognition (adapted to Arabic from Van der Kooy-Hofland et al., 2012, by Shalhoub-Awwad and Yassin, 2019a). This 12-item test assessed the ability to match the spoken form of word to its written form. The children were asked to choose the printed form of a spoken word from four alternatives which were assigned different scores according to the orthographic proximity to the correct target spelling as follows: the correct target word (3 points), a foil which began with the same two letters as the target word (2 points), a foil with the same initial letter as the target word (1 point), and a foil with no letters in common with the target word (0 points). Half of the target words were words that children are frequently exposed to in printed form in the kindergarten setting (according to the judgment of a panel of 16 kindergarten teachers); the other half were judged to be less frequent words (Cronbach's alpha = 0.76).

***Wordlikeness* (adapted to Arabic from Siegel et al., 1995 by Shalhoub-Awwad and Yassin, 2019b)**

This task measures children's sensitivity to legal and illegal orthographic patterns in written Arabic. The children were presented with a list of 24 pseudowords one at a time and asked to decide if the pseudo-word looked like a real Arabic word or not (half of the words contained legal orthographic patterns, and half contained orthographic patterns that do not exist in the Arabic script, such as numbers, English letters, numerals, etc. [e.g., ةُ A قا]). A correct answer was given 1 point (Cronbach's alpha = 0.70, test-retest reliability = 0.79).

2.4.2 Grade 1 measures

Three reading tasks were included: CV reading, Word reading, and Pseudoword reading. For all three reading tasks, the total reading time was recorded, as well as the number of correct words. Percentage accuracy and pure rate (correct and incorrect pronunciations) were calculated. All three tasks were discontinued after 3 min.

2.4.2.1 *CV Reading (developed by Shalhoub-Awwad and Jabbour-Danial, 2020a)*

The children were required to read aloud a list of 18 CV syllables as quickly and accurately as possible. Each CV consisted of a consonant letter with a short vowel diacritic (Cronbach alpha = 0.90, test-retest reliability = 0.89).

2.4.2.2 *Word reading accuracy and rate—vowel-restricted (Mashkoul) (developed by Shalhoub-Awwad et al., 2020)*

This task reflects children's acquired word-specific orthographic knowledge. In this task, child was required to read aloud 25 words selected on the basis of their frequency in the children's schoolbooks and containing only consonants and vowels that had been taught up to the time of the assessment (Cronbach's alpha = 0.91 test-retest reliability = 0.88).

2.4.2.3 *Pseudoword naming accuracy and (pure) rate (Mashkoul) (developed by Shalhoub-Awwad and Jabbour-Danial, 2020b)*

This test contained 25 pseudowords to be read aloud as quickly and accurately as possible. The task measures the child's ability to decode unfamiliar letter strings. The pseudowords included consonants and short-vowel diacritics, which had been taught to the children up to the time of testing. The words were based on syllabic structures that are common in the children's schoolbooks (Cronbach's alpha = 0.95).

2.5 Data analysis strategies

To examine the potential confounding effects of background measures, we compared the four subgroups with one another using either one-way analysis of variance with *post-hoc* Bonferroni follow-up comparisons or Chi-square tests. Next, we examined the differences between the four subgroups on the linguistic, cognitive, pre-literate and reading measures by performing one-way analyses. Significant tests were followed up with *post-hoc* comparisons using the Bonferroni correction. We also created composite Z-scores (as described below) based on the means and standard deviations of the entire sample of 639 children. Due to the large number of group comparisons, α was set at 0.01 instead of 0.05.

3 Results

3.1 Is there a dissociation between PA + MA and RAN in Kindergarten?

We first verified that the selection procedure successfully matched the four subgroups on potentially confounding biosocial and demographic measures. Table 1 shows that the four subgroups were well-matched in age, gender, non-verbal intelligence, and SES.

In order to explore the different cognitive, language and preliteracy profiles of the different subgroup, composite scores were calculated for all domains: PA, MA, RAN, vocabulary, syntax, letter knowledge, and orthographic knowledge. An overall language score was also calculated, encompassing all four language domains. For all three reading tasks, an overall rate and an overall accuracy measure were also calculated. All composite scores were based on the entire sample.

Pearson correlations between all composite measures (linguistic, cognitive, pre-literacy, and reading) revealed some interesting outcomes in our sample (see Table 2). The composite PA + MA measure had moderate to very strong correlations with all language measures ranging between $r = 0.53^{**}$ and $r = 0.91^{**}$ ($p < 0.01$) and moderate correlations with pre-literacy and reading measures ranging between $r = 0.40^{**}$ and $r = 0.63^{**}$ ($p < 0.01$). The RAN composite measure, on the other hand, showed very weak correlations with all language, early literacy, and reading measures ranging between $r = -0.10^{*}$ and $r = 0.21^{**}$ ($p < 0.05$). Notably, Grade 1 accuracy and pure rate were quite strongly correlated $r = 0.66^{**}$ ($p < 0.01$).

We first verified that the three disabled subgroups had unique profiles on the selection variables—PA, MA, and RAN. Table 3 presents these data.

As anticipated, the RAN disabled subgroup demonstrated a marked deficiency in RAN measures while maintaining intact performance on both PA and MA measures, confirming a genuine dissociation on the selection criteria. Conversely, the PA + MA disabled subgroup exhibited poor performance on both PA and MA measures but intact performance on the individual RAN measures. On the RAN composite measure, however, although the PA + MA mean was above-average relative to the mean of the entire sample of 637 children, performance was significantly lower ($z = -0.45$) relative to the non-disabled control group.

3.2 Does the PA + MA-disabled subgroup constitute a mild form of Developmental Language Disorder?

In Table 4, we report the additional language measures (vocabulary and syntax) that were not part of our selection criteria but are relevant to the question of the extent to which the deficits in the PA + MA disabled subgroup extend to other aspects of language.

Here we examined both the subgroup as a whole and individual members. According to Bishop et al. (2017), children with two or more composite scores below the 10th percentile (equivalent to 1.25 standard deviations or more below the mean) can be classified

TABLE 1 Background biosocial and demographic characteristics of the subgroups.

	Non-disabled control group	PA + MA disabled subgroup	RAN disabled subgroup	Doubly disabled subgroup	Statistical analyses	Partial η^2
	$N = 60$	$N = 50$	$N = 50$	$N = 47$		
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*		
Age	5.6 (0.21)	5.6 (0.27)	5.6 (0.24)	5.6 (0.24)	$F = 0.32$, *n.s.*	0.01
Gender						
Boys	21 (35%)	20 (40%)	23 (46%)	21 (45%)	$\chi 2(3) = 1.69$, *n.s.*	
Girls	39 (65%)	30 (60%)	27 (54%)	26 (55%)		
Non-verbal intelligence ability						
Raven	9.6 (1.81)	9.9 (1.83)	10.1 (1.67)	9.4 (1.58)	$F = 1.653$ *n.s.*	0.02
SES	4.5 (0.72)	4.5 (0.68)	4.5 (0.69)	4.5 (0.66)	$F = 0.06$, *n.s.*	0.00

TABLE 2 Pearson correlation between all composite measures.

Measures	1	2	3	4	5	6	7	8	9	10	11
1. PA	–										
2. MA	0.47**	–									
3. PAMA	0.86**	0.86**	–								
4. RAN	−0.18**	−0.21**	−0.18**	–							
5. Expressive vocabulary	0.44**	0.64**	0.63**	−0.16**	–						
6. Syntax	0.43**	0.47**	0.53**	−0.16**	0.47**	–					
7. Overall Language	0.75**	0.81**	0.91**	−0.15**	0.80**	0.76**	–				
8. Letter knowledge	0.47**	0.32**	0.45**	−0.25**	0.29**	0.25**	0.40**	–			
9. Orthographic knowledge	0.60**	0.46**	0.63**	−0.19**	0.45**	0.38**	0.60**	0.57**	–		
10. Overall reading accuracy	0.48**	0.28**	0.45**	−0.16**	0.30**	0.25**	0.42**	0.46**	0.46**	–	
11. Overall reading rate	0.46**	0.22**	0.40**	−0.21**	0.24**	0.18**	0.35**	0.38**	0.47**	0.66**	–

**Correlation is significant at the.01 level (2-tailed).

as having a language disorder. Table 4 shows that the PA + MA disabled subgroup demonstrated significant deficits in all language measures but with diminished severity in vocabulary and syntax. In our sample, the lowest mean for the PA + MA subgroup as a whole was observed on the morphological composite score ($M = -1.24$, $SD = 0.82$). Consequently, group-wise, this subgroup does not meet the Bishop et al. (2017) criteria for classification as DLD. However, examination of individual cases within this subgroup reveals that a substantial number could be considered as having DLD; 20 out of the 50 children scored below the 10th percentile on two or more language domains.

3.3 Can the three disabled subgroups be differentiated on early preschool literacy abilities?

As shown in Table 5, both the PA + MA and the doubly disabled subgroups, both performed significantly below the control group and the RAN disabled subgroup (almost a full standard deviation) on all preschool measures of letter knowledge and orthographic knowledge (word recognition and wordlikeness). The RAN disabled subgroup, in contrast, both achieved intact performance on these early literacy measures. Although their scores were slightly below those of the control group, the differences were not statistically significant. It is worth noting that all these kindergarten tests were untimed accuracy measures. These data confirm that the PA + MA-only subgroup and the RAN-only subgroup have distinct preschool literacy profiles.

3.4 Will Kindergartners who show selective deficits in RAN or PA + MA abilities develop into selectively rate-disabled and accuracy-disabled readers, respectively, and the doubly disabled group become accuracy-plus-rate disabled readers in first grade?

The PA + MA-only subgroup scored significantly below the control group not only on all pre-literacy Kindergarten accuracy measures but also on all Grade 1 reading accuracy measures.

TABLE 3 Means and standard deviations (in parentheses) on the selection variables (PA, MA, and RAN) in the four subgroups.

	Non-disabled control group	PA + MA disabled subgroup	RAN disabled subgroup	Doubly disabled subgroup		
	$N = 60$	$N = 50$	$N = 50$	$N = 47$		
Measures	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	$F_{(3,206)}$	Partial η^2
Phonological awareness						
Initial CV isolation in disyllabic words	75.6[a] (31.89)	37.8[b] (37.99)	78.5[a] (30.63)	41.1[b] (37.12)	20.53***	0.23
Initial CV isolation in monosyllabic CVC words	83.3[a] (27.6)	37.4[b] (37.19)	77.6[a] (28.61)	38.5[b] (35.01)	30.83***	0.31
Initial consonant isolation in CVC words	80.4[a] (25.20)	27.2[b] (35.63)	78.3[a] (33.12)	30.1[b] (37.09)	41.74***	0.38
Initial consonant isolation in CCVC words	82.4[a] (21.81)	26.3[b] (35.77)	84.2[a] (27.88)	21.1[b] (32.45)	69.66 ***	0.51
Composite *z*-score	0.82[a] (0.59)	−1.06[b] (0.58)	0.49[a] (0.68)	−1.1[b] (0.63)	135.88**	0.67
Morphological awareness						
Noun pluralization	80.1[a] (16.21)	47.6[b] (24.69)	77.1[a] (23.80)	49.7[b] (21.12)	34.08***	0.34
Verb derivation	91.1[a] (9.69)	69.7[b] (19.69)	90.5[a] (10.10)	64.0[b] (19.28)	43.90***	0.39
Resultative adjective derivation	83.5[a] (14.84)	56.7[b] (23.57)	84.7[a] (18.85)	54.8[b] (26.11)	31.40***	0.32
Composite *z*-score	0.46[a] (0.54)	−1.24[b] (0.82)	0.43[a] (0.81)	−1.4[b] (0.74)	96.66***	0.59
RAN						
RAN colors	60.1[a] (9.81)	70.3[a] (20.25)	96.0[b] (20.77)	111.4[c] (34.13)	57.80***	0.46
RAN objects	60.5[a] (8.85)	69.4[a] (13.12)	103.0[b] (19.50)	108.8[b] (23.85)	106.01***	0.61
Composite *z*-score	0.96[a] (0.35)	0.45[b] (0.60)	−1.12[c] (0.49)	−1.7[d] (1.11)	175.64***	0.73

[a,b,c] *Post-hoc* comparisons between the four subgroups. Subgroups with the same superscript letter did not differ from one another; subgroups with different superscripts differed significantly from one another at $p < 0.01$. $^{**}p < 0.01$, $^{***}p < 0.001$.

The RAN-only subgroup, in contrast, did not differ significantly from the controls on any accuracy measure. Turning to word reading rate, the RAN-only subgroup was significantly slower than controls, but, contrary to our earlier Grade 4 outcomes, the PA + MA subgroup were also slow readers. On both CV reading and pseudoword reading rate, the RAN-only mean fell midway between the control group and the PA + MA-only subgroup but did not differ significantly from either of the latter groups. With all three measures combined into an overall composite rate score, the RAN-only subgroup were reliably slow (but reasonably accurate) readers. Thus, both the singly disabled subgroups were found to be slow readers, but only the PA + MA-only showed reliable accuracy deficits as well (see Table 6).

The doubly disabled subgroup, unsurprisingly, obtained the lowest scores on all measures but, interestingly, did not differ from the PA + MA subgroup on any measure. In fact, the graphic depiction of the doubly disabled profile (see Figure 1) clearly shows a near-identical profile to the PA + MA-only group, with, of course, the single exception of the RAN. Figure 1 also brings to light the opposite pattern of relative strengths and weakness in the two singly disabled subgroups. Whereas, the PA + MA-only subgroup's Grade 1 reading rate was superior to their accuracy, the RAN-only subgroup showed the opposite pattern. Furthermore, this interaction was statistically significant [$F_{(1, 98)} = 6.75$, $p = 0.011$].

Summing up, whereas the RAN-disabled subgroup revealed the selectively slow but accurate profile observed in our previous work with fourth graders, the PA + MA disabled subgroup, contrary to our fourth-grade findings, were found to be both inaccurate and slow.

4 Discussion

Although phonological awareness is widely recognized as a significant cause of reading difficulties, it falls short of explaining all the variance in reading ability (e.g., Share and Stanovich, 1995; Wolf and Bowers, 1999; Snowling and Hulme, 2021; Price et al., 2022). An additional independent predictor of reading disabilities that has gained increasing recognition, distinct from that of PA, is RAN (e.g., Cornwall, 1992; Cutting and Denckla, 2001; Wolf et al., 2002; Kirby et al., 2003; Georgiou et al., 2012). Studies conducted on shallow orthographies have found that PA mainly affects reading accuracy (Elbeheri and Everatt, 2007; Saiegh-Haddad and Geva, 2008), whereas RAN is more related to reading speed (Bowers and Swanson, 1991; Wolf and Bowers, 1999; Kirby et al., 2003; Saiegh-Haddad, 2005; Breznitz, 2006; Puolakanaho et al., 2007; Moll et al., 2009; Papadopoulos et al., 2009; Taibah and Haynes, 2011; Torppa et al., 2013; Rakhlin et al., 2014; Protopapas, 2017; Landerl et al., 2019; Tibi and Kirby, 2019).

TABLE 4 Means and standard deviations (in parentheses) on additional language measures (vocabulary and syntax) in the four subgroups.

Measures	Non-disabled control group $N = 60$ *M (SD)*	PA-MA disabled subgroup $N = 50$ *M (SD)*	RAN disabled subgroup $N = 50$ *M (SD)*	Doubly disabled subgroup $N = 47$ *M (SD)*	$F_{(3,206)}$	Partial η^2
Vocabulary						
Expressive vocabulary (I)	83.0[a] (12.12)	69.1[bc] (13.24)	78.5[ab] (14.55)	64.8[c] (21.25)	15.48***	0.19
Expressive vocabulary (II)	79.4[a] (15.83)	59.0[b] (17.48)	83.2[a] (14.63)	56.2[b] (22.24)	31.24***	0.32
Composite *z*-score	0.32[a] (0.73)	−0.86[b] (0.90)	0.29[a] (0.78)	−1.1[b] (1.23)	33.80***	0.34
Syntax						
Expressive syntax	59.3[a] (23.71)	40.4[b] (22.04)	60.8[a] (21.93)	39.6[b] (20.00)	14.16***	0.17
Receptive syntax	77.6[a] (14.35)	65.3[b] (16.95)	81.7[a] (14.77)	60.1[b] (16.01)	21.43***	0.24
Composite *z*-score	0.27[a] (0.93)	−0.69[b] (0.92)	0.41[a] (0.94)	−0.90[b] (0.75)	27.14***	0.29
Composite *z*-score overall language	0.47[a] (0.40)	−0.96[b] (0.50)	0.40[a] (0.51)	−1.1[b] (0.56)	151.01***	0.70

[a,b,c] *Post-hoc* analysis for comparison between the four subgroups. Subgroups with the same letter did not differ from one another; subgroups with different letters differed significantly from one another at $p < 0.01$. Subgroups with two letters (e.g., [ab]) did not differ significantly from either of the two groups with these same superscript letters (in this case, [a] or [b]). ***$p < 0.001$.

TABLE 5 Means and standard deviations (in parentheses) of early literacy measures in pre-school in four subgroups.

Early literacy measures	Non-disabled control group $N = 60$ *M (SD)*	PA + MA disabled subgroup $N = 50$ *M (SD)*	RAN disabled subgroup $N = 50$ *M (SD)*	Doubly disabled subgroup $N = 47$ *M (SD)*	$F_{(3,207)}$	Partial η^2
Letter knowledge						
Letter name identification	91.7[a] (10.03)	76.0[bc] (24.82)	85.1[ab] (19.35)	71.4[c] (22.19)	11.53***	0.15
Letter name retrieval	82.5[a] (20.05)	56.5[b] (26.81)	74.7[a] (25.50)	49.5[b] (29.00)	19.46***	0.22
Composite *z*-score	0.48[a] (0.64)	−0.51[b] (1.05)	0.13[a] (0.93)	−0.77[b] (1.08)	19.72***	0.23
Orthographic knowledge						
Word recognition	49.2[a] (21.21)	29.1[b] (11.99)	43.3[a] (20.75)	24.4[b] (11.98)	23.40***	0.26
Word likeness	63.4[ab] (11.33)	60.9[ab] (7.85)	67.8[a] (14.77)	57.2[b] (9.94)	7.49***	0.10
Composite *z*-score	0.57[a] (0.75)	−0.54[b] (0.58)	0.24[a] (1.09)	−0.89[b] (0.60)	25.94***	0.28

[a,b,c] *Post-hoc* comparisons between the four subgroups. Subgroups with the same letter did not differ from one another; subgroups with different letters differed significantly from one another at $p < 0.01$. Subgroups with two letters (e.g., [ab]) did not differ significantly from either of the two groups with these same superscript letters (in this case, [a] or [b]). ***$p < 0.001$.

The present longitudinal study follows up earlier cross-sectional investigations (Shany and Breznitz, 2011; Shany and Share, 2011; Shany et al., 2023) demonstrating true double dissociation between dyslexics defined on the basis of word reading rate and word reading accuracy. Our subtyping study asked (i) whether the unique cognitive-linguistic profiles of young (Grade 4) readers with selective difficulties in reading accuracy or reading rate (with PA and MA deficits but no RAN deficit) a RAN deficit alone can be found among pre-literate preschoolers and (ii) do these preschool profiles presage distinct patterns of reading in Grade 1. Validation of the cognitive-linguistic (RAN/PA + MA) double dissociation in kindergarten *before* formal reading instruction would indicate that the pattern of impairment is not simply a consequence of learning to read. Because native Arabic-speaking children in Israel are educated in a literacy culture in which, reading instruction only begins at age 6 (like most European countries), our study provides a particularly clean adjudication of the cause-vs-consequence issue.

Our findings confirmed the existence of these two selectively disabled subgroups with distinct and non-overlapping cognitive-linguistic profiles in preschool. The RAN-disabled subgroup showed a specific impairment on RAN measures while achieving intact performance on PA and MA measures comparable to the non-disabled control group. The PA + MA disabled subgroup, on the other hand, exhibited comprehensive impairment on all PA and MA measures while attaining intact performance (again comparable to the non-disabled control group) on the individual RAN measures.

TABLE 6 Means and standard deviations (in parentheses) reading measures in Grade 1 in four subgroups.

	Non-disabled control group	PA + MA disabled subgroup	RAN disabled subgroup	Doubly disabled subgroup		
	$N = 60$	$N = 50$	$N = 50$	$N = 47$		
Reading measures						
CV Reading						
CV reading accuracy	86.4[a] (15.86)	63.4[b] (27.67)	81.9[a] (20.69)	55.3[b] (27.81)	21.17***	0.24
CV reading rate -WPM	36.4[a] (15.95)	25.2[b] (11.71)	29.2[ab] (14.53)	20.7[b] (15.36)	11.26***	0.14
Word reading						
Word reading accuracy	78.7[a] (20.6)	52.0[bc] (30.09)	67.0[ab] (26.96)	43.4[c] (31.21)	17.66***	0.21
Word reading rate-WPM	19.3[a] (9.76)	12.2[b] (5.96)	14.4[b] (8.06)	9.6[b] (6.65)	14.93***	0.18
Pseudoword reading						
Pseudoword reading accuracy	61.7[a] (28.61)	31.3[b] (26.82)	50.0[a] (33.64)	23.2[b] (23.58)	20.01***	0.23
Pseudoword reading rate- WPM	13.7[a] (6.41)	9.7[bc] (4.57)	11.4[ab] (6.39)	7.4[c] (4.21)	11.92**	0.15
Overall composite reading scores						
Overall accuracy composite *z*-score	0.52[a] (0.62)	−0.41[b] (0.86)	0.20[a] (0.85)	−0.70[b] (0.88)	13.99***	0.16
Overall rate composite *z*-score	0.44[a] (0.88)	−0.27[bc] (0.63)	−0.02[b] (0.87)	−0.58[c] (0.70)	16.17***	0.20

[a,b,c] *Post-hoc* analysis for comparison between the four subgroups. Subgroups with the same letter did not differ from one another; subgroups with different letters differed significantly from one another at $p < 0.01$. Subgroups with two letters (e.g., [ab]) did not differ significantly from either of the two groups with these same superscript letters (in this case, [a] or [b]). $^{**}p < 0.01$, $^{***}p < 0.001$.

On the RAN composite score, however, although their performance was intact in terms of absolute (population-norm) performance levels, they were found to score significantly below the non-disabled control group. A possible explanation for this significant difference may stem from the fact that in previous studies, the disabled subgroups were compared to regional norms, while in our study, we used more conservative comparison criteria by comparing our two singly disabled subgroups to a carefully matched (case by case) non-disabled control group with intact performance (above the 35th percentile) on all measures. Another explanation might be related to the type of RAN tasks we used. Unlike previous studies, we used non-alphanumeric tasks (Colors and Objects), which are known to be more weakly related to literacy and reading abilities than alphanumeric tasks (Digits and Letters). This decision was unavoidable because many Arabic-speaking kindergarten children have not mastered the names of many digits and letters. Furthermore, our PA + MA disabled subgroup exhibited generally low language abilities, including expressive vocabulary. Difficulties in name retrieval, therefore, might have affected the automaticity of retrieving the verbal labels of colors and objects.

Another objective of this study was to explore the cognitive and linguistic profiles of the two singly disabled subgroups going beyond their performance on the selection measures. The RAN-disabled subgroup was found to exhibit intact performance, comparable to the non-disabled control group, across all language measures: Phonological, morphological, vocabulary, and syntax, as well as the composite language measure. The PA + MA subtype, on the other hand, manifested broad and substantial difficulties on all individual and composite language measures, over and above the shortcomings observed in their selection measures (PA and MA). This provides further evidence for the double dissociation by showing that these two subgroups display distinct and non-overlapping cognitive-linguistic profiles.

Our findings align with previous studies by Shany and colleagues that have shown a clear pattern of double dissociation in cognitive-linguistic strengths and weaknesses between the two subgroups, rather than just relative differences. Therefore, our Kindergarten subtypes can be considered to be true or "hard" subtypes. Additionally, the assessment of cognitive-linguistic abilities was carried out *prior* to the commencement of reading instruction, minimizing any reciprocal influence with literacy learning. Furthermore, our findings were not confounded by biosocial or demographic factors.

We also inquired whether the PA + MA-disabled subgroup represents true Developmental Language Disorder (DLD) or a mild manifestation of DLD. This arose from the repeated but somewhat inconsistent findings in Shany and colleagues' studies showing variability in the extent to which the accuracy-disabled subgroup manifested broad language impairments beyond phonology and morphology. Shany et al. (2023) employed a comprehensive language battery in their Arabic-speaking subtyping analysis, encompassing vocabulary and syntax. The outcomes confirmed strong and reliable weaknesses in phonological awareness in the accuracy-disabled subgroup as well as in morphology and vocabulary but not syntax, although the deficits in morphology and

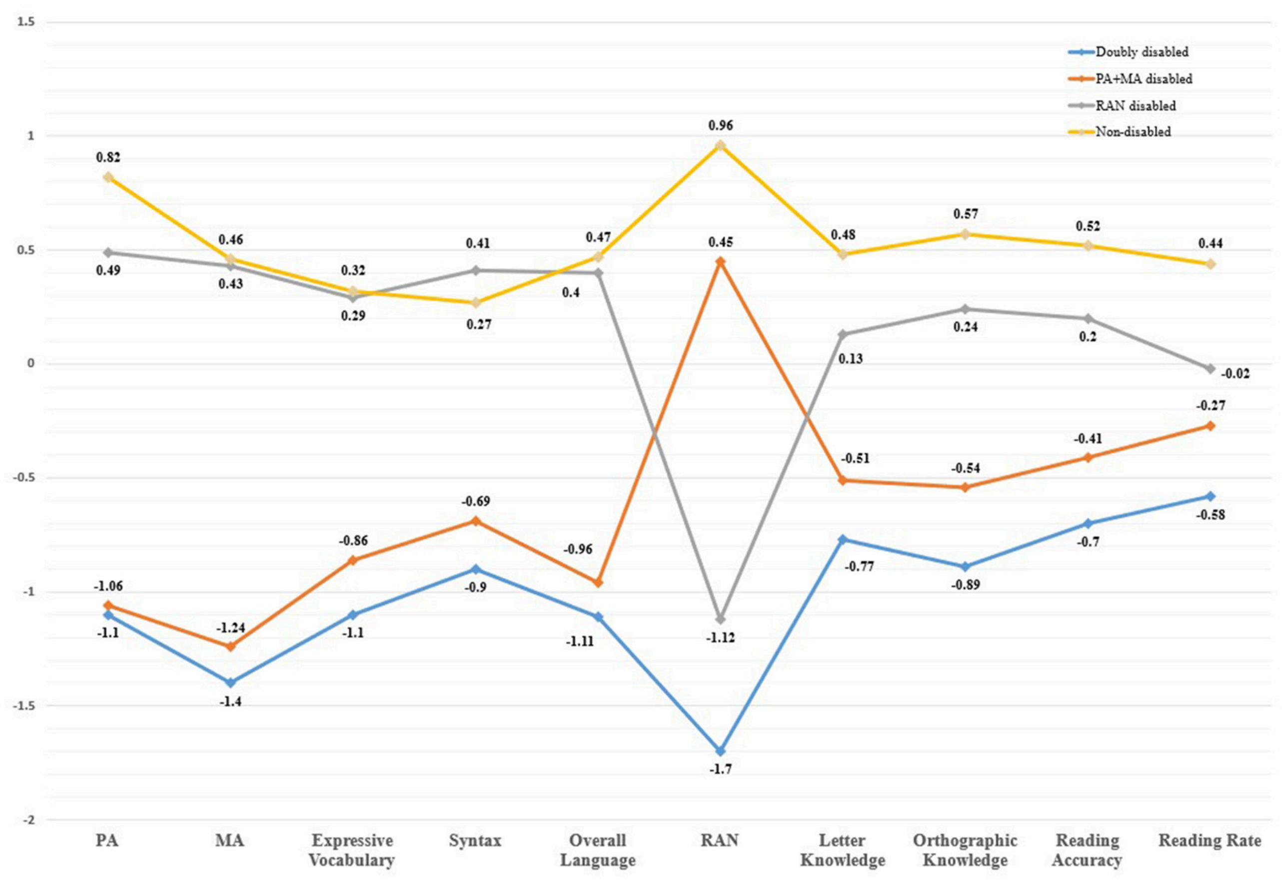

FIGURE 1
Composite *Z*-scores in four language domains (PA, MA, vocabulary, and syntax), overall language score, RAN early literacy, and reading measures across the four subgroups.

lexical knowledge were less severe than in phonology. Looking at mean performance levels in this subgroup as a whole, Shany et al. (2023) concluded that these findings did not warrant classifying the accuracy-disability subgroup as having comorbid DLD, but they did present broad non-trivial language weaknesses (see Shany et al., 2023, p. 18). We took this question a step further by examining both the subgroup as a whole and its individual members. According to the Bishop et al. (2017) criteria, this subtype, *as a group,* did not meet the criteria for classification as DLD. Examination of individual cases within the PA + MA disabled subgroup, however, revealed that 20 out of the 50 children in this subgroup scored below the 10th percentile on two or more language domains comprising (40% of the PA + MA subgroup). This evidence demonstrates that many members of the PA + MA subgroup are classifiable as cases of Developmental Language Disorder. The difference between the present findings and those reported in Shany et al. (2023) could be ascribed to different selection procedures: our selection criteria for this subgroup were founded on poor performance in language abilities (PA and MA), thereby targeting children with low proficiency in at least two language domains. Conversely, in the cross-sectional fourth grade study (Shany et al., 2023), the selection criteria for the accuracy-disabled subgroups were based on low performance in reading accuracy, leaving the question open regarding the reasons behind this weakness.

Our results align with the claim that many individuals with dyslexia have language problems that go beyond phonology (e.g., Catts et al., 2005; Snowling and Melby-Lervåg, 2016). They also align with a large body of research showing that estimates of the prevalence of DLD among children with dyslexia are high ranging from 30% (Catts et al., 2005; Snowling and Melby-Lervåg, 2016) up to 50% (McArthur et al., 2000; Price et al., 2022). These findings emphasize the importance of multiple oral language skills (both phonological and non-phonological) in the development of reading literacy beyond the well-documented role of PA. Our data are also congruent with a recent study in Arabic by Mansour-Adwan et al. (2023), which explored the relationships between the different linguistic skills and emergent literacy in kindergarten based on a two-way phonological and/or non-phonological classification. This study revealed poor literacy among children with poor non-phonological language skills as well as poor phonological skills, demonstrating that both linguistic dimensions are crucial for literacy development. The Mansour-Adwan et al. (2023) study also revealed that children with both phonological and non-phonological deficits had the lowest literacy performance (Bishop and Snowling, 2004; Share and Leikin, 2004; Snowling et al., 2020).

The third aim of the current study was to determine whether kindergartners with selective deficits in RAN or PA + MA before learning to read would exhibit distinct patterns of early preliteracy measures as well as later word reading accuracy and rate when they began learning to read in Grade 1. We also predicted that preschoolers in doubly disabled would result in both inaccurate and slow reading Our findings confirmed that the RAN-disabled subgroup had indeed developed into slow but accurate readers by mid-Grade 1. This intact performance on word reading accuracy is further reinforced by their Kindergarten pre-literacy abilities, where they showed unimpaired performance on all pre-literacy measures of letter knowledge and orthographic knowledge—both of which are accuracy measures.

Despite the slow reading rate of the RAN-disabled subgroup (when averaged across all three first grade reading measures), variability was apparent among the three reading tasks. When each task was examined separately, the reading rate of the RAN disabled subgroup was significantly slower than the non-disabled group on *word reading* but not on CV and pseudoword reading tasks. It is worth noting first that the word reading task is considered to be the most definitive tool used in the definition and classification of reading disability (British Psychological Association, 1999; DSM-5, 2013; Catts et al., 2024). In our own work, tests of reading aloud isolated words (speed and accuracy) have been the sole measure for defining dyslexia and dyslexic subtypes. With regard to reading CV units and pseudowords, the RAN-only subgroup was around 20% slower, but these differences did not attain significance compared to our control group of non-disabled readers. In the case of pseudoword reading, we suspect that part of the reason concerns the very low accuracy levels. The fact that these novice readers committed, on average, an error on every second word seems likely to affect reading rate. In fact, the correlation in this sample between rate and accuracy was quite strong ($r = 0.66$). This compares with a correlation of only $r = 0.44$ in the fourth-grade Arabic-speaking sample reported in Shany et al. (2023). It appears that in the earliest stages of learning to read, when the instructional focus is typically on mastering the code, i.e., accuracy, speed is largely a by-product of accuracy levels. This strong association between accuracy and speed at this point in reading development also explains the slowness of the PA + MA subgroup, which was both inaccurate and slow resembling the doubly disabled subgroup. We anticipate a clearer dissociation between rate and accuracy in this sample in later grades when accuracy approaches ceiling levels, and the rate is less influenced by errors; namely, our PA + MA disabled subgroup will develop into accuracy disabled, while the doubly disabled will maintain the severe reading deficiency on both accuracy and rate dimensions. Another factor accounting for the instability of outcomes across the three measures could be the specific type of rapid automatized naming (RAN) measures (objects and colors) employed as selection criteria. Previous studies have shown that RAN digits and letters have a closer correlation with reading ability than RAN colors and objects (Wolf et al., 1986; Georgiou et al., 2008). Hence, it is possible that the contrast in reading rates might have been sharper had it been feasible to use alphanumeric RAN measures. However, as already discussed, this was not possible owing to the very low levels of letter and digit name knowledge in this preschool population.

We wish to point out that the relatively low levels of reading ability may seem at odds with the fact that Arabic is a highly transparent orthography with near-perfect one-to-one symbol-sound mappings (Saiegh-Haddad and Henkin-Roitfarb, 2014). However, as Daniels and Share (2018) have emphasized, phonological transparency is only one of a number of dimensions of writing system variation likely to impede the progress of the novice reader. Despite being highly transparent in the classical orthographic depth sense, Arabic poses unique challenges to the developing reader, including diglossia (Saiegh-Haddad, 2018, 2022), similarity of letter forms, ligaturing, and allography (Yassin et al., 2020).

4.1 Conclusion and implications

Two separate and non-overlapping disabled groups were identified in kindergarten, leading to distinct reading profiles in grade 1. The RAN disabled subgroup demonstrated accurate yet slow word reading skills, whereas the PA + MA disabled subgroup showed both inaccurate and slow reading in grade 1, similar to the third severe doubly disabled subgroup. These findings underscore the feasibility of early preschool identification of later reading difficulties. Diagnosing reading disabilities early in kindergarten is crucial for several reasons. Firstly, early identification allows for prompt intervention, which can mitigate the negative impact of reading difficulties on a child's academic progress and self-esteem. Secondly, early diagnosis enables educators to tailor instructional strategies to meet the specific needs of struggling readers, potentially preventing long-term reading difficulties. Additionally, identifying reading disabilities early can facilitate collaboration between educators, parents, and specialists to provide comprehensive support and resources for affected children. The instructional needs of each subtype are different; the RAN disabled subtype requires targeted intervention in reading rate, while the PA-MA disabled subgroup necessitates additional broad-based language intervention. The doubly disabled subgroup, however, requires intervention in both domains. These instructional needs may become even more distinct once the decoding skills are acquired. By grade 1, it may be appropriate to involve the RAN-disabled subgroup in reading acceleration programs (e.g., Breznitz et al., 2013; Abendan et al., 2024), while the PA + MA subgroup may benefit from reading acceleration programs coupled with language-based enhancements. Our findings lead us to assert that while it is crucial to determine general guidelines for the kindergarten curriculum to establish a common foundation, it is equally important to recognize each child's individual strengths and weaknesses to initiate early prevention interventions. Furthermore, numerous studies consistently highlight the predictive importance of RAN, spanning diverse orthographies, and particularly as the exclusive predictor of the RAN-disabled subgroup in our investigation. Recognizing this significance, we deem it essential to explore intervention initiatives aimed at addressing intervention programs in reading fluency.

Finally, our findings underscore the importance of considering the heterogeneity of the dyslexic population. No single account, not even phonology, can adequately capture all the variability in this population. This implies that different dyslexic subtypes require different interventions. If the problem is reading speed rather than accuracy, a phonological intervention is unlikely to be effective. If, on the other hand, accuracy is the obstacle and linguistic knowledge (primarily phonology and morphology) is deficient, language-based interventions such as phonological and morphological awareness may be the right choice.

Data availability statement

The data that support the findings of this study are available from the corresponding author [YS-A], upon reasonable request.

Ethics statement

The studies involving humans were approved by Office of the Chief Scientist—Ministry of Education (permit #9667) Research Ethics Committee of the Department of Education at the University of Haifa. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

MJ-D: Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Validation, Visualization, Writing – original draft, Writing – review & editing. DS: Conceptualization, Investigation, Methodology, Resources, Supervision, Validation, Visualization, Writing – review & editing. YS-A: Conceptualization, Investigation, Methodology, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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