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Spoken verb learning in children with language disorder

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ABSTRACT

The current study examined spoken verb learning in elementary school children with language disorder (LD). We aimed to replicate verb learning deficits reported in younger children with LD and to examine whether verb instrumentality, a semantic factor reflecting whether an action requires an instrument (e.g., "to chop" is an instrumental verb), influenced verb learning. The possible facilitating effect of orthographic cues presented during training was also evaluated. In an exploratory analysis, we investigated whether language and reading skills mediated verb learning performance. General language skills and verb learning were assessed in Dutch children with LD and age-matched typically developing controls (n = 25 per group) aged 8 to 12 years (M = 9;9 [years;months], SD = 1;3). Using video animations, children learned 20 nonwords depicting actions comprising 10 instrumental and 10 noninstrumental verbs. Half of the items were trained with orthographic information present. Verb learning was assessed using an animation–word matching and animation naming task. Linear mixed-effects models showed a main effect of group for all verb learning measures, demonstrating that children with LD learned fewer

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words and at a slower rate than the control group. No effect of verb instrumentality, presence of orthographic information, or the included mediators was found. Our results emphasize the importance of continued vocabulary instruction in elementary school to strengthen verb encoding. Given that our findings are inconsistent with the overall literature showing an orthographic facilitation effect, future studies should investigate whether participants pay attention to the written word form in learning contexts with moving stimuli.

Introduction

The ability to learn new words not only is essential for people's ability to express themselves clearly but also affects their written communication abilities and modulates academic achievement (Bleses et al., 2016). However, for children with language disorder (LD),[1] vocabulary acquisition is less successful than for the typically developing peers (Kan & Windsor, 2010; McGregor et al., 2013). Learning novel verbs, as compared with nouns, is especially challenging for children with LD (e.g., Kan & Windsor, 2010; Rice et al., 1994), but there is still a lack of understanding of the mechanisms that contribute to establishing correct verb representations (Horvath & Arunachalam, 2019). A deeper understanding about what, in particular, is challenging about verb learning and the identification of facilitators for learning are important for the development of assessment tools and intervention approaches aiming to narrow the vocabulary gaps between typically developing children and children with LD. Therefore, the current study sought to investigate the effects of verb instrumentality and orthographic information on spoken verb learning in children with LD.

Verb learning in children with LD

Learning new spoken words is a dynamic process during which an accurate mental representation is formed of the semantic information (i.e., a word's meaning) and phonological information (i.e., a word's pronunciation) for a word, which then must be linked. In addition, the syntactic properties of a word (e.g., word class) need to be retained. Because verbs are the cornerstone of sentences, verb learning is of high importance for successful communication. Research has shown that verbs are more difficult to learn than nouns for children with LD (e.g., Kan & Windsor, 2010; Oetting et al., 1995; Rice et al., 1994) and typically developing children (e.g., Childers & Tomasello, 2002; Gentner, 1982) and that children with LD can have difficulties with encoding and storing phonological information (McGregor et al., 2013; Nash & Donaldson, 2005; Oetting et al., 1995) and semantic information (Kelly & Rice, 1994; Nash & Donaldson, 2005; Penner et al., 2003; Steele & Watkins, 2010). Furthermore, children with LD may have difficulties with specific semantic features such as telicity (i.e., the meaning of a telic action, such as "to close", refers to a specific endpoint in contrast to an atelic action, such as "to tickle"; Leonard & Deevy, 2010; Leonard et al., 2007). These factors may contribute to children with LD having smaller and less diverse verb lexicons (Conti-Ramsden & Jones, 1997).

Most existing studies have investigated spoken verb learning in children with LD of preschool age (Oetting et al., 1995; O'Hara & Johnston, 1997; Rice et al., 1994). However, verb learning is a lifelong task and is necessary in increasing language complexity in older children. In addition, spoken and written word learning difficulties are still observed in upper elementary school (Kan & Windsor,

[1] Although most of the discussed studies included children with specific language impairment (SLI) or developmental language disorder (DLD), these are referred to as being diagnosed with LD. LD is an umbrella term for children with language problems, including children with comorbid disorders or nonverbal cognitive deficits (Bishop et al., 2017). This also includes children with SLI and DLD.

2010; Steele & Watkins, 2010). Here, we further explored the presence of and mechanisms underlying spoken verb learning difficulties in children with LD attending elementary school. This investigation is a step toward evaluating the necessity for targeted vocabulary instruction in this age group.

Mechanisms underlying verb learning impairments

Previous research has investigated the mechanisms underlying verb learning difficulties (Johnson & de Villiers, 2009; Oetting, 1999; O'Hara & Johnston, 1997; Rice et al., 2000). Compared with nouns, verbs differ in their semantic properties (e.g., verbs are less concrete), syntactic properties (e.g., verbs possess an argument structure), and phonological properties (e.g., verbs are less salient because they tend to be embedded in the middle of sentences) (Black & Chiat, 2003). Given the high prevalence of morphosyntactic difficulties in children with LD, most research has focused on syntactic bootstrapping abilities (i.e., the use of morphosyntactic cues in a sentence to infer verb meanings; e.g., Naigles, 1996). Several studies showed that children with LD have syntactic bootstrapping difficulties (Johnson & de Villiers, 2009; Rice et al., 2000). Yet, this was not supported in all studies (Oetting, 1999; O'Hara & Johnston, 1997), and it has been argued that the verb learning difficulties in children with LD are caused by a limited general processing capacity instead (O'Hara & Johnston, 1997).

Children diagnosed with LD are also prone to phonological and semantic impairments which may contribute to their word learning difficulties, including their difficulties with learning verbs (Black & Chiat, 2003). Among others, nonword repetition skills, which reflect phonological memory capacity, are often impaired (Graf Estes et al., 2007). The ability to repeat nonwords has been shown to moderate word learning, influencing the accuracy of phonological representations (Adlof & Patten, 2017; Gathercole & Baddeley, 1990; Jackson et al., 2021). Yet, previous research investigating the influence of nonword repetition skills has largely focused on noun learning (Adlof & Patten, 2017; Jackson et al., 2021). A smaller existing semantic network may also affect learning novel words by, for example, reducing the ability to distinguish words of different semantic categories (Adlof & Patten, 2017). On the other hand, semantically rich linguistic contexts may benefit verb learning in typically developing children when presented within a rich syntactic context (Arunachalam & Waxman, 2015) (i.e., transitive, reflecting whether a verb requires a direct object, such as "to receive"). Hence, it may be that semantically rich verbs are learned more easily by children with LD.

Verb instrumentality

Instrumentality is one dimension that determines semantic richness. The instrumentality of a verb refers to whether an action requires an instrument (not a body part). Within Jackendoff's (1990) *conceptual semantics framework*, the meaning of a concept is decomposed into elements or semantic primitives (such as events, states, or instruments). Instrumental verbs include the semantic primitive of an instrument in their conceptual composition. For example, the instrumental verb "to polish" requires a rag for the action to be performed, whereas the noninstrumental verb "to clean" does not require an instrument. According to Jackendoff (1990), these two verbs have identical conceptual representations apart from the incorporation of the instrument (a rag) in the representation of the verb "to polish". This increased semantic richness of instrumental verbs may facilitate action naming in adults with fluent post-stroke aphasia, particularly when the verb has no name relation to its instrument (e.g., whereas the instrument "rag" is not phonologically similar to the verb "to polish", the instrument "mop" and the verb "to mop" share their phonology and are name-related; Jonkers & Bastiaanse, 2007; Kambanaros & Van Steenbrugge, 2006). According to the spreading activation theory (Dell, 1986), instrumental verbs are easier to name because the semantic representation of a verb is activated simultaneously with that of its instrument. It has been suggested that this coactivation lowers the threshold for activating the phonological form of the verb, thereby resulting in better verb retrieval (Jonkers & Bastiaanse, 2007). Following this line of reasoning, children with LD might benefit from increased semantic richness when retrieving the phonological representation of a verb. In other words, children with LD might find it easier to learn instrumental verbs.

Yet, the opposite pattern has been shown in children with LD, with instrumental verbs being more difficult to name than noninstrumental verbs (Kambanaros, 2013). This might be explained by the increased number of semantic features of instrumental verbs, making them more complex and challenging to learn, access, and retrieve. This suggests that children with LD might have problems with fast mapping the meaning of verbs that are semantically more specific because of their instrumentality (Rice & Bode, 1993). Yet, no study has explored this in spoken verb learning.

Factors facilitating verb learning

The need to identify learning contexts that may aid novel verb learning has been emphasized in previous work as essential to the further development of evidence-based language intervention (Horvath & Arunachalam, 2019). For example, studies have demonstrated that children with LD may benefit from an increased number of exposures (Nash & Donaldson, 2005; Rice et al., 1994) or from multiple opportunities to practice retrieving new verbs (Leonard et al., 2023). Given that children with LD tend to have poorer linguistic processing skills, they might also benefit from a learning context with diminished processing demands such as by presenting novel verbs using a slowed speech rate (Ellis Weismer & Hesketh, 1996).

The orthographic facilitation effect

Apart from a phonological, semantic, and syntactic representation, words also contain an orthographic (i.e., a word's spelling) representation in literate individuals. Orthography can increase the specificity of a word's phonological representation during spoken word learning if its orthographic representation is presented simultaneously with its phonological (i.e., auditory) presentation (Ehri & Wilce, 1979). This orthographic facilitation effect has been shown to improve retention of the phonological and semantic representations of words across multiple learning contexts and may be first observed during learning as well as immediately following learning or after several days or weeks (Colenbrander et al., 2019; Ehri & Wilce, 1979; Lucas & Norbury, 2014; Rosenthal & Ehri, 2008). This effect can occur implicitly, without instructing readers to pay attention to the orthographic cues (Ricketts et al., 2009; Rosenthal & Ehri, 2008).

Two cognitive theories have been put forward to explain orthographic facilitation. According to the *lexical quality hypothesis,* a word's lexical quality is dependent on the number of well-integrated representations of that word in the lexicon (Perfetti & Hart, 2002). For example, a word for which accurate and robust orthographic, phonological, and semantic representations are stored in the lexicon has higher quality than a word for which only the phonological and semantic representations are stored. Following this reasoning, adding the written word form during spoken word learning may increase both the number of representations of a word and the specificity of its phonological representation, resulting in more accurate and efficient retrieval of the pronunciation, meaning, and/or spelling of that word. The *connectionist theory* or t*heory of sight word learning* (Ehri & Wilce, 1979) argues that the simultaneous presentation of a word's phonemes (i.e., sounds) and graphemes (i.e., letters) facilitates learning a word's pronunciation by forming a connection between the orthography and phonology of a word that is then linked to a word's meaning.

The orthographic facilitation effect has been demonstrated to aid spoken vocabulary acquisition not only in typically developing children (Ricketts et al., 2009; Salins et al., 2023) but also in several atypical populations such as children with autism, children with Down syndrome, and children with dyslexia (e.g., Baron et al., 2018; Clark & Reuterskiöld, 2023; Ricketts et al., 2015; see Clark & Reuterskiöld, 2021, and Colenbrander et al., 2019, for reviews). It has been argued that in children with spoken language difficulties, strengths in orthographic decoding skills can be used as a compensatory strategy (Ricketts et al., 2009, 2015). For example, in children with Down syndrome, who can have relatively intact word reading skills in contrast to spoken language difficulties, an orthographic facilitation effect has been demonstrated (Mengoni et al., 2013).

Some children with LD may still acquire age-appropriate grapheme–phoneme encoding skills (McArthur et al., 2000). In addition, Also, given that children with dyslexia still may benefit from added orthographic information (Baron et al., 2018) and that reading performance does not always influence the magnitude of an orthographic facilitation effect (Clark & Reuterskiöld, 2023; Ricketts et al., 2015; Valentini et al., 2018), a similar pattern might be observed in children with LD, including those with poorer reading skills.

Only one study evaluated the orthographic facilitation effect in children with LD (Ricketts et al., 2015). In this study, 27 English-speaking children with LD aged 8 to 13 years were taught nonword–referent mappings, half of which were presented with the written word form. Both children with LD and typically developing controls performed similarly for word learning and benefited equally from orthographic information during training (across all learning blocks). Yet, this study evaluated word learning during picture–word matching, which does not evaluate expressive vocabulary knowledge. If orthographic facilitation assists with building a more precise phonological representation, it may be important to use outcome measures that assess this precision (e.g., a naming task). Furthermore, all studies investigating orthographic facilitation effects included only nouns as stimuli. Due to the verb learning difficulties in children with LD, it is important to explore whether orthographic facilitation occurs when learning verbs.

The current study

In an attempt to fill the above-described gaps in the literature, we aimed to evaluate fast mapping of novel verbs (i.e., the formation of the initial representation between a word and its referent; Carey & Bartlett, 1978) in children with LD in the second and third grades of elementary school. First, we tried to replicate verb learning impairments reported in younger children with LD. Second, we investigated whether verb instrumentality affects verb learning success. Third, we evaluated whether adding the written word form facilitates verb learning and might increase the chances of children with LD to increase their vocabulary skills as text becomes more present in their education. Following the studies by Ricketts et al. (2009, 2015), we adopted a paired-associate learning paradigm. Rather than learning novel actions, children learned nonword synonyms for existing actions. This more controlled approach has been used in previous studies (Oetting, 1999; O'Hara & Johnston, 1997; Steele & Watkins, 2010) and fits with the increase in growth and depth of vocabulary in upper elementary school, when children learn novel labels for existing concepts such as "to grab" and "to seize" (Steele & Watkins, 2010). Posttests consisted of animation–nonword matching and animation naming because we wanted to evaluate the specificity of the learned phonological representations. The current study aimed to answer three primary research questions:

1. Do children with LD in elementary school have more difficulty with learning novel verbs than typically developing children?
2. Does verb instrumentality influence verb learning in children with LD and typically developing children?
3. Do children with LD and typically developing children learn novel verbs more readily when these are presented with orthographic information?

In addition to these main research questions, we asked a more exploratory question concerning the skills that potentially mediate verb learning. Based on previous work, we explored the relationship between verb learning performance and phonological working memory (Adlof & Patten, 2017; Jackson et al., 2021). Furthermore, given that Adlof and Patten (2017) hypothesized that existing semantic knowledge would be particularly relevant when distinguishing between semantic categories, we investigated whether vocabulary size mediated a possible instrumentality effect. Finally, the relation between reading skills and orthographic facilitation was investigated. The following research question captures these explorations:

4. Which measures of children's existing language skills mediate verb learning ability?

We were particularly interested in the following subquestions:

a. Is there a relation between nonword repetition skills and verb learning performance?
b. Does vocabulary size mediate a possible instrumentality effect?
c. Do reading skills mediate a possible orthographic facilitation effect?

Method

Participants

Participants were recruited via social media, parent groups, and regular primary schools in the Netherlands. Children with LD were also recruited via so-called Cluster 2 schools that provide special education services for children with LD. Children were excluded from the study if they had hearing or uncorrected vision problems, severe articulatory difficulties that would restrict intelligibility during testing, or a nonverbal intelligence score below 70 (see "Background measures" below). Typically developing children did not have a history of language, learning, psychiatric, or neurodevelopmental impairment associated with language impairment (e.g., autism).

Children with LD were diagnosed by a licensed professional, following national guidelines (Stichting Siméa, 2017). To receive the diagnosis, children had an overall score of at least 2 standard deviations below the mean of a standardized language battery. Alternatively, as measured by two subscales of that language battery, children scored at least 2 standard deviations below the mean for one of four language functions (i.e., speech, morphosyntax, lexical semantics, or pragmatics), 1.5 standard deviations below the mean on two functions, or 1.3 standard deviations below the mean on three functions. The language impairments could not be attributed to a general developmental delay, hearing problems, or a multilingual background. Children with and without co-occurring biomedical conditions (e.g., children with autism) were included. Because of this, we did not refer to the sample as children with developmental language disorder but instead referred to the sample as children with LD as outlined in the CATALISE study (Bishop et al., 2017).

The final sample consisted of 25 children with LD and 25 typically developing controls ranging in age from 8;1 (years;months) to 12;7 (M = 9;9, SD = 1;3). Groups were recruited to be matched for age. All children were native speakers of Dutch, but 5 children were also acquiring another language. In the LD group, 4 children were also diagnosed with dyslexia, 4 children with autism, and 1 child with 22Q deletion syndrome; in addition, 1 child was diagnosed with both dyslexia and autism in addition to LD. In the typically developing group, 1 child was diagnosed with attention-deficit/hyperactivity disorder. Children with LD attended special education (n = 17) or mainstream primary schools (n = 8). All typically developing children attended mainstream schools. See Table 1 for the demographic characteristics of the participants. Mann–Whitney U tests showed no significant difference of age between groups (U = 336, p = .655), but education level of parents differed significantly (U = 172.50, p = .025).

Materials

Background measures

Nonverbal intelligence. The brief form of the Wechsler Nonverbal Scale of Ability (WNV; Wechsler & Naglieri, 2008) was administered to measure nonverbal cognitive abilities. This test consists of two subtests. In the Matrices subtest, the child needs to select the missing piece of an incomplete figural matrix out of five options. In the Spatial Span subtest, the child taps a series of blocks in the same order (Spatial Span Forward) or reverse order (Spatial Span Backward), as demonstrated by the examiner.

Vocabulary skills. Vocabulary skills were measured with the Dutch Peabody Picture Vocabulary Test (PPVT; Schlichting, 2005) and the word definition subtest of the Wechsler Intelligence Scale for Children (WISC; Hendriks et al., 2018). The PPVT is a test of receptive vocabulary in which the child needs to select one of four pictures to match an auditorily presented word (predominantly nouns). The word definition task is a measure of expressive vocabulary in which the child must define words.

Phonological short-term memory. This language function was assessed using the quasi-universal nonword repetition task in which the child repeats nonwords of varying lengths (i.e., two to five syllables) (Boerma et al., 2015).

Table 1
Demographic characteristics of participants.

	LD (n = 25)	TD (n = 25)
Age (years;months)		
M (*SD*)	9;10 (1;4)	9;7 (1;3)
Range	8;1–12;7	8;0–12;1
Gender (male)	16	11
Language background (monolingual)	23	22
Education level of parents		
M (*SD*)	2.74 (0.54)	3.33 (0.97)
Range	2.00–4.00	2.00–5.00

Note. LD, language disorder; TD, typically developing; Education level of parents, average education level of the two parents/guardians of each participant, ranging from 1 (primary school) to 5 (Ph.D.).

Word-level reading. Word reading fluency and accuracy were measured with Version A of the One Minute Test (EMT; Brus & Voeten, 1973) and the Klepel-R (Van den Bos et al., 1994) in which children need to read a word list as fast and accurately as possible. The EMT measures word recognition with a time limit of 1 minute, whereas the Klepel-R is a test of orthographic decoding in which pronounceable nonwords must be read within 2 minutes.

Verb learning task

Stimuli. The stimuli consisted of 20 nonwords representing verbs. The stem of the novel verbs consisted of three or four phonemes with a CVC structure (e.g., "fem-en"), CVCC structure (e.g., "pilk-en"), or CCVC structure (e.g., "zwok-en"), with C denoting consonant sound, V denoting vowel sound, and "-en" representing the Dutch infinitive marker. Every nonword was paired with an animation video depicting a familiar change-of-state action (e.g., "to stir"). Given some evidence that verb syntax (e.g., whether a verb is transitive; Scott & Fisher, 2012) can affect learning, all novel verbs were transitive. Originally, 40 animations matched pairwise for instrumentality (see next paragraph for a more detailed explanation) were developed. Each animation lasted 4 seconds. These animations were piloted on 10 adults to evaluate animation–name agreement. More specifically, adults were asked to name the animations to validate whether these represented the targeted actions. The 10 pairs for which 80% agreement was reached were used as referents for the final stimuli (see Appendix A). A professional voice actress, a native speaker of Dutch, recorded all task instructions and the final stimuli.

The 20 actions were divided into 10 pairs, with each pair consisting of an instrumental verb and a noninstrumental verb that achieved the same result. For example, in the pair "to cut" and "to tear", both actions resulted in a piece of paper being divided into two pieces. Both items of an instrumentality pair had the same phonemic structure (e.g., "pilken" and "gorpen"), and instrumental and noninstrumental actions were matched for age of acquisition, concreteness, and word frequency using the databases of Brysbaert et al. (2014) and the SUBTLEX-NL database (Keuleers et al., 2010). In addition to matching conditions in age of acquisition, only verbs with an age of acquisition rating under 8 years were included to maximize the likelihood that these were familiar to participants (who were aged 8–12 years) (see Appendix A). A different instrument was used for each instrumental action, and a different object was manipulated in every verb pair. Every participant was exposed to 10 instrumental and 10 noninstrumental actions. Furthermore, 10 actions (i.e., five verb pairs) were presented with orthographic information.

Overall task structure (see Fig. 1). The verb learning task was developed in a space theme in which an astronaut explained to children that they would be learning an alien language. At the end of the task, it was emphasized that the learned words were not real and that the children could forget them. Children were presented with instructions and examples to ensure understanding. All items were presented on a computer screen. Responses of the children were audio-recorded and written down by the examiner during the testing session.

To have enough items to achieve appropriate statistical power while keeping the experimental sessions short, verb learning was completed across two sessions. Verb learning in each session included 10 items and lasted 20 to 25 minutes following the same task structure. Four versions of the task were created (see Table 2). In Versions 3 and 4 of the task, the nonword referents of the actions were reversed within each instrumentality pair as compared with Versions 1 and 2 (e.g., a given nonword paired to an instrumental action in Version 3 was paired to a noninstrumental action in Version 1). In addition, children were presented with one of two pseudorandomized orders of the task.

Training. Children were first familiarized with the nonwords during a repetition task. Every nonword was repeated until the children could pronounce it correctly. This was followed by a training phase consisting of three blocks in which the children first needed to repeat the novel verbs in a subject–verb–object sentence (e.g., ''het meisje *pilkt* het haar'' [the girl *pilks* the hair]). Afterward, children needed to name the animations depicting the actions. In the naming trials, the correct response was played to the children regardless of the accuracy of their response. Children were exposed to the written word form for half of the verbs, which was placed on the top middle of the screen above the animation and appeared when the novel verb was spoken, remaining on the screen until the sentence was repeated or feedback was received. For example, for the stimulus ''het meisje *pilkt* het haar'', the written word form ''pilkt'' appeared when the word ''pilkt'' was spoken.

Posttests. Recognition (auditory comprehension) and production of the novel verbs were evaluated immediately after the training phase in two posttests. In the animation–nonword matching task, receptive knowledge of the nonwords was evaluated. In every trial, the children heard a stimulus nonword and needed to select the target verb out of four choices (i.e., the target verb and three distractors), with the four corresponding animations presented in a 2 × 2 grid. The distractors were other animations in part of the learning trials that did not match the presented verb. These were, as depicted in Fig. 2 for the noninstrumental target verb ''hannen'' (to tear), other choices comprising (a) a related concept corresponding to the other verb of the instrumentality pair (i.e., a noninstrumental action vs. a semantically similar instrumental action), (b) an unrelated concept of the same instrumentality condition but which had been presented in another modality during learning (i.e., with or without orthographic information), and (c) an unrelated concept of another instrumentality and modality. Children answered by pointing to one of the pictures on the screen. The naming posttest was identical to the training phase except that the children did not receive feedback. If children responded ''I don't know'', they were prompted to try to answer.

Procedure

Testing comprised three sessions of approximately 1 hour spread across several days that were scheduled within 4 weeks of each other. During the first testing session, standardized tests were administered evaluating nonverbal intelligence, vocabulary skills, and phonological short-term memory. The second testing session comprised the first part of the verb learning task and four subtests of a verb battery under development by the Child's Language Disorders Lab of the neurolinguistics research group at the University of Groningen. This battery is not discussed further in this article. During the final testing session, one test of the verb battery, the second part of the verb learning task and the standardized reading tests were completed. Children were tested at home, at school, or in the neurolinguistics lab at the university depending on parental preference.

In addition, a parent or caretaker for each child filled out two questionnaires. The first questionnaire considered demographic information of the child, his or her language background, parents' education level, and the child's history of language and neurodevelopmental disorders. The second questionnaire was the Dutch Children's Communication Checklist (Geurts, 2007). This standardized checklist screens for communication and pragmatic difficulties and was used to confirm the absence of language impairments in typically developing children. Ethical approval for data collection was obtained from the research ethics committee for the Faculty of Arts of the University of Groningen.

Table 2
Overview of the four task versions based on two pseudorandomized orders of items (A vs. B) and two types of nonword–referent pairings (Appendix A and reverse pairing).

Task version	Order of items	Nonword–referent pairing
1	A	Default pairing (“nugen” = “to stir”)
2	B	Default pairing (“nugen” = “to stir”)
3	A	Reverse instrumentality pairing (“nugen” = “to shake”)
4	B	Reverse instrumentality pairing (“nugen” = “to shake”)

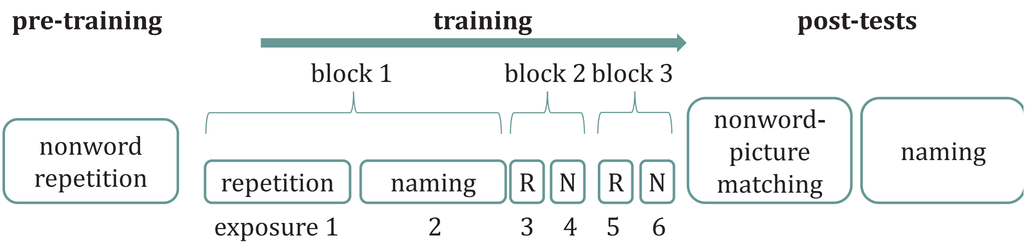

Fig. 1. Diagram adapted from Ricketts et al. (2015) illustrating the procedure of the verb learning task. R, repetition; N, naming.

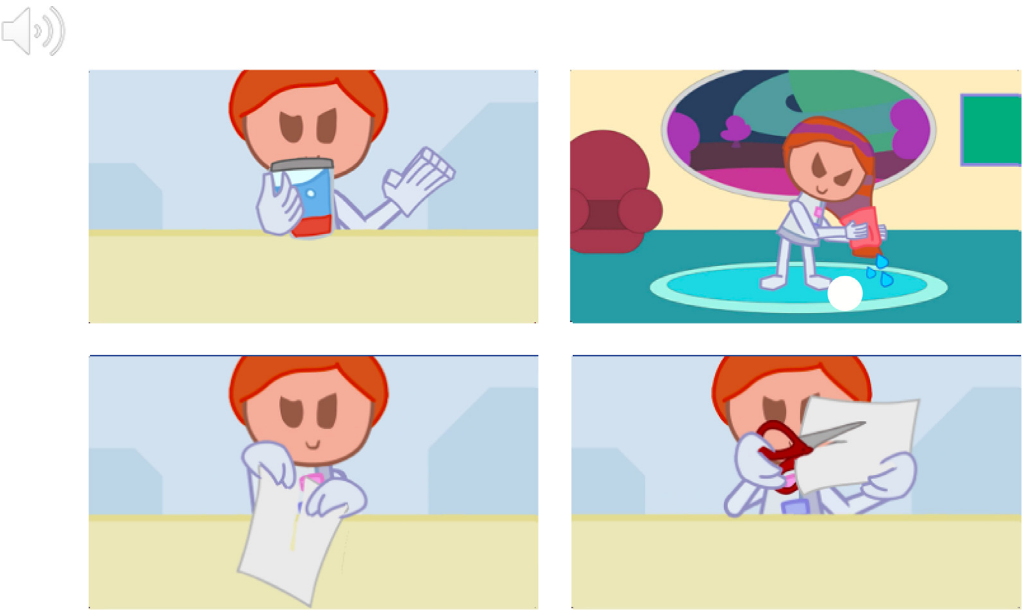

Fig. 2. Example item of the matching posttest for the noninstrumental verb “hannen” (to tear) not presented with orthographic information during the learning trials. The target animation is displayed in the bottom left corner. Distractor 1—“mellen” (to cut)—is presented in the bottom right corner, reflecting the instrumental counterpart of the target verb, also only auditorily presented. Distractor 2—“femen” (to shake)—in the top left corner is a noninstrumental verb that is not conceptually related to the target verb. This item was presented with orthographic information during the learning trials. Distractor 3—“gorpen” (to wring)—in the top right corner is a conceptually unrelated instrumental verb that was presented with orthographic information during learning. See online supplementary material for examples of the animations.

Data coding

When scoring the naming task, both the number of completely correct answers (i.e., the stem of the novel verb was produced correctly) and correctly produced phonemes of the stem were counted. This resulted in a dichotomous decision for the number of completely correct answers (i.e., correct or incorrect) and a score ranging from 0 to 3 or 4 for the number of correct phonemes, depending on the length of the stem (e.g., "meuzen" instead of the target verb "beuzen" contained two correct phonemes). This allowed us to investigate whether orthographic information resulted in retaining more correct phonemes even if the given response was not completely accurate. A response during the naming trial was considered completely correct if either the infinitive form of the novel verb (e.g., "pilken") or its third-person singular (e.g., "pilkt") was produced. Transpositions, deletions, substitutions, and additions of phonemes were penalized. All answers were transcribed, and the incorrect responses were assigned to one of four error categories (see Table 3). Animation–nonword matching was scored as either correct or incorrect. If incorrect, the selected distractor was noted. All background measures were scored following the standardized scoring procedures.

Plan for statistical analyses

After testing for normality, scores on background measures between children with LD and typically developing controls were compared using independent Student's *t* tests or Mann–Whitney *U* tests. Verb learning data were analyzed using generalized linear mixed-effects models (GLMER; for binomial accuracy on the naming and matching task) and linear mixed-effects models (LMER; for naming scored as the proportion of correct phonemes) with sum contrasts. To answer the main research questions, the models were fit by maximum likelihood with group (LD vs. typically developing), the instrumentality condition (instrumental vs. noninstrumental), and the orthography or modality condition (sound only vs. sound + text) as predictors of verb learning performance in the posttests. In relation to the first research question, the difference between groups during the learning trials was explored by fitting a model by maximum likelihood by group and block (1 vs. 2 vs. 3) for the training naming data. Exploratory analyses were conducted to answer the fourth research question, investigating whether background measures mediated verb learning performance. A first exploratory model was fit with group and nonword repetition performance as predictors for verb learning performance in the posttests. For verb instrumentality, the model was fit with group, instrumentality condition, and vocabulary size as predictors. A final model was fit by maximum likelihood with group, modality, and word reading performance as predictors. Parents' education level and children's nonverbal intelligence scores were added as covariates to all models, and all numeric predictors were scaled and centered. Analysis of variance (ANOVA) Type III sum of squares was used to test significance and obtain *p* and χ^2 values. Post hoc comparisons were conducted using "emmeans" and "emtrends" packages. Percentages were calculated for the types of errors made on the posttests.

Results

Background measures

Table 4 shows the performance of the participants on the background measures. Children with LD scored higher than the typically developing controls on both composites of the Children's Communication Checklist, with higher scores reflecting lower language skills. For all other measures, the LD group scored lower than the typically developing group, with lower scores reflecting lower language skills. These comparisons confirm a significant language skill difference between the two groups.

Verb learning task: Main analyses

The verb learning data were analyzed using mixed-effects models (see Table 5 for descriptive statistics). Before the study, a power analysis was performed, indicating that with 25 participants in

Table 3
Error categorization for the naming trials of the verb learning task.

Error category	Explanation	Example
Partly correct	Child produced one or more correct phonemes of the target verb, but the answer was not completely correct.	"kilpen" instead of "pilken"
Other item	Child produced another nonword part of the stimuli.	"gorpen" instead of "mellen"
Guess	Child guessed the answer using a nonword that was not part of the stimuli. (Note that "-en" marks the infinitive and was not scored as partially correct).	"kuren" instead of "femen"
Existing verb	Child produced an existing verb instead of the nonword.	"roeren" ("to stir") instead of "nugen"
No response	Child gave no response or said 'I don't know".	-

Table 4
Scores on background measures for the children with LD in comparison with the typically developing controls.

	LD		TD		*t*	*p*
	M (*SD*)	Range	*M* (*SD*)	Range		
Children's Communication Checklist						
General communication composite	117.30 (9.31)	102–135	69.08 (14.68)	50–102	13.21	<.001
Social interaction deviance composite	55.95 (5.69)	48–67	35.25 (8.90)	24–57	9.33	<.001
Nonverbal intelligence (WNV)	95.80 (15.90)	71–131	110.48 (14.77)	81–137	−3.38	.001
Receptive vocabulary (PPVT)	88.00 (14.84)	54–114	108.68 (13.22)	86–142	−5.14	<.001
Expressive vocabulary (WISC)	7.04 (2.70)	2–11	13.56 (3.18)	8–19	40.50[a]	<.001
Nonword repetition (QU-NWR)	94.20 (9.35)	76–107	105.80 (6.16)	86–112	70.50[a]	<.001
Word reading (EMT)	35.48 (8.93)	22–61	57.28 (12.40)	37–75	−7.13	<.001
Nonword reading (Klepel)	37.72 (11.10)	20–70	57.44 (11.55)	36–80	−6.15	<.001

Note. LD, language disorder; TD, typically developing; WNV, Wechsler Nonverbal Scale of Ability; PPVT, Peabody Picture Vocabulary Test; WISC, Wechsler Intelligence Scale for Children; QU-NWR, quasi-universal nonword repetition task; EMT, One-Minute Test.
[a] *U* value.

each group, effect sizes of .40 or greater could be detected with a power of 80%. Another data-estimated power analysis for orthographic facilitation for mixed-effects models was conducted post hoc because preliminary results prompted the need to confirm that power was sufficient to detect orthographic facilitation effects. This analysis with 25 children in each group, using data from children with hearing loss (Salins et al., 2021), showed a power of 87% to detect an orthographic facilitation effect during learning.

Animation–nonword matching posttest

For the animation–nonword matching posttest, a main effect of group (χ^2 = 11.19, p < .001) was found (see Fig. 3). No main effect was found for verb instrumentality (χ^2 = 0.52, p = .471) or modality (χ^2 = 1.06, p = .303), and there were no significant interactions[2]. Because of the large body of evidence showing an orthographic facilitation effect in children with and without neurodevelopmental impairment (Colenbrander et al., 2019), contrasts were run on the model to test for modality effects in LD and typically developing groups separately. Neither the LD group (z = 1.30, p = .194) nor the typically developing group (z = 0.41, p = .683) showed an effect of modality. The full regression model can be found in Appendix Table B1.

Naming posttest

There was a main effect of group (χ^2 = 18.88, p < .001) for the number of completely correct responses on the naming posttest (see Fig. 4). No main effect of verb instrumentality (χ^2 = 2.92,

[2] Test statistics for interactions can be found in the models in Appendix B.

Table 5
Means (and standard deviations) for the verb learning task.

	Group	All items *M* (*SD*)	Instrumentality condition		Modality condition	
			Instrumental *M* (*SD*)	Noninstrumental *M* (*SD*)	Sound *M* (*SD*)	Sound + text *M* (*SD*)
Training (naming)						
Block 1						
Completely accurate	LD	0.20 (0.50)	0.16 (0.37)	0.04 (0.20)	0.16 (0.47)	0.04 (0.20)
	TD	1.00 (1.89)	0.60 (1.08)	0.40 (0.91)	0.48 (0.96)	0.52 (1.08)
Correct number of phonemes	LD	5.32 (3.47)	3.00 (2.40)	2.32 (1.99)	2.92 (2.50)	2.40 (2.04)
	TD	8.96 (7.00)	4.44 (4.43)	4.52 (3.63)	5.04 (3.92)	3.92 (3.96)
Block 2						
Completely accurate	LD	0.84 (1.75)	0.52 (1.05)	0.32 (0.85)	0.44 (0.92)	0.40 (0.91)
	TD	4.24 (3.42)	2.16 (1.65)	2.08 (1.98)	2.24 (2.11)	2.00 (1.68)
Correct number of phonemes	LD	9.96 (6.65)	5.68 (4.20)	4.28 (3.32)	5.76 (3.84)	4.20 (3.54)
	TD	21.96 (12.49)	11.28 (6.39)	10.68 (7.27)	11.48 (7.20)	10.48 (6.35)
Block 3						
Completely accurate	LD	2.12 (2.44)	1.36 (1.35)	0.76 (1.23)	1.44 (1.58)	0.68 (1.18)
	TD	7.16 (4.79)	3.72 (2.70)	3.44 (2.29)	3.88 (2.80)	3.28 (2.35)
Correct number of phonemes	LD	14.88 (10.56)	8.52 (5.34)	6.36 (5.61)	8.16 (6.13)	6.72 (5.53)
	TD	32.56 (17.57)	16.52 (9.69)	16.04 (8.78)	16.80 (9.52)	15.76 (8.80)
Posttests						
Animation-nonword matching	LD	9.52 (4.33)	4.92 (2.23)	4.60 (2.48)	4.44 (2.38)	5.08 (2.50)
	TD	14.72 (4.71)	7.40 (2.68)	7.32 (2.25)	7.28 (2.48)	7.44 (2.52)
Naming						
Completely accurate	LD	2.24 (2.99)	1.36 (1.63)	0.88 (1.48)	1.32 (1.73)	0.92 (1.47)
	TD	8.60 (5.47)	4.36 (3.04)	4.24 (2.65)	4.76 (3.14)	3.84 (2.53)
Correct number of phonemes	LD	15.80 (12.98)	8.68 (6.77)	7.12 (7.05)	9.04 (7.18)	6.76 (6.64)
	TD	37.04 (18.78)	18.60 (9.96)	18.44 (9.26)	19.68 (10.75)	17.36 (8.56)

Note. LD, language disorder; TD, typically developing. For binomial accuracy, the possible range of scores was 0 to 20 for all items and 0 to 10 for the instrumentality and orthography conditions. For the number of correctly named phonemes, the possible scores ranged from 0 to 72 for all items and from 0 to 36 for the instrumentality and modality conditions.

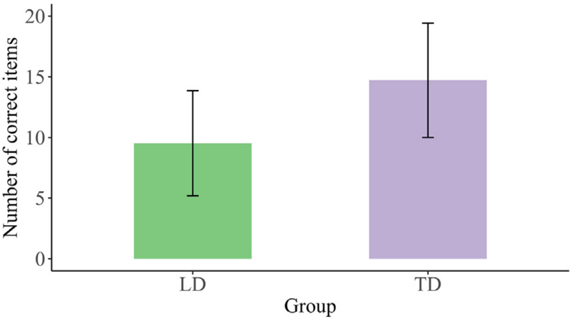

Fig. 3. Mean (with standard deviation) scores on the animation word-matching posttest. LD, language disorder; TD, typically developing.

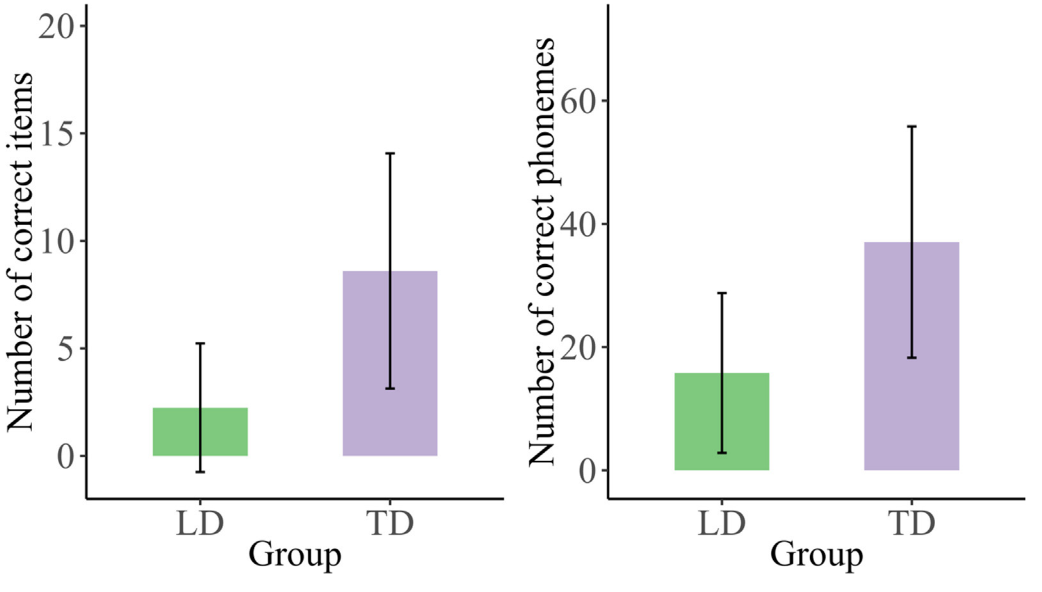

Fig. 4. Mean (with standard deviation) scores on the naming posttest. LD, language disorder; TD, typically developing.

p = .087) or modality (χ^2 = 1.94, p = .163) was found. There were no significant interactions (see Note 2). Contrasts showed that neither the LD group (z = −1.22, p = .222) nor the typically developing group (z = −1.34, p = .181) showed a modality effect. Similar results were found for the proportion of correct phonemes, with a main effect of group (χ^2 = 13.98, p < .001), but not of verb instrumentality (χ^2 = 1.27, p = .259) or modality (χ^2 = 1.55, p = .213), and there were no significant interactions (see Note 2). No modality effect was observed for the LD group (t = −1.10, p = .280) or the typically developing group (t = −1.14, p = .263) separately. See Appendix Tables B2 and B3 for the complete regression models.

Naming during training

For the number of completely accurate responses, the GLMER showed main effects of group (χ^2 = 15.56, p < .001) and training block (χ^2 = 130.50, p < .001) (see Fig. 5). There was no interaction (see Note 2) between these fixed effects. Contrasts showed significant group differences for every block, with a larger effect for block 2 (z = −4.07, p < .001) and block 3 (z = −4.01, p < .001) than for

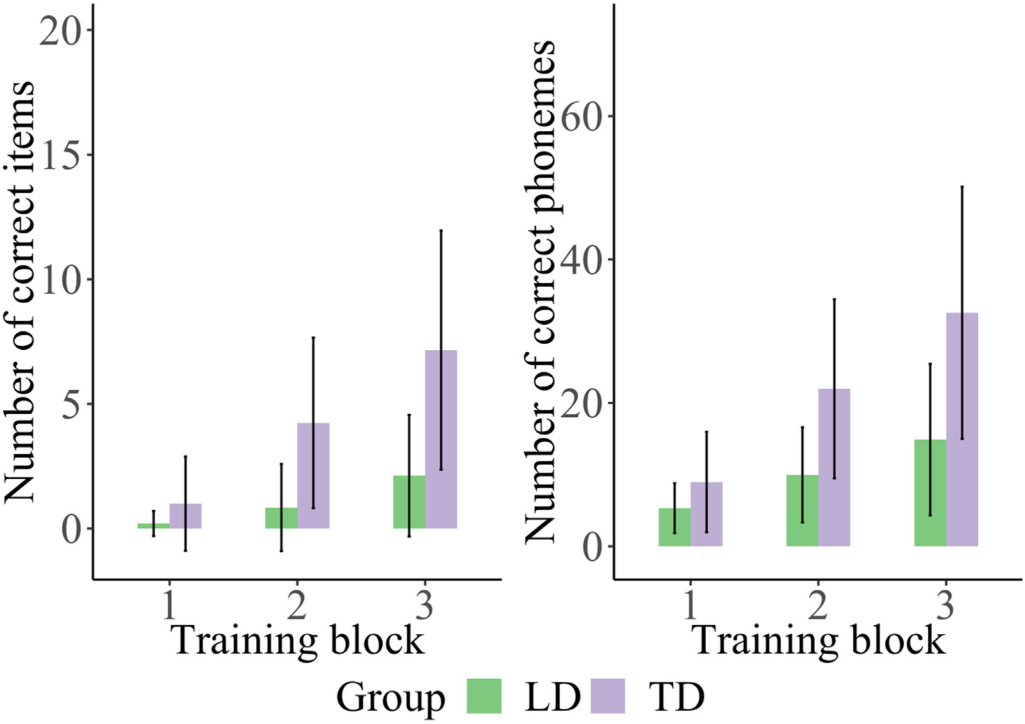

Fig. 5. Mean (with standard deviation) scores on the naming trials during training. LD, language disorder; TD, typically developing.

block 1 (z = –2.47, p = .014). For the proportion of correct phonemes, main effects of group (χ^2 = 10.70, p = .001) and block (χ^2 = 293.31, p < .001) and a significant interaction between group and block (χ^2 = 52.74, p < .001) was found. Group contrasts showed a significant difference between groups for block 2 (t = –3.33, p = .002) and block 3 (t = –5.15, p < .001), but not for block 1 (t = –0.69, p = .495). Full regression models can be found in Appendix Tables B4 and B5.

Verb learning task: Exploratory analyses

We conducted several exploratory analyses to investigate whether language and reading skills mediated the above-described verb learning outcomes. Given that we wanted to know whether vocabulary size and reading skills mediated an instrumentality or modality effect, we focused on reporting interactions within.

Nonword repetition in relation to verb learning performance

A first exploratory analysis with group and nonword repetition skills as fixed effects showed no main effect of nonword repetition skills (χ^2 = 3.21, p = .073) on the matching posttest. The interaction between the two effects was not significant (χ^2 = 1.11, p = .292). For the naming posttest, no effect of nonword repetition skills (χ^2 = 1.83, p = .176) was found when predicting the number of completely correct responses. No interaction was found between group and nonword repetition skills (χ^2 = 1.75, p = .186). For the proportion of correct phonemes, there was again no effect of nonword repetition skills (χ^2 = 3.16, p = .075), and the interaction between variables was not significant (χ^2 = 0.78, p = .378). See Appendix Table C1 for the full regression models.

Vocabulary size in relation to verb instrumentality

A second exploratory analysis showed no significant interaction between expressive vocabulary (χ^2 = 0.04, p = .843) and receptive vocabulary (χ^2 = 0.21, p = .649) and verb instrumentality when predicting scores on the matching posttest. For the naming posttest, the interaction between instrumentality and scores on the WISC was not significant for either predicting the number of completely correct responses (χ^2 = 0.05, p = .819) or the proportion of correct phonemes (χ^2 = 0.01, p = .917). The same null results were found for the interaction between instrumentality and PPVT scores when predicting complete accuracy (χ^2 = 0.09, p = .763) and the proportion of correct phonemes (χ^2 = 0.09, p = .763). See Appendix Tables C2 and C3 for the full regression models.

Reading skills in relation to orthographic facilitation

The third exploratory analysis showed no significant interaction between modality and either word reading (χ^2 = 0.21, p = .644) or nonword reading (χ^2 = 0.17, p = .679) when predicting accuracy on the matching posttest. Analyses of the naming posttest also yielded no interaction between word reading and modality when predicting complete accuracy (χ^2 = 0.35, p = .553) or for the proportion of correct phonemes (χ^2 = 0.77, p = .381). The same pattern was found for nonword reading when predicting complete accuracy (χ^2 = 0.07, p = .799) and the proportion of correct phonemes (χ^2 = 1.49, p = .222). See Appendix Tables C4 and C5 for the full regression models.

Verb learning task: Errors

When responding incorrectly on the matching posttest, the LD group most often (45.80% of errors) chose the other verb of the instrumentality pair (i.e., the instrumental or noninstrumental counterpart of the target verb). In other cases, children with LD chose the unrelated distractor (29.01%) or the distractor of the same instrumentality as the target verb that was presented in a different modality (25.19%). The same pattern was observed for the typically developing group, with children primarily choosing the other verb of the instrumentality pair (56.82%), followed by the unrelated distractor (21.97%) and the distractor of the same instrumentality but different modality (21.21%).

Regarding errors on the naming posttest (see Table 3 for the types of errors), children with LD most often guessed the answer or gave no response and least often produced another item instead of the target verb. Typically developing children also most often guessed the answer when giving an incorrect response, but the second most common error was producing another item. They least often produced an existing verb (see Table 6).

Discussion

The current study examined spoken verb learning in elementary school children with LD, investigating the effects of verb instrumentality (i.e., a measure of semantic complexity reflecting whether an action requires an instrument or not) and orthographic information on verb learning performance. The main analyses showed that children with LD learned fewer verbs than the typically developing controls, replicating results of previous studies (Kan & Windsor, 2010; Oetting et al., 1995; Rice et al.,

Table 6
Errors on the naming posttest.

Error category	Group	
	LD (%)	TD (%)
Partly correct	16.93	22.46
Other item	11.74	24.21
Guess	33.86	30.88
Existing verb	14.45	6.32
No response	23.02	16.14

Note. LD, language disorder; TD, typically developing.

1994). No effect of verb instrumentality or orthographic information on verb learning was found, and none of the included mediators was a significant predictor of receptive or expressive knowledge of the learned verbs.

Verb learning in children with LD

Children with LD performed worse than the typically developing controls for the learning trials and posttests, showing that problems with the rapid encoding of novel verbs can still be observed in elementary school (McGregor et al., 2013; Steele & Watkins, 2010). These results replicate previous findings in younger children (Oetting et al., 1995; O'Hara & Johnston, 1997; Rice et al., 1994). Accuracy increased across learning trials for both typically developing children and children with LD, but the ramp-up of the children with LD was slower and not sufficient to catch up with typically developing children, who showed a greater improvement across trials. Group differences were smaller for animation–nonword matching than for the action naming posttest, confirming that receptive form–referent linking may be a relative strength for children with LD, whereas verb form production is more challenging (Gray, 2004). The significant interaction between group and block during the learning trials implies that children with LD not only learned fewer words than their peers but also did so at a slower rate. This confirms previous findings that children with LD have difficulties with encoding (McGregor et al., 2017). Additional exposures to verbs may be required to achieve the level of verb learning displayed by the typically developing group.

The error analysis showed that when selecting the wrong item, both children with and without LD most often selected the semantically related distractor (i.e., the other item of the instrumentality verb pair). This could mean that although they had not created a full representation of those items, children had retained some semantic features of the novel verbs. The high occurrence of this error type and lower accuracy of children with LD are in line with the *storage hypothesis* (Kail et al., 1984), which states that children with LD create fewer and less detailed semantic representations of novel words. Future studies should rule out that the selection of the semantically related item was not merely a visual effect given that animations within one instrumentality pair were visually similar. When answering incorrectly during naming, the second most common error in the typically developing group was producing another item, whereas the LD group gave no response. This suggests that the two groups approached the naming task differently, possibly reflecting differences in learning or confidence.

Although children with LD had reduced nonword repetition skills compared with their peers, these did not mediate verb learning performance. This is in contrast to previous studies that found an effect of nonword repetition skills on word learning (Adlof & Patten, 2017; Jackson et al., 2021). In older children, improved lexical skills might reduce the importance of phonological short-term memory during word learning because of lexical restructuring, a process in which the phonological representations of words are more fine-grained (segmental instead of holistic) as vocabulary size increases (Metsala, 1999). In addition, Jackson et al. (2021) showed a greater effect of nonword repetition skills on word learning performance when learning longer words (up to five syllable words), whereas the stimuli in our task consisted of only two syllables. Further research could explore the effects of phonological short-term memory when manipulating verb length.

Verb instrumentality

No effect of instrumentality on verb learning was found. Although Kambanaros (2013) showed an effect of verb instrumentality during action naming, instrumentality might not pose a difficulty or has a small effect for children with LD during verb acquisition. However, our findings need to be replicated before firm conclusions can be drawn. Another possible explanation for the lack of effect is the absence of impairments of existing semantic knowledge in our clinical group. Although children with LD demonstrated problems with storing semantic detail for new representations, they performed in the average to low average range for the lexical semantic measures evaluating current vocabulary knowledge, a pattern that has been previously reported (e.g., McGregor et al., 2012). It is possible that for an instrumentality effect to occur during learning, semantic impairments need to be present. This was emphasized by (Sloot & Jonkers, 2011) in a study with people with Alzheimer's dementia with mild semantic impairments, failing to find a negative effect of verb instrumentality. Yet, Kambanaros (2013) reported an effect of verb instrumentality in typically developing children, although younger children (i.e., in preschool or first grade) than the current sample. Vocabulary size did not mediate our results, but the included vocabulary measures were largely noun-based. Because of possible differences in noun and verb acquisition, a verb-based measure could have been more appropriate (although rarely in use in clinical practice).

Orthographic facilitation

Somewhat surprisingly, we did not find an orthographic facilitation effect during verb learning. This is in contrast to the majority of previous studies demonstrating this effect in a similar age group during noun learning, particularly when encoding phonological information (Colenbrander et al., 2019; Ricketts et al., 2015). Mixed results have been found for semantic learning (i.e., picture–word matching) with small effect sizes (Colenbrander et al., 2019). Based on our power analysis and because the strength of an orthographic facilitation effect does not vary systematically with different sample sizes and numbers of items (Colenbrander et al., 2019), we do not believe our null effect to be caused solely by a lack of power.

One other study did not find an orthographic facilitation effect in typically developing children in which children were exposed to novel and familiar written word forms while simultaneously listening to a story (Valentini et al., 2018). In our design, we avoided the possible interference of other orthographic forms by presenting only the orthographic form of the novel verb. Yet, to the best of our knowledge, this was the first study to use animations instead of images as stimuli, and in the orthography-present condition the written word form was presented simultaneously with the animation. Thus, the movement of the animation could have drawn attention away from the orthographic cue. Unfortunately, we cannot be sure that participants noticed the orthographic information. Future studies should evaluate whether children pay attention to orthographic information when presented with moving stimuli, for example, using eye-tracking data (Lucas & Norbury, 2014). Nonetheless, it has been demonstrated that children pay attention to subtitles while watching animations (Cambra et al., 2014). Future research could also evaluate whether presenting the written word form slightly before the beginning or after the end of the animation fosters an orthographic facilitation effect and/or could directly compare orthographic facilitation during noun and verb learning in children with and without LD. This could increase our understanding regarding differences in learning of these word classes in LD.

In alignment with the findings of Ricketts et al. (2015), reading skills did not mediate an orthographic facilitation effect in our sample. This might be because the orthographically simple two-syllable stimuli were easy to read even for poor readers given that previous studies using more complex items did find an influence of reading skills (Ricketts et al., 2009). On the other hand, the absence of an orthographic facilitation effect might suggest insufficient variability to find an influence of reading skills.

It is important to note several limitations of our study. Although our sample was relatively large, it was diverse in terms of comorbid disorders and learning outcomes. The interplay between LD and other comorbid disorders might have influenced our results. In addition, although our experimental design showed group differences for verb learning, it is different from learning in a naturalistic setting in which vocabulary is learned across different learning contexts and an extended amount of time. Although tightly controlled experimental studies are important, future studies may choose to further investigate verb learning differences in a more naturalistic setting.

Conclusion

The current study investigated verb learning in children with LD in elementary school. We did not find an effect of verb instrumentality and orthographic facilitation, but the LD group learned fewer verbs and at a slower rate than the control group. These results highlight the need for further vocabulary instruction in elementary school, strengthening the initial encoding of verbs. Further research should examine orthographic facilitation during verb learning further and evaluate learning contexts in which orthographic information would be beneficial.

CRediT authorship contribution statement

Cheyenne Svaldi: Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Visualization, Writing – original draft, Writing – review & editing. **Saskia Kohnen:** Conceptualization, Methodology, Supervision, Writing – review & editing. **Serje Robidoux:** Formal analysis, Methodology, Writing – review & editing. **Kim Vos:** Investigation, Methodology, Writing – review & editing. **Aliene Reinders:** Investigation, Methodology, Writing – review & editing. **Sudha Arunachalam:** Conceptualization, Methodology, Writing – review & editing. **Roel Jonkers:** Conceptualization, Methodology, Supervision, Writing – review & editing. **Vânia de Aguiar:** Conceptualization, Funding acquisition, Methodology, Resources, Supervision, Writing – review & editing.

Data availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Appendix A. Experimental stimuli and ratings for psycholinguistic variables

	Instrumental						Noninstrumental				
Pair	Nonword	Action	Instrument	Concreteness	Word frequency	AoA	Nonword	Action	Concreteness	Word frequency	AoA
Part 1											
1	nugen[a]	roeren (to stir)	spoon	3.87	2.17	6.28	femen[a]	schudden (to shake)	4.20	19.90	6.40
2	mellen	knippen (to cut)	scissors	4.60	9.08	4.96	hannen	scheuren (to tear)	4.07	6.61	6.46
3	pilken[a]	afdrogen (to dry)	towel	3.87	1.35	6.28	gorpen[a]	uitwringen (to wring)	3.73	0.11	7.70
4	rijlpen	schieten (to shoot)	catapult	4.47	132.34	6.21	kuirden	gooien (to throw)	4.27	49.62	4.84
5	gluinen[a]	hakken (to chop)	axe	4.13	12.42	8.01	blieren[a]	breken (to break)	4.07	44.00	5.65
Part 2											
1	vieden[a]	smeren (to smear)	knife	3.93	13.63	6.03	beuzen[a]	dippen (to dip)	3.80	0.37	9.78
2	Waten	prikken (to sting)	thumbtack	3.93	4.23	6.09	lijssen	knijpen (to pinch)	4.47	6.11	6.15
3	deerken	vissen (to fish)	fishing rod	4.27	40.27	5.51	paasten	vangen (to catch)	3.40	36.91	5.34
4	zwoken	afstoffen (to dust)	feather duster	3.73	0.75	7.70	truven	blazen (to blow)	4.40	17.65	5.03
5	kruffen[a]	spuiten (to spray)	spray	4.27	5.53	6.78	steggen[a]	insmeren (to rub)	3.80	1.07	7.00
			Total *M* (*SD*):	4.11 (0.29)	22.18 (40.41)	6.39 (0.92)			4.02 (0.33)	18.24 (18.93)	6.44 (1.47)

Note. AoA, age of acquisition.

[a]Presented with orthographic information.

Appendix B. Generalized and linear mixed-effects models and model estimated means for the main analyses

Table B1 Generalized linear mixed-effects model for the animation–nonword matching posttest.

Predictor	Odds ratio	CI	*p*
(Intercept)	1.88	[1.29, 2.74]	.001
Group (LD)	0.51	[0.35, 0.76]	.001
Modality (sound)	1.11	[0.91, 1.36]	.303
Instrumentality (I)	1.06	[0.91, 1.22]	.471
IQ NV s	1.07	[0.73, 1.57]	.739
ED mean s	1.27	[0.89, 1.79]	.185
Group (LD) × Modality (sound)	1.05	[0.91, 1.22]	.496
Group (LD) × Instrumentality (I)	1.03	[0.89, 1.19]	.731
Modality (sound) × Instrumentality (I)	1.09	[0.94, 1.27]	.245
Group (LD) × Modality (sound) × Instrumentality (I)	1.01	[0.87, 1.17]	.900
Random effects			
σ^2	3.29		
$^{\tau}00$ Participant	1.25		
$^{\tau}00$ Item	0.10		
ICC	.29		
$N_{\text{Participant}}$	50		
N_{Item}	20		
Observations	1000		
Marginal R^2 / Conditional R^2	.120 / .376		

Note. CI, confidence interval; LD, language disorder; IQ NV s, scaled nonverbal intelligence; ED mean s, scaled mean education level of parents; ICC, intraclass correlation coefficient.

Table B2. Generalized linear mixed-effects model for the naming post-test (binary accuracy).

Predictor	Odds ratio	CI	*p*
(Intercept)	0.16	[0.08, 0.32]	<.001
Group (LD)	0.27	[0.15, 0.49]	<.001
Modality (sound)	0.72	[0.46, 1.14]	.163
Instrumentality (I)	1.19	[0.97, 1.46]	.087
IQ NV s	1.18	[0.67, 2.07]	.567
ED mean s	1.02	[0.60, 1.72]	.952
Group (LD) × Modality (sound)	0.99	[0.81, 1.22]	.945
Group (LD) × Instrumentality (I)	1.15	[0.94, 1.42]	.176
Modality (sound) × Instrumentality (I)	0.95	[0.77, 1.16]	.600
Group (LD) × Modality (sound) × Instrumentality (I)	1.02	[0.83, 1.25]	.847
Random effects			
σ^2	3.29		
$^{\tau}00$ Participant	2.64		
$^{\tau}00$ Item	0.85		
ICC	.51		
$N_{\text{Participant}}$	50		
N_{Item}	20		
Observations	1000		
Marginal R^2 / Conditional R^2	.237 / .630		

Note. CI, confidence interval; LD, language disorder; IQ NV s, scaled nonverbal intelligence; ED mean s, scaled mean education level of parents; ICC, intraclass correlation coefficient.

Table B3. Linear mixed-effects model for the naming posttest (proportions of correct phonemes).

Predictor	Estimate	CI	*p*
(Intercept)	0.37	[0.30, 0.44]	<.001
Group (LD)	−0.14	[−0.21, −0.07]	<.001
Modality (sound)	−0.03	[−0.07, 0.02]	.213
Instrumentality (I)	0.01	[−0.01, 0.03]	.260
IQ NV s	0.02	[−0.05, 0.09]	.627
ED mean s	0.02	[−0.04, 0.09]	.541
Group (LD) × Modality (sound)	0.00	[−0.02, 0.02]	.963
Group (LD) × Instrumentality (I)	0.01	[−0.01, 0.03]	.322
Modality (sound) × Instrumentality (I)	−0.01	[−0.03, 0.01]	.457
Group (LD) × Modality (sound) × Instrumentality (I)	0.02	[−0.01, 0.04]	.150
Random effects			
σ^2	0.11		
$^{\tau}00$ Participant	0.05		
$^{\tau}00$ Item	0.01		
ICC	.32		
$N_{\text{Participant}}$	50		
N_{Item}	20		
Observations	1000		
Marginal R^2 / Conditional R^2	.125 / .408		

Note. CI, confidence interval; LD, language disorder; IQ NV s, scaled nonverbal intelligence; ED mean s, scaled mean education level of parents; ICC, intraclass correlation coefficient.

Table B4. Generalized linear mixed-effects model for the naming trials during the training phase (binary accuracy).

Predictor	Odds ratio	CI	*p*
(Intercept)	0.04	[0.02, 0.07]	<.001
Group (LD)	0.41	[0.27, 0.64]	<.001
Block (1)	0.21	[0.15, 0.30]	<.001
Block (2)	1.26	[0.99, 1.61]	.059
IQ NV s	1.35	[0.90, 2.03]	.152
ED mean s	1.03	[0.70, 1.50]	.891
Group (LD) × Block (1)	1.09	[0.78, 1.54]	.611
Group (LD) × Block (2)	0.91	[0.72, 1.16]	.455
Random effects			
σ^2	3.29		
$^{\tau}00$ Participant	1.38		
$^{\tau}00$ Item	0.69		
ICC	.39		
$N_{\text{Participant}}$	50		
N_{Item}	20		
Observations	3000		
Marginal R^2 / Conditional R^2	.318 / .582		

Note. CI, confidence interval; LD, language disorder; IQ NV s, scaled nonverbal intelligence; ED mean s, scaled mean education level of parents; ICC, intraclass correlation coefficient.

Table B5. Linear mixed-effects model for the naming trials during the training phase (proportion of correct phonemes).

Predictor	Estimate	CI	p
(Intercept)	0.22	[0.18, 0.26]	< .001
Group (LD)	−0.07	[−0.11, -0.03]	.001
Block (1)	−0.12	[−0.14, -0.10]	<.001
Block (2)	0.01	[−0.01, 0.02]	.446
IQ NV s	0.02	[−0.02, 0.06]	.298
ED mean s	0.01	[−0.02, 0.05]	.469
Group (LD) × Block (1)	0.05	[0.04, 0.07]	<.001
Group (LD) × Block (2)	−0.01	[−0.02, 0.01]	.450
Random effects			
σ^2	0.09		
$^{\tau}$00 Participant	0.01		
$^{\tau}$00 Item	0.00		
ICC	.16		
$N_{\text{Participant}}$	50		
N_{Item}	20		
Observations	3000		
Marginal R^2 / Conditional R^2	.137 / .272		

Note. CI, confidence interval; LD, language disorder; IQ NV s, scaled nonverbal intelligence; ED mean s, scaled mean education level of parents; ICC, intraclass correlation coefficient.

Appendix C. Generalized and linear mixed-effects models and model estimated means for the exploratory analyses

Table C1. Exploratory (generalized) linear mixed-effects models investigating interactions between nonword repetition and the verb learning posttests.

Predictor	Matching (GLMER)			Naming–binary accuracy (GLMER)			Naming–proportion of phonemes (LMER)		
	Estimate	CI	*p*	Estimate	CI	*p*	Estimate	CI	*p*
(Intercept)	1.62	[1.03, 2.55]	.039	0.13	[0.06, 0.29]	<.001	0.35	[0.26, 0.44]	<.001
Group (LD)	0.65	[0.41, 1.02]	.060	0.36	[0.18, 0.72]	.004	−0.09	[−0.18, −0.01]	.032
NWR s	1.53	[0.96, 2.43]	.073	1.61	[0.81, 3.19]	.176	0.08	[−0.01, 0.17]	.075
IQ NV s	1.05	[0.72, 1.52]	.805	1.15	[0.67, 1.99]	.612	0.01	[−0.06, 0.08]	.703
ED mean s	1.17	[0.83, 1.65]	.373	0.92	[0.54, 1.56]	.762	0.01	[−0.06, 0.07]	.854
Group (LD) × NWR s	0.78	[0.50, 1.23]	.292	0.63	[0.32, 1.25]	.186	−0.04	[−0.13, 0.05]	.378
Random effects									
σ^2	3.29			3.29			0.11		
$^{\tau}00$ Participant	1.14			2.45			0.05		
$^{\tau}00$ Item	0.11			0.94			0.01		
ICC	.27			.51			.32		
$N_{\text{Participant}}$	50			50			50		
N_{Item}	20			20			20		
Observations	1000			1000			1000		
Marginal R^2 / Conditional R^2	.133 / .371			.231 / .621			.134 / .411		

Note. GLMER, generalized linear mixed-effects model; LMER, linear mixed-effects model; CI, confidence interval; LD, language disorder; NWR s, scaled nonword repetition; IQ NV s, scaled nonverbal intelligence; ED mean s, scaled mean education level of parents; ICC, intraclass correlation coefficient.

Table C2. Exploratory (generalized) linear mixed-effects models investigating interactions between expressive vocabulary and verb instrumentality.

Predictor	Matching (GLMER)			Naming–binary accuracy (GLMER)			Naming–proportion of phonemes (LMER)		
	Estimate	CI	*p*	Estimate	CI	*p*	Estimate	CI	*p*
(Intercept)	2.46	[1.36, 4.46]	.003	0.30	[0.12, 0.74]	.009	0.43	[0.32, 0.54]	<.001
Group (LD)	0.63	[0.37, 1.07]	.088	0.42	[0.20, 0.91]	.027	−0.09	[−0.19, 0.01]	.065
Instrumentality (I)	1.13	[0.90, 1.41]	.296	1.15	[0.87, 1.53]	.333	0.02	[−0.02, 0.05]	.301
WISC s	1.27	[0.75, 2.16]	.374	1.72	[0.78, 3.82]	.181	0.05	[−0.05, 0.15]	.301
IQ NV s	1.08	[0.72, 1.61]	.704	1.24	[0.70, 2.21]	.460	0.02	[−0.05, 0.10]	.577
ED mean s	1.41	[0.95, 2.10]	.088	1.26	[0.70, 2.27]	.442	0.04	[−0.03, 0.12]	.242
Group (LD) × Instrumentality (I)	1.01	[0.81, 1.27]	.919	1.19	[0.90, 1.59]	.222	0.01	[−0.02, 0.04]	.465
Group (LD) × WISC s	1.44	[0.78, 2.63]	.241	2.27	[0.92, 5.61]	.076	0.08	[−0.03, 0.19]	.154
Instrumentality [I] × WISC s	0.98	[0.78, 1.22]	.844	1.04	[0.73, 1.48]	.819	0.00	[−0.03, 0.03]	.917
[Group (LD) × Instrumentality (I)] × WISC s	1.09	[0.87, 1.36]	.441	0.94	[0.67, 1.33]	.735	0.01	[−0.03, 0.04]	.698
Random effects									
σ^2	3.29			3.29			0.11		
$^{\tau}00$ Participant	1.18			2.39			0.05		
$^{\tau}00$ Item	0.11			0.94			0.01		
ICC	.28			.50			.32		
$N_{\text{Participant}}$	50			50			50		
N_{Item}	20			20			20		
Observations	1000			1000			1000		
Marginal R^2 / Conditional R^2	.127 / .374			.263 / .634			.134 / .411		

Note. GLMER, generalized linear mixed-effects model; LMER, linear mixed-effects model; CI, confidence interval; LD, language disorder; WISC s, scaled expressive vocabulary subtest of the Wechsler Intelligence Scale for Children; IQ NV s, scaled nonverbal intelligence; ED mean s, scaled mean education level of parents; ICC, intraclass correlation coefficient.

Table C3. Exploratory (generalized) linear mixed-effects models investigating interactions between receptive vocabulary and verb instrumentality.

Predictor	Matching (GLMER)			Naming–binary accuracy (GLMER)			Naming–proportion of phonemes (LMER)		
	Estimate	CI	*p*	Estimate	CI	*p*	Estimate	CI	*p*
(Intercept)	2.04	[1.25, 3.33]	.005	0.19	[0.09, 0.43]	<.001	0.39	[0.29, 0.48]	<.001
Group (LD)	0.62	[0.40, 0.97]	.036	0.38	[0.20, 0.71]	.003	−0.09	[−0.18, -0.01]	.026
Instrumentality (I)	1.07	[0.89, 1.29]	.473	1.11	[0.87, 1.42]	.381	0.01	[−0.02, 0.04]	.496
PPVT s	1.44	[0.91, 2.28]	.124	1.83	[0.93, 3.57]	.079	0.08	[−0.00, 0.17]	.065
IQ NV s	0.97	[0.65, 1.47]	.893	0.99	[0.55, 1.79]	.980	−0.01	[−0.08, 0.07]	.846
ED mean s	1.36	[0.91, 2.04]	.138	1.08	[0.61, 1.94]	.786	0.03	[−0.04, 0.11]	.414
Group (LD) × Instrumentality (I)	1.02	[0.85, 1.23]	.837	1.15	[0.91, 1.47]	.241	0.01	[−0.02, 0.03]	.552
Group (LD) × PPVT s	1.14	[0.68, 1.91]	.612	1.23	[0.60, 2.54]	.566	0.02	[−0.08, 0.11]	.729
Instrumentality (I) × PPVT s	0.96	[0.79, 1.15]	.649	0.96	[0.73, 1.25]	.763	−0.00	[−0.03, 0.02]	.763
[Group (LD) × Instrumentality (I)] × PPVT s	0.99	[0.83, 1.20]	.949	0.86	[0.66, 1.12]	.268	−0.00	[−0.03, 0.02]	.741
Random effects									
σ^2	3.29			3.29			0.12		
τ_{00} Participant	1.18			2.33			0.05		
τ_{00} Item	0.12			0.94			0.01		
ICC	.28			.50			.31		
$N_{\text{Participant}}$	49			49			49		
N_{Item}	20			20			20		
Observations	980			980			980		
Marginal R^2 / Conditional R^2	.134 / .379			.248 / .623			.132 / .405		

Note. GLMER, generalized linear mixed-effects model; LMER, linear mixed-effects model; CI, confidence interval; LD, language disorder; PPVT s, scaled Peabody Picture Vocabulary Test; IQ NV s, scaled nonverbal intelligence; ED mean s, scaled mean education level of parents; ICC, intraclass correlation coefficient.

Table C4. Exploratory (generalized) linear mixed-effects models investigating interactions between word reading and modality.

Predictor	Matching (GLMER)			Naming–binary accuracy (GLMER)			Naming–proportion of phonemes (LMER)		
	Estimate	CI	*p*	Estimate	CI	*p*	Estimate	CI	*p*
(Intercept)	1.55	[0.94, 2.56]	.089	0.15	[0.06, 0.35]	<.001	0.36	[0.26, 0.46]	<.001
Group (LD)	0.67	[0.41, 1.09]	.111	0.41	[0.19, 0.87]	.020	−0.08	[−0.17, 0.01]	.091
Modality (sound)	1.04	[0.81, 1.33]	.759	0.85	[0.51, 1.41]	.523	−0.03	[−0.07, 0.02]	.312
EMT s	1.68	[0.99, 2.83]	.053	2.04	[0.90, 4.59]	.087	0.10	[0.00, 0.20]	.046
IQ NV s	0.89	[0.60, 1.32]	.567	0.92	[0.51, 1.65]	.775	−0.01	[−0.09, 0.06]	.736
ED mean s	1.20	[0.86, 1.68]	.275	0.98	[0.59, 1.62]	.933	0.01	[−0.05, 0.08]	.644
Group (LD) × Modality (sound)	1.08	[0.88, 1.32]	.480	1.06	[0.78, 1.43]	.722	−0.01	[−0.04, 0.02]	.540
Group (LD) × EMT s	0.75	[0.46, 1.24]	.267	0.84	[0.38, 1.84]	.654	−0.01	[−0.11, 0.08]	.813
Modality (sound) × EMT s	1.05	[0.85, 1.30]	.644	1.12	[0.77, 1.61]	.553	−0.01	[−0.05, 0.02]	.381
[Group (LD) × Modality (sound)] × EMT s	0.90	[0.72, 1.11]	.321	1.28	[0.88, 1.84]	.193	0.00	[−0.03, 0.04]	.839
Random effects									
σ^2	3.29			3.29			0.11		
τ_{00} Participant	1.10			2.32			0.04		
τ_{00} Item	0.10			0.85			0.01		
ICC	.27			.49			.31		
$N_{Participant}$	50			50			50		
N_{Item}	20			20			20		
Observations	1000			1000			1000		
Marginal R^2 / Conditional R^2	.155 / .380			.259 / .622			.145 / .412		

Note. GLMER, generalized linear mixed-effects model; LMER, linear mixed-effects model; CI, confidence interval; LD, language disorder; EMT s, scaled One-Minute Test; IQ NV s, scaled nonverbal intelligence; ED mean s, scaled mean education level of parents; ICC, intraclass correlation coefficient.

Table C5. Exploratory (generalized) linear mixed-effects models investigating interactions between nonword reading and modality.

Predictor	Matching (GLMER)			Naming–binary accuracy (GLMER)			Naming–proportion of phonemes (LMER)		
	Estimate	CI	*p*	Estimate	CI	*p*	Estimate	CI	*p*
(Intercept)	1.51	[0.94, 2.41]	.087	0.15	[0.07, 0.33]	<.001	0.36	[0.26, 0.45]	<.001
Group (LD)	0.62	[0.39, 0.96]	.034	0.40	[0.21, 0.78]	.007	-0.09	[−0.17, −0.00]	.040
Modality (sound)	1.03	[0.81, 1.29]	.831	0.81	[0.50, 1.31]	.395	-0.02	[−0.07, 0.02]	.327
Klepel s	1.56	[0.96, 2.52]	.070	2.17	[1.07, 4.42]	.032	0.10	[0.01, 0.19]	.025
IQ NV s	0.87	[0.58, 1.32]	.510	0.87	[0.47, 1.60]	.657	-0.02	[−0.10, 0.06]	.635
ED mean s	1.18	[0.84, 1.66]	.331	0.94	[0.57, 1.55]	.794	0.01	[−0.05, 0.07]	.779
Group (LD) × Modality (sound)	1.07	[0.88, 1.29]	.507	1.00	[0.77, 1.28]	.970	-0.01	[−0.04, 0.02]	.437
Group (LD) × Klepel s	0.71	[0.45, 1.13]	.149	0.81	[0.40, 1.64]	.565	-0.02	[−0.11, 0.06]	.618
Modality (sound) × Klepel s	1.04	[0.86, 1.26]	.680	1.04	[0.78, 1.39]	.799	-0.02	[−0.05, 0.01]	.222
[Group (LD) × Modality (sound)] × Klepel s	0.87	[0.72, 1.06]	.165	1.22	[0.91, 1.63]	.181	0.01	[−0.02, 0.03]	.672
Random effects									
σ^2	3.29			3.29			0.11		
$^{\tau}00$ Participant	1.13			2.26			0.04		
$^{\tau}00$ Item	0.10			0.85			0.01		
ICC	.27			.49			.31		
$N_{\text{Participant}}$	50			50			50		
N_{Item}	20			20			20		
Observations	1000			1000			1000		
Marginal R^2 / Conditional R^2	.148 / .379			.263 / .621			.148 / .412		

Note. GLMER, generalized linear mixed-effects model; LMER, linear mixed-effects model; CI, confidence interval; LD, language disorder; NWR s, scaled Klepel; IQ NV s, scaled nonverbal intelligence; ED mean s, scaled mean education level of parents; ICC, Intraclass correlation coefficient.

Appendix D. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jecp.2024.105881.

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