Finger-Writing Intervention Impacts Spelling and Handwriting Skills of Children with Specific Language Impairment: A Multiple Single-Case Study

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Finger-Writing Intervention Impacts the Spelling and Handwriting Skills of Children with Developmental Language Disorder: A Multiple Single-Case Study

Learning to use grapheme-phoneme correspondences (GPCs) provides a powerful mechanism for the foundation of reading skills in children (Share, 1999). However, for some children, such as those with Developmental Language Disorder (DLD), the GPC learning process takes time, is laborious, and impacts the entire reading and spelling processes. Previous studies have demonstrated the positive impact of a haptic intervention – tactile exploration of the grapheme – on GPC learning in reading for typically developing children (Bara, Gentaz, Colé, & Sprenger-Charolles, 2004; Gentaz, Colé, & Bara, 2003). Finger-writing is a type of haptic training that explores the shape of the letter with one's finger, forcing the child to follow the trajectory of the handwriting production of the letter. This teaching practice gives the child a multisensory experience that creates supplementary memory traces in comparison to visual traces, which could potentially foster the learning of GPC. To date, studies have investigated the impact of haptic intervention on reading skills amongst typically developing children. However, until now, no study has assessed the effect of finger-writing intervention (which includes the trajectory of handwriting) on spelling skills and on handwriting. Nevertheless, the transfer appears to be logical since the writing task shares similarities with handwriting production of the letter through accessing the motor programme of the grapheme. The impact of this type of intervention has also not been previously explored in children with DLD, even though it could constitute a compensatory mechanism used by those children. For these reasons, the objective of the present study was to evaluate the benefits of a finger-writing intervention on reading, spelling and handwriting for children with DLD.

Children with Developmental Language Disorder

DLD has been defined as a failure in spoken language development despite average intelligence, adequate hearing and vision, no known neurological, physical, emotional or social problems, and appropriate learning environment (McArthur, Hogben, Edwards, Heath, & Mengler, 2000). Approximately seven per cent of the population suffers from DLD, with much heterogeneity regarding the manifestation of the deficits. Yet children with DLD typically develop spoken language very slowly and with great effort, while typically developing children acquire it rapidly and effortlessly (Leonard, 2014). DLD children demonstrate phonological impairments as well as non-phonological language deficits at various levels such as semantics, syntax or discourse. Once in primary school, those impairments affect learning to read in both decoding and reading comprehension components (Bishop & Snowling, 2004). Those children frequently struggle with learning to read (Macchi, Schelstraete, & Casalis, 2014) and with learning to spell (Cordewener, Bosman, & Verhoeven, 2012; Dockrell, Lindsay, Connelly, & Mackie, 2007). In written text production, they also experience slow handwriting (Connelly, Dockrell, Walter, & Critten, 2012; Dockrell, Lindsay, & Connelly, 2009). The altered phonological representations may be linked to their specific difficulty learning GPC in reading and phoneme-grapheme correspondence (PGC) in spelling.

More specifically in reading, Macchi et al. (2014) assessed the word identification skills of children with DLD within the ‘dual-route model’ (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). They demonstrated that DLD children showed an average delay of 3.5 years in reading. They also exhibited a higher lexical effect in reading words and pseudowords, compared to reading level-matched control children. Indeed, pseudowords were less correctly read by DLD children, which suggested a deficit in the phonological procedure of reading. In spelling, Naucler (2004) showed in a longitudinal study that the majority of errors made by DLD children are phonetically unacceptable (e.g., the mistake cannot be pronounced like the intended word), including a high number of omissions or substitutions of letters. These errors also indicate a deficit in the phonological procedure of spelling. Cordewener et al. (2012) studied the speed of acquisition of spelling for DLD children. They demonstrated that those children already showed a delay in grapheme spelling in the beginning of first grade and that they need more practice in PGC than typically developing children. Together, these studies supply evidence in favour of a deficit in the phonological procedure of reading and spelling amongst children with DLD. However, the foundation of the phonological procedure is the knowledge of GPC and the understanding of alphabetic principle (Byrne & Fielding-Barnsley, 1989). In turn, the phonological procedure constitutes a powerful self-teaching mechanism, which enables the acquisition of the lexical strategy in reading. As stated in Share's self-teaching hypothesis (Share, 1999), the repeated phonological recoding of novel letter strings, through the indirect route of reading, is a main way to form word-specific representations in the lexicon. In this way, phonological processes affect the development of the two reading strategies: the direct and the indirect routes. Because of the critical importance of having an efficient phonological procedure for reading acquisition, it is essential to help DLD children establish foundations for the reading and the spelling processes. In particular, it is important to ensure a good mastery of the GPC.

Learning the Grapheme-Phoneme Correspondences

It is well established that initial programmes for elementary reading must include a strong emphasis on phonics and phonemic awareness (Adams, 1990; National Reading Panel, 2000; Bus & van Ijzendoorn, 1999). In alphabetic writing, children need to learn the correspondences between letters and speech segments to acquire reading skills. Slavin, Lake, Chambers, Cheung, and Davis (2009) also showed that other features might impact the efficacy of reading programmes, such as cooperative learning. Of particular interest to the current study, it has been demonstrated that some instructional practices in phonics teaching may be more efficient than others. For example, providing articulation pictures (Boyer & Ehri, 2011) helps students learn GPC. Indeed, learning correspondences is highly complex for various reasons. There are a large number of correspondences to learn, with some letters difficult to discriminate visually (e.g., between *b* and *d*). Moreover, some children encounter difficulties in aurally recognising the phonemes (Ehri et al., 2001). This difficulty may be particularly aggravated for DLD children since they suffer from underspecified phonological representations (Maillart, Schelstraete, & Hupet, 2004) or poor phonological discrimination abilities (Nithart, et al., 2009). Finally, the letter-sound associations are arbitrary, which makes the learning more difficult. For all these reasons, it seems essential to support the learning of abstract associations by means of a meaningful intermediary (De Partz, 1986), small characters (Van Reybroeck, 2002), articulation pictures (Boyer & Ehri, 2011), or haptic modality (Bara et al., 2004). Up to now, the impact of a finger-writing intervention has never been demonstrated on the learning of GPC amongst children with DLD. However, given their impaired spoken representations, this meaningful support based on visuomotor skills could act as a compensatory mechanism.

Haptic Training

The haptic modality corresponds to the kinaesthetic exploration of the shape of the graphemes with the fingers, based on relief-graphemes (e.g., raised cut-out letters on paper) with and without visual control. It has been demonstrated that haptic training leads to greater gains than visual support in improving letter recognition in reading. In several previous experiments amongst typically developing children, Bara and colleagues (Bara et al., 2004; Gentaz et al., 2003) showed that using the haptic modality enabled children to learn GPC more efficiently in reading. In particular, Bara et al. (2004) showed that haptic-visual-auditory-metaphonological training (HVAM) was more beneficial than visual-auditory-metaphonological training for kindergartners to improve letter recognition and pseudo-word decoding. This teaching approach was inspired by the Montessori method, based on a multisensory experience, which is supposed to strengthen connexions between visual and auditory word information (Montessori, George & Mayer, 1964). According to Gentaz et al. (2003), the sequential exploration of the letter, required in the haptic modality and not in the visual modality, is one of the reasons that the haptic modality favours the learning of correspondences. Another reason responsible for better learning may be the type of memory trace provided by the finger-tracing activity. In a study focusing on the learning of abstract graphic forms, Hulme (1979) demonstrated that tracing forms creates a different motor memory trace than visual exploration does. This trace constitutes an additional source of information facilitating form recognition.

In a more recent study, Bara and Gentaz (2011) also demonstrated the benefits of haptic training for recognition and handwriting quality in a copying task for kindergartners. However, so far, the impact of haptic training on spelling skills has never been investigated. Nevertheless, the haptic exploration of the shape of the grapheme with the finger shares common components with handwriting, and handwriting abilities are known to interact with spelling acquisition (see the following sections). For this reason, it may be interesting to evaluate the impact of a type of haptic practice on spelling itself, which could potentially have implications for teaching practice.

Handwriting

Handwriting is a multicomponent act that includes the integration of orthographic knowledge with the fine-motor demands of handwriting, called orthographic-motor integration (Christensen, 2004). Indeed, orthographic knowledge (e.g., the visual abstract representation of written letters or words in the mental lexicon, Berninger, 1994) must be integrated with the fine perceptual-motor skill, which comprises a perceptual component related to the shape of the letter and a motor component linked to the letter trajectory (Vinter

& Chartrel, 2010). The shape of the letter is memorised through allographic representations of the letter specifying its visuospatial features. The letter trajectory corresponds to the motor sequences of strokes used to write down the selected allograph (De Partz, Lochy, & Pillon, 2005).

Handwriting is a new task for children at the end of kindergarten. The writing modality requires the mastery of this new visuomotor ability, whereas reading is supported by spoken language production, which is already mastered. The learning of this perceptual-motor skill is a long process since it continues to improve well beyond the end of primary school (Graham, Weintraub, & Berninger, 1998; Alves & Limpo, 2015). Concomitant processes that need to be learned simultaneously, such as transcription processes (handwriting, phonetic, lexical and grammatical spelling), translating and planning processes (linguistic forms, idea generation and organisation in text production, Hayes & Flower, 1980), can explain why learning occurs so slowly. It is also not surprising to observe various types of interactions between handwriting and writing or spelling skills.

With regards to the visuomotor skill, both perceptual and motor components need to be trained to improve handwriting quality. Indeed, Vinter and Chartrel (2010) demonstrated that 5-year-old children benefitted more from visuomotor training than from isolated visual or motor training for improving the quality of handwritten letters. An intervention study conducted amongst first-grade children also showed the importance of the letter trajectory. Indeed, the authors demonstrated the benefits of writing the letters from memory on the basis of a model with arrows showing the direction of the strokes, compared to four other training methods without arrows or without memory demand – a copying task (Berninger et al., 1997). A more recent neuroimaging study has even revealed that handwriting training of letters creates stronger activations in visual and motor brain regions amongst preschool children compared to tracing or typing (Vinci-Booher, James, & James, 2016). The authors suggested that handwriting enabled the increase of visuomotor communication pathways. They even showed that those combined visual and motor brain regions were activated during visual perception of the letters, reflecting memory traces of handwriting experience. Several studies have demonstrated that handwriting skills impacted orthographic performances (Wicki, Lichtsteiner, Geiger, & Müller, 2014), grammatical spelling (Van Reybroeck & Hupet, 2009), or even entire essay production quality amongst school-aged and undergraduate students (Connelly, Dockrell, & Barnett, 2005; Graham, 1997; Limpo & Alves, 2013; Limpo, Alves & Connelly, 2017). Moreover, the spelling or writing processes significantly impact the handwriting when, for instance, writing irregular words (Kandel & Perret, 2015) or when children with dyslexia compose text (Sumner, Connelly, & Barnett, 2013). Interventional experiments conducted by Graham, Harris and Fink (2000) and Jones and Christensen (1999) provided experimental evidence of a causal relationship between handwriting skills and writing outcomes. After having trained children's handwriting, they showed that first-grade children made greater gains than the control children not only in handwriting but also in writing sentences (Graham et al., 2000) or writing stories (Jones & Christensen, 1999). Thus, the mastery of handwriting seems to be a cornerstone all along writing acquisition since it impacts different processes at different language levels and different periods of time.

Finger-Writing Training

So far, haptic training, based on the exploration of the letter with the fingers with and without visual control, has been demonstrated to influence the decoding of GPC. There is no experimental evidence showing its impact on spelling skills. However, in considering the close relationship between writing and handwriting, as well as the similarities between haptic training and handwriting, this type of training may have an impact on spelling skills. Furthermore, the specific nature of finger-writing compared to haptic training is to force the child to follow the trajectory of the handwriting production of the letter with the index finger, with excavated letters and with arrows, while haptic training is based on relief-graphemes. The importance of the trajectory of the letter used in handwriting has been demonstrated to significantly impact writing skills. This motor activity is thought to create supplemental and strong memory traces. Therefore, it could be determinant to assess the impact of finger-writing training, including the trajectory of the handwriting production of the letter, and to see whether this instruction may have an impact on spelling PGC as well as on the handwriting quality of the letters.

Present Study

Currently there is no experimental evidence showing that children with DLD benefit from finger-writing training to improve their mastery of GPC in reading. To the best of our knowledge, previous studies have also never investigated the impact of finger-writing on spelling performance, even if the relationship between finger-writing, handwriting and spelling seems to be obvious.

The aim of the present study was to demonstrate whether the finger-writing intervention could help children with DLD (i) to learn specific GPC in reading, (ii) to learn specific PGC in spelling and (iii) to improve their handwriting skills. This teaching practice was supposed to help children with DLD to overcome their reading and spelling difficulties by providing them with a compensatory mechanism. Indeed, they suffer from impaired phonological representations, which are required to learn the correspondences in reading and in spelling. A finger-writing training was thought to enable them to create additional motor memory traces that could facilitate the learning of the correspondences.

To assess the benefits related to the finger-writing treatment, children were randomly assigned to a finger-writing treatment condition or to a control treatment condition. The two treatments aimed to teach five complex GPC. Since the mastery of the phoneme representations is required to learn correspondences, we also conducted phonological awareness training. The two treatments were conducted in the same way, except for two exercises that were either provided only in the finger-writing modality or only in the visual modality. To examine the efficacy of the treatment, the five trained correspondences were evaluated in reading and spelling at both pre-test and post-test (trained grapheme reading, trained grapheme spelling and words spelling containing trained graphemes). The treatment effects were also evaluated on reading and spelling tasks to potentially observe a transfer for the other GPC: grapheme reading, simple syllable reading, complex syllable reading, complex grapheme reading, pronunciation variations in reading, syllable spelling, and word spelling. Phonological awareness was evaluated at both testing times, since part of the treatment aimed to increase this ability. A graphomotor test including copying words was also administered at both pre-test and post-test to assess participants' improvement in handwriting quality. We made the following predictions: (i) if finger-writing constitutes a meaningful means of support for literacy acquisition, we anticipate that the DLD children will benefit more from the finger-writing than from the control treatment in reading. We also anticipate an improvement in phonological awareness, trained during the treatments; (ii) if the finger exploration of the shape of the grapheme shares common components with handwriting and with spelling, we anticipate that the children benefitting from the finger-writing treatment will increase their spelling and handwriting skills more than the children in the control condition.

Method

Participants and Design

Data were collected in a pre-test post-test multiple single-case intervention study, with a treatment condition and a control treatment condition. Five French-speaking children aged from 7.42 to 10.17 (4 boys) from a primary special-education school took part in the experiment. They originated from an urban school in Belgium, from a middle social economic status. In Belgian special-education schools, the classes are made up of a small number of children so that more assistance can be provided to them. Children came from the same class, which was originally composed of eight children. Out of those eight children, five had been previously diagnosed with DLD by a multidisciplinary team of professionals. Those five children participated in the present study.

Children in special-education schools can belong to different group levels, according to their level of acquisition of school-based learning in French and Maths. There can be two group levels within the same class. The group level sets out the learning objectives of each child. The GPC mastered by the children were hence different depending on each child's group level. There are small classrooms within the school that make it possible to differentiate instruction. Reading and writing are usually taught through grapheme-phoneme activities based on letters. No finger-writing approach had been proposed for these children's classes. Two children from the experiment were from the first group level (aged 7.42 and 7.92), while the other three were from the second group level (aged 8.08, 9.17 and 10.17). To avoid interpretation biases related to various group levels, children were randomly assigned to one of the two intervention groups (i.e., one child from the first group level in each of the two groups). The characteristics of the participants at pre-test are reported in Table 1. Note that pseudonyms were used to protect the children's identity. The five children had non-verbal reasoning, phonological awareness and graphomotor performance in the normal range for the average population. Their reading and spelling performances were primarily two standard deviations below the mean (< 3rd percentile), except Enzo, who had a low literacy profile.

INSERT TABLE 1 ABOUT HERE

The teachers, the children and their parents gave their active consent to participate in the experiment. The study was approved by the Ethics Committee of the Psychological Science Research Institute.

Procedure

All testing and interventions took place at the school. Participants were assessed and trained by the same experimenter. The literacy and handwriting tasks of pre-test and post-test were individually administered in two sessions. All the tasks were presented before (February) and immediately after (April) the interventions. The test of non-verbal reasoning was administered at the pre-test only. To ensure a blind process, the score sheets were anonymised prior to scoring. Both treatments were carried out throughout eight 30-min lessons implemented individually and once a week. The same instructor implemented the treatments for all children.

Intervention Programmes

The two treatments – finger-writing and control – focused on the learning of five GPC. Since the children did not belong to the same group level, the five GPC differed according to this characteristic. For children from the first group level, the following correspondences were trained during the treatment: *on, in, ch, oi, an*. For children from the second level, the following correspondences were trained: *eu, ph, ien, gn, oin*. In both treatments, children performed seven exercises for each correspondence. Among these exercises, only two differed across conditions. Specifically, the fourth and fifth exercises involved finger-writing exercises in the finger-writing condition and visual exercises in the control condition. To avoid bias related to the simultaneous literacy teaching instruction in the classroom, it was agreed that the ten target GPC would not be taught throughout the duration of the intervention.

The finger-writing treatment was based on the intervention used in Bara et al. (2004) and on the handwriting intervention used in Berninger et al. (1997), while the phonological awareness exercises were based on those used in Van Reybroeck, Content and Schelstraete (2006). The treatment consisted of seven exercises for each of the five GPCs (i.e., 35 exercises in total) in which the children were asked to identify the phonemes (i.e., phonological awareness) and the corresponding graphemes and to explore the shape of the grapheme with their finger. For the material, pictures were used to identify phonemes within words. To ensure that the children knew the vocabulary, the words were selected from those occurring frequently in the word-frequency database Manulex (Lété, Sprenger-Charolles, & Colé, 2004).

Exercise 1. In the first exercise (repeated five times, one per grapheme taught), the children began with a nursery rhyme in which they were asked to identify the phoneme and to repeat the rhyme. A visual representation of the grapheme was simultaneously presented, similar to the one they were used to in their classroom.

Exercise 2. In this exercise, the children were asked to select the words amongst six pictures that included the target phoneme in the first syllable of the word. For example, the targets for *in* were *indienne* (Indian), *insecte* (insect), and *princesse* (princess), while the distractors were *papillon* (butterfly), *ongle* (nail), and *chenille* (caterpillar).

Exercise 3. In this exercise, the children were asked to select the words that included the target phoneme in the last syllable of the word.

Exercise 4. In the fourth exercise, the modality differed between the two treatments. In the finger-writing treatment, the children were asked to explore the shape of the grapheme with their index finger with a relief-grapheme and with an excavated-grapheme, on which the trajectory of the grapheme was presented with arrows. The relief-graphemes were raised cut-outs graphemes made of foam paper 5 mm thick, creating a relief on the sheet of paper. The excavated-graphemes were created by carving out the grapheme's shape from 5 mm thick foam paper. The carved-out zone, like a stencil, was large enough to allow children to place their finger within the shape created by the foam paper. This modality forces the child to follow the trajectory of the handwriting production of the grapheme, since his finger is framed by the thick foam paper, which naturally guides the finger. In the control treatment, the children were asked to visually discriminate between the target grapheme and several distractors, which were visually similar.

Exercise 5. In the fifth exercise, the modality also differed between the two treatments. In the finger-writing treatment, the children were asked to explore the grapheme with their finger only (without the arrow as visual support) and to differentiate the target grapheme from a distractor (e.g., differentiate *in* from *eu*). In the control treatment, they were asked to explore visually and to select the target grapheme amongst several distractors.

Exercise 6. In the sixth exercise, the children were asked to select the words that include the target phoneme in the initial syllables amongst 12 words, which increased the level of difficulty compared to the second exercise. In the seventh exercise, the experimenter presented the same exercises with words that included the target phoneme in the final syllables amongst 12 words.

Treatment fidelity. To ensure that the treatments were delivered as planned and as similarly as possible in the two groups, the following precautions were taken: a manual was created including the exercises and the instructions; the experimenter received training on the theoretical background of the study and on the practical aspects of implementing the treatment; and during the treatment, the experimenter had to use a checklist to ensure that all the exercises were completed. Examination of the checklist showed that all exercises were performed for all children (the seven exercises for each of the five GPC).

Measures

Trained grapheme reading. Amongst the items of the complex graphemes reading task, five were selected that corresponded to the graphemes taught in the intervention. The five items for children from the first group level were *ch, on, an, in, oi*. The five items for children from the second group level were *ph, eu, oin, ien, gn*. The children were asked to read graphemes in isolation and were given one point for each correctly spelled grapheme, resulting in a maximum score of 5 for this measure.

Grapheme reading. Grapheme reading was measured with the standardised subtest from the Batterie d'évaluation de lecture et d'orthographe [BELO, Battery of Assessment of Reading and Spelling] (Pech-Georgel & George, 2006). Children were asked to read 26 graphemes presented in isolation. They were given one point for each correct response. The internal reliability (Cronbach's α) is not provided by the test. For a sample of another experiment composed of 61 first graders, the grapheme reading was found to have an internal consistency coefficient of .92.

Simple syllable reading. Simple syllable reading was measured with the standardised subtest from BELO (Pech-Georgel & George, 2006). Children were asked to read 11 simple syllables, composed of consonant-vowel (CV) or vowel-consonant (VC) structure, presented in isolation. One point was attributed to each simple syllable correctly read. The maximum score was 11. For the sample of first graders, the simple syllable reading was found to have an internal consistency coefficient (Cronbach's α) of .91.

Complex syllable reading. Complex syllable reading was measured with the standardised subtest from BELO (Pech-Georgel & George, 2006). Children were asked to read 15 complex syllables, composed of three or four graphemes having the following syllabic structure: CVC, CCV, VCC, CCCV, presented in isolation. One point was attributed to each complex syllable correctly read. The maximum score was 15. Reliability analyses revealed an alpha coefficient of .95 for the sample of first graders.

Complex grapheme reading. Complex grapheme reading was measured with the standardised subtest from BELO (Pech-Georgel & George, 2006). Children were asked to read 33 complex graphemes in French including two or three letters associated with one or two phonemes (e.g., *ain*, which corresponds to one phoneme). One point was attributed to each complex grapheme correctly read. The maximum score was 33.

Pronunciation variations (reading). Pronunciation variations were measured with the standardised subtest from BELO (Pech-Georgel & George, 2006). Children were asked to read 15 monosyllabic or disyllabic pseudowords including contextual spelling rules (e.g., *gé* or *gue*). One point was attributed to each complex grapheme correctly read. The maximum score was 15.

Phonological awareness. Phonological awareness was measured with the standardised subtest of phoneme identification from the Nouvelles épreuves pour l'examen du langage [N-EEL, New Tasks for Language Assessment] (Chevrie-Muller & Plaza, 2001). Children were asked to isolate and produce the first phoneme of 12 pseudowords, either a vowel or consonant (maximum raw score of 12). The internal consistency coefficient (Cronbach's α) found for the first graders sample was .79.

Trained grapheme spelling. Children were asked to spell monosyllabic or disyllabic pseudowords including the graphemes taught during the intervention, which were different depending on the children's group level. For children from the first group level, the pseudowords were *floi, blin, choi, finr, chon, namin, blonch, chanl, donfin, achoi*. For the children from the second group level, the pseudowords were *fleu, blien, choin, phien, gneu, namien, bloinph, gneul, dienfoin, agnien*. In both cases, several pseudowords contained two target graphemes, which led to a maximum score of 16 (four pseudowords containing one target grapheme and six pseudowords containing two target graphemes). The children were given one point for each correctly spelled grapheme trained during the intervention (e.g., two trained graphemes evaluated in the item *chon – ch* and *on* -, and one trained grapheme assessed in the item *namin – in* –).

Word spelling with trained graphemes. Children were asked to spell words that contained the graphemes taught during the intervention. For children from the first group level, the words were *choisir* (to choose), *cochon* (pig), *poisson* (fish), *lapin* (rabbit), and *chanson* (song). For children from the second group level, the words were *éléphant* (elephant), *chien* (dog), *poignée* (handle), *bleu* (blue), and *coin* (corner). The children were given one point for each correctly spelled word, with a maximum score of 5.

Syllable spelling. Syllable spelling was measured with the standardised subtest from BELO (Pech-Georgel & George, 2006). Children were asked to spell 10 monosyllabic or disyllabic pseudowords (e.g., *tra, namo, palon*). The children were given one point for each correctly spelled pseudoword, with a maximum score of 10.

Word spelling. Word spelling was measured with the standardised subtest from BELO (Pech-Georgel & George, 2006). Children were asked to spell 15 words (e.g., *voiture, lion, classe,* etc.). The children were given one point for each correctly spelled word, with a maximum score of 15.

Graphomotor skills. Graphomotor skills were measured with the standardised subtest from Echelle d'évaluation des préalables pour le CP et batterie analytique de lecture/orthographe [NBA, Assessment scale of prerequesites for Grade 1 and analytical battery of reading/spelling] (Ravard & Rabreau, 1982). Seven items comprised the graphomotor subtest. Children were asked to draw alternatively large and small loops, to draw several straight or curved lines, and to copy a sentence, *Lili joue avec son frère* (Lili is playing with her brother). The maximum score was 15.

Handwriting quality. Handwriting was also assessed in fine-grained detail by scoring the copied sentence from NBA (Ravard & Rabreau, 1982) with five aesthetic criteria inspired by the Echelle d'évaluation rapide de l'écriture chez l'enfant [BHK, Rapid assessment scale of writing in children] (Charles, Soppelsa & Albaret, 2004) and used in Gosse, Carbonnelle, de Vleeschouwer and Van Reybroeck (2018): (1) distortion of a letter, resulting in an abnormal letter form; (2) inconsistent letter size, referring to a situation where there is an abnormal variation of the letter size within the same word; (3) inconsistent relative height of letters, meaning that small letters (e.g., *a, i, s*) are produced at the same height as tall or tail letters (e.g., *y, t, h*) and vice versa; (4) correction of letter forms, noticeable by the presence of a graphic correction on paper; (5) bad letter alignment within the word, when horizontality of the handwriting is violated. For each criterion, the score of 1 is attributed in the case of the presence of a graphic abnormality. The five words of the sentence were scored (total maximum score of 25).

Non-verbal reasoning test. Non-verbal reasoning was measured by the standardised test of the Progressive Matrices Standard (PM 38, Raven, Court, & Raven, 1998). Children were asked to select the choice among five response options that best corresponded to the adequate missing piece to fill the matrix. Five series of 12 exercises were presented within an unlimited time. The maximum raw score was 60. Each child's score was converted to a standardised score in percentile. The reported internal consistency coefficient for this test is .83.

Results

Table 2 shows the pre-test and post-test results for the five children regarding the dependent variables. Statistical analyses were run with SPSS 23. To determine whether both treatments were efficient for each child, we used the non-parametric McNemar test (Siegel, 1956), which is a by-items statistical analysis comparing the pre-test performance to the post-test performance for each item and each participant separately. We also combined this by-items statistical analysis with a control condition – a control treatment – which enables us to evaluate the specific efficacy of the treatment. The McNemar chi-square test for equality of proportion was used to evaluate the significance of changes from pre-test to post-test for each child. Since each person is used as his or her own control, this might be used to test the effectiveness of a treatment. The analysis is based on a 2x2 frequency table describing the correctness of each item at pre-test and post-test, leading to four options for each item:

incorrect at pre-test and correct at post-test, incorrect at both pre-test and post-test, correct at both pre-test and post-test, and correct at pre-test and incorrect at post-test.

Impact of Finger-Writing Treatment on Reading

The impact of the treatment on reading was first examined for the trained grapheme reading task, involving the GPC that were taught during the intervention. Thus, the scores reflected the performance for different graphemes with regard to each child's group level (first group level or second group level). Then, the impact of the treatment on the other reading tasks was examined.

For the trained syllable reading, the results showed no significant improvement over time for the five children, even if the raw scores increased more for the children from the finger-writing treatment than for the children from the control treatment (maximum score of 5).

Regarding the potential transfer to the overall performance in reading, the analysis did not reveal any significant change between the pre-test and the post-test for the following variables: grapheme reading, simple syllable reading and complex syllable reading, For the variable complex grapheme reading, including the five graphemes taught during the interventions, the analysis revealed a significant improvement for two of the three children who benefitted from the finger-writing, Julien: $p = .039$ and Diane: $p = .012$, but not for Enzo: $p = .125$. When compared to the BELO norms, Julien maintained a score below the 1st percentile at post-test for Grade 2 (even though it corresponds for Grade 1 to a transition from the 27th percentile to the 73rd percentile). Diane improved from below the 1st percentile at pre-test to the 8th percentile at post-test, which enabled her to reach a low score instead of a deficit score. Enzo improved from the 2nd percentile at pre-test to the 42nd percentile at post-test (norm with population average of Grade 2). In doing so, he moved from a deficit score to an average score. Mathieu and Louis still performed at post-test at a score below 1st percentile for Grade 2. For the variable pronunciation variations, no significant changes appeared in the analysis, while for the variable total reading, the same two children demonstrated a significant improvement, Julien: $p = .007$ and Diane: $p = .002$.

For the variable phonological awareness, the analysis did not reach the level of significance.

Impact of Finger-Writing Treatment on Spelling

For trained grapheme spelling, the analysis revealed that the three children who benefitted from the finger-treatment improved more, Julien: $p < .001$; Diane: $p < .01$ and Enzo: $p = .021$, than the two children who did not benefit from it, Mathieu and Louis.

For the variable word spelling with trained graphemes, the analysis did not reach a significant level for any child. For the variable total trained grapheme spelling, combining syllables and words, the results revealed a significant efficacy of the finger-writing treatment since the children from this group improved more, Julien: $p < .001$; Diane: $p < .001$ and Enzo: $p < .01$, than the children from the control group, who did not show a significant change from pre-test to post-test.

With regard to the other spelling tasks, for both variables, syllable spelling and word spelling, the analysis did not reveal a significant change over time for the five children.

Impact of Finger-Writing Treatment on Handwriting

Regarding the potential impact of the finger-writing treatment on handwriting, two dependent variables were investigated: graphomotor skills and handwriting quality.

For the graphomotor skills variable, the analysis did not reveal any significant results. For the handwriting quality variable, the analysis revealed a positive impact of the finger-writing treatment for two of the three children having followed this treatment, Julien: $p = .039$, Diane: $p = .250$ and Enzo: $p = .031$, while the children from the control group did not show such improvement. When combining the two variables in the graphomotor skills composite score, the extent of the significance increased: Julien: $p = .007$; Diane: $p = .125$; Enzo $p = .004$.

Discussion

The aim of this study was to evaluate the efficacy of a finger-writing treatment amongst children with DLD (i) to learn GPC in reading, (ii) to learn PGC in spelling, and (iii) to improve their handwriting skills. The finger-writing treatment was administered to three DLD children and compared to a control treatment administered to two DLD children. The efficacy of the treatment was assessed individually on reading, spelling and handwriting tasks. Those tasks were either standardised or included the graphemes trained during the intervention. The efficacy was also measured for handwriting and phonological awareness tasks.

Impact of Finger-Writing Treatment on Reading

In line with our predictions, the results showed that the three DLD children who benefitted from the finger-writing intervention reached a higher level of mastery of the correspondences taught compared to the two DLD children from the control group. In fact, significant progress did not appear in the trained grapheme reading task, but this result is likely due to the few items in the task (maximum score of 5), which is not suited to the method of analysis. The progress was mainly observed for the complex grapheme reading task, which included the graphemes trained during the intervention (maximum score of 33). Two of the three children from the finger-writing treatment significantly improved their reading of complex graphemes. The third child from this group did not significantly improve his performance, but he had the highest score at pre-test and he nevertheless moved from the 2^{nd} percentile at pre-test to the 42^{nd} percentile at post-test when compared to the BELO norms. The intervention enabled two of the three children to move from a deficit score compared to second graders to a low or average score at post-test.

The efficacy of the finger-writing-specific component of the treatment was proved through the design of the experiment, which included a control treatment in which the children performed all the same exercises – mainly phonological awareness and visual discrimination training – except for the two finger-writing activities. Even if the children from the control group did train their phoneme identification and visual discrimination abilities, the key factor that seems to have enabled the learning is the orthographic-motor integration forced by the finger-writing task.

How can we understand the positive impact of finger-writing intervention for children with DLD? As explained in the introduction, DLD children suffer from impaired oral representations that can partially explain their reading difficulties. Indeed, the foundation of the two reading strategies is based on the mastery of GPC, which are themselves based on the establishment of solid relationships between the phonological representations and the orthographic representations of the correspondence. A lack of precise phonological representation may lead to imprecise or incorrect GPC knowledge. The finger-writing treatment is likely to have provided DLD children with a support that acted as a different learning key to overcome their difficulties with the learning of correspondences. The finger-writing treatment provided visuomotor memory traces in addition to oral memory traces that partially or together enable better learning. It could be either the multimodality that facilitates learning, or the specificity of the visuomotor memory traces through an orthographic-motor integration. Indeed, as in the Montessori approach, the multimodality has been demonstrated to be beneficial for DLD children for the learning of complex syntax, including a motor and tactile dimension (Zwitserlood, Wijnen, Van Weerdenburg, & Verhoeven, 2015). With regard to the visuomotor learning itself, since it is not based on a prerequisite in the domain of impairment for DLD children, it enables them to learn without prior difficulties. In this sense, it may be reasonable to infer that the modality of the treatment of a DLD child should be adapted to his or her intact skills, if the treatment objective allows it. However, in this way, the potential intact skills should be assessed before treatment. Indeed, for instance, Vugs, Hendriks, Cuperus, and Verhoeven (2014) demonstrated that the visuospatial modality, which was thought to be intact amongst DLD children, was in fact also affected by their deficits. In their experiment, DLD children faced difficulties not only in verbal working memory but also in visuospatial working memory. Care should thus be taken when selecting the modalities based on children's intact skills.

An impact of both treatments on phonological awareness skills was not observed in the results. However, since the treatments included several activities regarding phoneme identification, one would have thought that students would improve their skills in phonological awareness. The following two reasons could explain why this was not the case: first, the phonological awareness task comprised only 12 items and demonstrated a ceiling effect; second, the task focused on simple phoneme identification, while the treatments were based on complex GPC. It would have been interesting to create a trained phonological awareness task containing items related to the graphemes taught during the interventions.

Impact of Finger-Writing Treatment on Spelling

The second hypothesis, regarding the impact of finger-writing treatment on spelling, was confirmed and constitutes empirical evidence that has never been demonstrated before. The three children who benefitted from the finger-writing treatment learned to spell the graphemes taught during the intervention better. The efficacy of the treatment was demonstrated by the observation of a significant change for each of the three children from the finger-writing group, who increased the number of correct responses from 1 to 14, 2 to 12 and 3 to 11, while the children from the control group did not increase their performance between the pre-test and the post-test. Since the control intervention included phonological awareness and visual discrimination tasks, the impact of the finger-treatment is clearly due to the two specific finger-writing activities. How can we understand this transfer from finger-writing to spelling modality? In the finger-writing tasks, the children traced the letter trajectory with their finger. This motor activity is part of the handwriting process, which creates supplemental and stronger memory traces in comparison to visual traces (Vinci-Booher et al., 2016). To a certain extent, our results confirm those observed by Longcamp, Zerbato-Poudou, and Velay (2005), who demonstrated the benefits of handwriting training on letter recognition, compared to typewriting training. It also provides some explanation to the significant contribution of handwriting to writing skills. Indeed, the transcription component of the simple view of writing (Berninger et al., 2002), which includes handwriting and spelling, plays a critical role in the entire writing process. It was, moreover, stated by moderator analyses in the meta-analytic review of Feng, Lindner, Ji, and Joshi (2017) that handwriting contribution to writing was robust, since moderators such as the genre or the grade level did not constrain this relationship.

The fact that the impact is observed for spelling, in addition to reading, suggests that the learning was deeper, and created solid memory traces to enable the production of the grapheme. Indeed, the reading modality only requires recognition of the grapheme and production of the phoneme, while the spelling modality necessitates the retrieval and production of the grapheme (Ehri, 1997; 2005), including the selection of the motor programme.

Impact of Finger-Writing Treatment on Handwriting

With regard to the impact of the finger-writing treatment on handwriting, the hypothesis was partially confirmed, since two of the three children who benefitted from the finger-writing treatment did improve the quality of their handwriting at the post-test. The third child did not show a significant change, although his scores did improve from pre-test to post-test. This impact of finger-writing treatment on handwriting may be surely explained by the similar underlying processes of the two tasks, expect for the absence of a pen for the finger-writing treatment. For the other processes, children are required to trace the letter trajectory in both cases, as well as to visually control their finger movement. It is worth noting that in our study, children had to trace the letters with the support of the arrows showing the letter trajectory. The presence of the arrows is potentially a key component of the treatment, such as in the study of Berninger et al. (1997). These arrows probably forced children to trace the grapheme in the correct direction of production by providing a good model of the trajectory. This scaffolding may potentially enable children to create motor programmes for each grapheme more rapidly and more easily. Indeed, it is possible that this model helped the children to form the letter in the easiest way, while some of them could have performed it differently and potentially in a non-economical way (e.g., starting the letter on the right-hand side, or tracing the stroke of the letter twice). The model could also provide stability in production because the arrows force the movement along a certain trajectory, while it is well known that memory traces are difficult to create if the motor sequence of the strokes changes each time.

Limitations

This study has several limitations that should guide future research. First, the case study approach in itself limits the extent to which the results can be generalised. It may be interesting to replicate this experiment with a higher number of DLD participants, even if it is highly complicated to conduct this type of research since these children already need to juggle school requirements and therapeutic treatments. Second, our results are limited to the DLD children population, but it could be interesting to evaluate the transfer of finger-writing treatment to spelling skills amongst typically developing children. Even more, a comparison between the benefits of the treatment for DLD children and for typically developing children would also give interesting hints regarding, for example, a better aid of motor for DLD children. Third, another possible limitation of our study is that our trained grapheme reading task had too few items, which limited the observation of an improvement in this task. Fortunately, some improvements were observed in the complex grapheme reading task. Fourth, regarding the treatment fidelity, it would have been better to independently observe the lessons to ensure that the training was conducted effectively as explained by the experimenter.

Educational implications

This study has clear implications for teaching practices. It demonstrated that providing a finger-writing approach is efficient for DLD children not only to learn the correspondences in reading and in spelling but also to improve their handwriting quality. While other training experiments observed the impact of handwriting on standardised tests such as the alphabet task, we demonstrated in this experiment the impact of handwriting training on the quality of the handwritten production. Finger-writing teaching practices could also be combined with other evidence-based handwriting practices (e.g., Berninger, et al., 1997) to improve children's handwriting skills. The impact of finger-writing work is important for handwriting skills. However, showing the benefits of handwriting work on other learning processes, such as reading and spelling, confirms the cornerstone position of handwriting for all basic school learning. It constitutes strong empirical evidence in favour of the necessity of deep handwriting instruction, while there is a current trend to downplay handwriting teaching.

Conclusion

In conclusion, the present study shows that a finger-writing treatment was beneficial for DLD children to learn complex GPC. It highlights the impact of finger-writing on spelling abilities and, for two of the three children, on handwriting quality. Our results provide clear educational implications. They highlighted the importance of providing different teaching approaches for DLD children who face spoken language difficulties. They also put emphasis on the importance of providing them with a modality whereby they do not have basic difficulties. We also demonstrated the great value of finger-writing or similar handwriting approaches as a support for memory, while tablets and digital support might estrange children from this fruitful support.

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Table 1

Participant Characteristics at Pretest

	Finger-writing treatment			Control treatment	
	Julien	Diane	Enzo	Mathieu	Louis
Gender	Male	Female	Male	Male	Male
Age (years;months)	7;5	8;1	9;2	7;11	10;2
Level of academic skills at school	1	2	2	1	2
Non-verbal reasoning test (Raven) [a]	25th-50th	50th-75th	10th-25th	50th-75th	5th
Phonological awareness (Neel)[b]	98	89	100	100	110
Reading (Belo)[c]					
Simple graphemes	2nd	1st	100th	1st	22nd
Simple syllables	< 9th	< 9th	9th	< 9th	9th
Complex syllables	4th	< 1st	13th	< 1st	1st
Complex graphemes	< 1st	< 1st	2nd	< 1st	< 1st
Pronunciation variations	< 1st	< 1st	5th	< 1st	< 1st
Spelling (Belo)[c]					
Syllables	3rd	5th	38th	16th	2nd
Words	< 1st	1st	6th	< 1st	1st
Graphomotor (NBA)[b]	70th-80th	30th-40th	20th-30th	50th-60th	10th-20th

Note. [a] Percentile scores according to the chronological age of each child. [b] Standardized scores with population average and age upper limit of 8;7 years (M = 100 and SD = 15). [b] Percentiles scores with population average and age upper limit of the first semester of Grade 1. [c] Percentile scores with population average of Grade 2.

Table 2

Number of Correct Answers for Dependent Variables by Children and Testing Time

	Finger-writing treatment									Control treatment					
	Julien			Diane			Enzo			Mathieu			Louis		
	Pre-test	Post-test	*p*	Pre-test	Post-test	*p*	Pre-test	Post-test	*p*	Pre-test	Post-test	*p*	Pre-test	Post-test	*p*
Reading (total) (/100)	56	72	.007	62	79	.002	81	86	.332	56	64	.134	63	64	1.000
Trained graphemes reading (/5)	2	4	.625	1	4	.250	1	4	.250	2	3	1.000	0	2	/
Graphemes reading (/26)	22	25	.250	21	23	.625	26	26	/	21	23	.687	24	21	.250
Simple syllables reading (/11)	8	11	/	9	10	1.000	10	11	/	10	11	/	10	10	1.000
Complex syllables reading (/15)	12	12	1.000	9	12	.375	13	13	1.000	13	12	1.000	10	11	1.000
Complex graphemes reading (/33)	8	16	.039	15	24	.012	22	27	.125	7	12	.063	12	14	.727
Pronunciation variations (/15)	6	8	.727	8	10	.687	10	9	1.000	5	6	1.000	7	8	1.000
Phonological awareness (/12)	9	10	1.000	10	11	1.000	11	11	1.000	11	11	1.000	12	11	/
Trained graphemes spelling (total) (/21)	1	18	< .001	3	15	< .001	5	16	.003	11	10	1.000	0	1	/
Trained graphemes spelling (/16)	1	14	< .001	3	12	.004	3	11	.021	9	6	.250	0	0	/
Words spelling with trained graphemes (/5)	0	4	/	0	3	/	2	5	/	2	4	.500	0	1	/
Syllables spelling (/10)	6	9	.250	7	9	.625	9	9	1.000	8	9	1.000	5	9	.125
Words spelling (/15)	1	4	.250	6	9	.375	10	9	1.000	3	5	.625	6	5	1.000
Graphomotor skills (composite score) (/40)	16	7	.007	12	7	.125	14	6	.004	18	19	1.000	20	22	.824
Graphomotor skills (/15)	3	5	.687	4	6	.625	5	7	/	11	11	1.000	13	10	.375
Handwriting quality (/25)[a]	13	5	.039	8	5	.250	9	3	.031	7	8	1.000	10	9	1.000

Note. [a]Handwriting quality positive score represents abnormality of the handwriting, a decrease from pre-test to post-test corresponds to an improvement in handwriting quality.