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MSL in the digital ages: Effects and effectiveness of computer-mediated intervention for FL learners with dyslexia

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Abstract

The longitudinal intervention study reported here is the first to investigate the efficiency of computer learning software specifically designed for dyslexic Swiss German learners of Standard German as a second language (L2) and English as a third language (L3). A total of 40 subjects (20 of them dyslexics and 20 of them nondyslexics; 10 students from each group participated in interventions and the other 10 from each group served as control groups) were assessed with a battery of verbal and written pre- and posttests involving phonological/orthographic and semantic measures of their L2 and L3 before and after three months of daily intervention with the software. The results show that computer-based training in the L3 is potentially an important tool of intervention for dyslexic students as it has a positive effect on the components of L3 as well as L2 learning. As a consequence of their progress in acquiring the relationships between L3 graphemes and phonemes, the experimental groups, but not the control groups, made significant gains on L2 naming accuracy and speed, L2 and L3 word reading, L2 and L3 phonological awareness, and L2 and L3 receptive and productive vocabulary and comprehension tasks.

Keywords: dyslexia, L3 acquisition, multisensory instruction, intervention, literacy skills

1. Introduction

An accumulating body of evidence indicates that students with dyslexia (henceforth dyslexic readers) require assistance and special training in the first language (L1) and particularly in any foreign language (FL) from an early stage (e.g., Ganschow & Sparks, 2000; Kormos, Sarkadi, & Csizér, 2009; Nijakowska, 2010). In many European countries, such assistance has traditionally taken the form of special instruction classes taught by a teacher-therapist or specialist at school or at a psychological-pedagogical clinic. However, in light of general consent among researchers that weak students better be provided with tutoring assistance (Ganschow, Sparks, & Javorsky, 1998; Nijakowska 2008, 2010; Sparks, Ganschow, & Patton, 2008; Sparks, Humbach, & Javorsky, 2008) there is an increasing need for research such as this on the effects of training methods and intervention tools that can be used by individuals in their private time.

This study analyses the effects and efficiency of learning software which aims to transfer the multisensory techniques that were found to facilitate the learning of basic literacy skills of school-age struggling readers into the field of FL learning. The software was specifically designed for at risk native speakers of Swiss German who were learning Standard German as a second language (L2) and English as a third language (L3). The purpose was to (a) equip children, teachers, tutors and parents with supplementary language training tools to help students with dyslexia and (b) allow for activities that children with dyslexia are typically in need of to be further continued by parents and children at home. The paper presents a longitudinal intervention study of 40 elementary school students (20 nondyslexic readers and 20 learners with dyslexia) in two mainstream schools in the Swiss state school system which are not specialized in learning disabilities. Half of the participants underwent daily training with the software for a period of three months.

This study is novel in several respects. Despite the abundance of literature on the most effective types of intervention in the classroom, there are no studies to date that have examined the usefulness of a computer-based learning support for an FL outside the classroom. With an increasing number of European countries introducing policies to accelerate the exposure to multiple FLs of school children, there is a great need for controlled evaluations of different types of interventions for struggling readers (see Lovett et al., 2008, p. 335). Moreover, there is a multilingual component to this study, as the participants are followed over three months of intensive intervention in the L3 and their oral and written proficiency in the L2 and L3 is measured. Finally, my research aims to bridge the research-practice gap that has so often been described in the literature (e.g., Kormos et al., 2009; Nijakowska, 2010) by providing further evidence for the effectiveness of multisensory instruction while also making research-based and verified techniques available to parents as well as FL teachers and tutors.

2. Definitions

Dyslexia is defined as a life-long genetically and neurologically based language processing disorder that displays weaknesses in phoneme-grapheme awareness (phonics), short term and working memory, or perception of short or rapidly varying sounds, which generally persists through life (e.g., Helland & Kaasa, 2005; Nijakowska, 2010; Vellutino, Fletcher, Snowling, & Scanlon, 2004). This leads to varying degrees of reading, spelling and writing difficulties (e.g., Hulme & Snowling, 2009; Snowling, 2001). Secondary consequences include poor motivation, anxiety and behavioral issues (see e.g., Sparks and Ganschow 1995). Research has unequivocally shown that there is an interrelation between dyslexics' difficulties in their language of literacy and their difficulties in their native language and their problems in FL learning; specifically in the areas of phonological processing and phonics students' processing problems transfer from L1 to a FL. Sparks and Ganschow's often-cited and empirically supported linguistic coding deficits hypothesis (LCDH) is built upon the following assumptions (Ganschow et al., 1998; Ganschow & Sparks, 1995; Sparks, 1995):

1. Both L1 and FL learning depend on basic language skills; poor foreign language learners have a common significant weakness in phonological, syntactic and/or semantic coding, all of which are fundamental to language acquisition.
2. The L1 difficulties of dyslexic FL learners may only be apparent in one language "code" (phonological/orthographic, syntactic, or semantic); weak phoneme/grapheme processing skills have been identified as the most common problem area.
3. L1 skills serve as the foundation for FL learning; L1 reading, listening and speaking difficulties, be they subtle or overt, are likely to be responsible for similar difficulties in FL learning.
4. The strength of the L1 language codes will determine the extent to which a student will be able to learn, or become proficient in, an FL.

The impact of poor abilities to make phoneme-grapheme correspondences has been found to be stronger in languages with so-called deep orthographies, in which the mapping between letters, speech sounds, and whole-word sounds is ambiguous and a high number of irregular or exceptional spellings cannot be decoded via grapheme-phoneme translation (Landerl, 2003; Landerl, Wimmer, & Frith, 1997; Snowling, 2000). Consequently, the rather inconsistent, complex English orthography poses a particular challenge for dyslexic learners. The many different spelling and pronunciation options present an almost insurmountable challenge for correct reading, writing, spelling and pronunciation (see Chen, 2001 for Chinese; Ferrari & Palladino, 2007 for Italian; Helland & Kaasa, 2005 for Norwegian; Miller-Guron & Lundberg, 2000 for Swedish, Nijakowska, 2008 for L1 Polish, and Oren & Breznitz, 2005 for L1 Hebrew). Even though there are no studies to date that have analyzed L1 Swiss German learners with reading impairments, EFL has been found to cause problems for dyslexic learners with L1 (Standard) German (e.g., Ganschow, Schneider, & Evers, 2000; Landerl, 2003; Landerl et al., 1997), which is the language of literacy in Switzerland (see below for a description of the linguistic and curricular landscape in Switzerland). For example, as to orthography, there are different degrees of orthographic consistency in (Swiss/Standard) German and English, which leads to different reading acquisition processes (to be discussed in the next session). German does not have perfect one-to-one grapheme-phoneme correspondences either but is much more on the shallow side of the continuum of orthographic consistency (Landerl, 2003, p. 15). It has to be kept in mind, however, that even dyslexic speakers of languages with more consistent orthographies, such as German, can compensate their phonological-orthographic impairment only to a certain extent as the coactivation of orthographic and phonological representations is less effective in dyslexics than in nondyslexics (Landerl, Frith, & Wimmer, 1996; Landerl et al., 1997; Landerl, 2003). In other words, due to the weak link between the orthographic and phonological facility in dyslexics, the sound of a word does not automatically evoke the inner orthographic image necessary for fluent reading and spelling, meaning the letters and the letter clusters do not become connected with the phonemes and the larger segments of the phonological word representation (Landerl et. al., 1997, p. 330).

Finally, there is general consent in the literature (e.g., Nijakowska, 2010; Paulesu et. al., 2001) that the clinical picture of dyslexia is quite individual and dynamic. Symptoms can change due to differing social/academic expectations and the individual development of coping mechanisms due to appropriate remedial instruction. This will be discussed next.

3. The role and impact of instruction and intervention

A solid body of research provides evidence for effective intervention approaches to address significant reading/spelling difficulties. These findings show that a lack of explicit instruction of the structure, forms and rules of a language, the almost exclusive use of the new FL or L2 and the frequent demand for inferring language rules implicitly from context cues stand in conflict with the learning support needs of students with dyslexia (Nijakowska, 2008, 2010). Ganschow and Sparks (2000) also point to the importance of explicit instruction about similarities and differences between languages for students who have difficulties learning an FL. In Switzerland, L2 German (i.e., the primary literary and written language) is conveyed both explicitly and implicitly to school children, as they encounter the German language daily through media such as TV, computer programs, and public discourse, in addition to being taught in school. By contrast, English as an L3 is mainly taught through implicit approaches in elementary school, in accordance with content and language integrated learning (CLIL) approach, as described in Schneider (1999). As the students have already been taught to read and write at this point, they usually learn L3 English through the whole-word method, in which explicit teaching of the phoneme-grapheme correspondence rules is not a central component. This complicates particularly the development of phonological awareness for dyslexic learners (Helland & Kaasa, 2005).

As opposed to such nonexplicit FL teaching approaches, research has shown that so-called multisensory structured learning (MSL) approaches are effective ways to meet native, FL and SL learning needs of dyslexics (Ganschow et al., 1998; Miller & Bussman Gillis, 2000; Nijakowska, 2008; Schneider, 1999, 2009; Sparks et al., 1998). These studies represent consistent results regarding the effect of MSL instruction. The MSL approach involves methods that teach phonological awareness and letter-sound correspondences explicitly while utilizing the simultaneous engagement of several sensory learning channels in carefully structured ways. There have been consistent results from these studies; the MSL approach yields successful results in teaching reading and spelling skills to learners with dyslexia, not only in their L1, but also in an FL. Unfortunately, such special methods of teaching FLs are currently not offered during regular FL teaching hours in most European countries because FL teacher training programs do not focus on how to best address struggling FL learner needs through explicit instruction. This confines highly recommended, specialized learning support to after school hours only (see Ganschow et al., 2000; Lovett et al., 2000, 2008; Torgesen, 2004, 2005; Scanlon, Vellutino, Small, Fanuele, & Sweeney, 2005). To address this dire need for after school learning support for dyslexics, commercial software programs have been developed recently to address the L1/FL-based problems of students with dyslexia early on. The one discussed in this paper follows the MSL approach by supporting simultaneous input in oral, written, and visual forms and incorporates an intervention component (daily one-to-one tutoring), as discussed in the following section.

4. The computer-based learning software (CLS)

Based on the guidelines outlined in the previous section, the computer-based learning software Lesikus (henceforth CLS) assessed in this study focuses on the direct and explicit teaching of the phonology/orthography (spelling-sound relations) and morphology (meaning units) systems of the L3 (English) (Baumann, 2012; Baumann & Scherling, 2011).[1] Learning how to read and spell words is realized by the integration of visual and auditory stimuli and involves simultaneous presentation of information coming from various senses (see Nijakowska, 2010, p. vii). To be more specific, the teaching of new pronunciation, spelling and vocabulary rules is conducted in a structured, linear, step-by-step fashion. It follows a carefully planned scope and sequence that moves from less to more complex rules, focusing on the differences in phoneme-grapheme correspondence rules between Standard German and English (see Reid, 1998). Every new rule is practiced in four modes. The first mode concerns reading: The learner has to read out loud a sequence of words that appear on the screen, while a training partner (in this case the experimenter and/or the parents) decides whether the pronunciation is correct or incorrect and clicks on the respective symbol. To facilitate reading, individual phonemes and morphemes are systematically color-coded and related to their written representations. Likewise, words are separated into color-coded syllables or prefixes, roots and suffixes (for a discussion of this, see Hodge, 1998; Schneider, 1999; Schneider & Crombie, 2003). The remaining modes concern spelling, that is, copying words that appear on the screen, and word dictation. These tasks do not necessarily require the presence of a training partner, since learners can check their answers on their own by clicking on the relevant correction symbols. Specific and immediate feedback is provided in that the learner earns a point for every word that is spelt or pronounced correctly. If learners produce a spelling mistake, they are encouraged to correct it ("please try again"). The vocabulary is taken from major EFL course books used in Swiss elementary schools and is frequently recapitulated and reviewed. Note that for every word, CLS provides German translations and pronunciation sound files in Standard British English.

Finally, the learner can choose between different types of exercises that can be completed at any desired pace of presentation and work. The program is interactive and therefore motivating and inspiring, making learning a pleasant experience. Since the literacy problems of dyslexic learners can only be minimized by automatizing their skills over a long period of time (see Nicolson & Fawcett, 2001), CLS is designed as a long-term training program. The use of a

[1] This computer program is commercially available from http://www.lesikus.com/

computer for editing, note-taking, and writing is also of great help inasmuch as poor handwriting does not disqualify children's work along with poor spelling (see Nijakowka, 2010, p. 148).

5. The study

5.1. Research questions and design

This control study included 20 classified dyslexic and 20 successful, nondyslexic readers and spellers. Both the test group receiving CLS intervention and the control group without intervention consisted of 10 randomly selected dyslexic students (labeled Test Dyslexic group) and 10 nondyslexic students (Test Non-dyslexic group). The purpose of this design was to ascertain that gains over time in the Test Dyslexic group stem from exposure to the CLS training. The study investigated the following research questions (RQs):

1. To what extent do phonological, morphological and semantic abilities in the L2 and L3 of the experimental groups change as a function of a 3-month individualized training with CLS, relative to the control groups (as measured by pre-post test comparisons)?
2. To what extent do the dyslexic learners (Test Dyslexic) benefit from the training with respect to phonological, morphological and semantic abilities, relative to the nondyslexic students (Test Nondyslexic)?
3. To what extent does the training in the L3 English phonological/orthographic abilities influence the L2 phonological and morphological abilities of the subjects?

Based on previous findings (see the literature review above), it is hypothesized that:

1. There will be significant between-group differences favoring the two non-dyslexic groups (Test Nondyslexic and Control Nondyslexic) on the pretest as well as the posttest measures in the battery (see Vellutino et al., 2004).
2. The experimental groups (Test Dyslexic and Test Nondyslexic) will show greater pre- and posttest gains than the control groups with regard to the level of posttest gain between groups.
3. The Test Nondyslexic group is expected to show the greatest pre- and posttest gains (see Lovett et al., 2008).

Taking Sparks and Ganschow's LCDH one step further, it is also of interest to see whether improved L3 skills have a positive effect (facilitation) on some components of both L2 and L3 learning (see RQ 3). Since Standard German represents both the L2 and language of literacy for the participants in this study, we can hypothesize that the improvement of L3 (English) skills might have a positive effect on L2 German as well.

5.2. Participants

Forty male students from two public elementary schools in one of the major cities in Switzerland were recruited (mean age 9;7, range 9;0-11;1). The 20 dyslexics were randomly assigned to either the Test Dyslexic group or the Control Dyslexic group; the 20 nondyslexic students were randomly assigned to either the Test Nondyslexic group or the Control Nondyslexic group.

All participants were in third grade and their socioeconomic background was middle class. They had completed at least 2.5 years of L2 Standard German (approximately 285 hours of direct German language instruction)[2] and 1.5 years of L3 English (approximately 114 hours of instruction).[3] Three subtests of the Wechsler Intelligence Scale for Children (WISC IV, see Petermann & Petermann, 2010) were used to evaluate children's nonverbal reasoning ability (vocabulary, block design and digit span forwards and backwards). All the participants had IQ scores within or near the average range.

While 15 of the 20 dyslexic learners had been identified as dyslexic by the school, a private psychologist or a speech therapist, the five remaining students had not been identified with any type of dyslexia until they were referred to us. They were categorized as dyslexic in this study because they were described by their parents and teachers as having severe deficits in L2 and L3 production (problems with grapheme-phoneme correspondences, word segmentation, capitalization, omission of letters). Their reading fluency scores revealed a considerably slower speed of learning and reading than that of the nondyslexic groups (see Tables 3 and 4 below). At least one of their relatives had been diagnosed as dyslexic by speech and language therapists or specially trained educators. Like the readers exhibiting average abilities, all the dyslexic students were integrated

[2] Note, however, that in Switzerland, all school subjects, and thus all participants in this study, are taught in Standard German, which increases their exposure to the L2 substantially.

[3] Note that while Swiss German is a High Alemannic variety of German, it is hardly understandable to someone who knows only Standard German, as the two languages differ to some extent in lexicon, phonology and syntax (for a discussion of this, see, e.g., Berthele, 2010). According to Lüdi (2007), most Swiss citizens are monolingual during their childhood, but they usually become bilingual in the early primary grades at the latest when they receive formal literacy training in L2 German from 1st grade on (age 7). This means that German-speaking Swiss children have to learn to read, write, and use a relatively unknown language all at once.

in mainstream classes. However, five of the 15 officially classified dyslexic subjects had to repeat second grade, which indicates significant delays in the development of language skills early on, at a time when letter-sound awareness skills are typically developing. However, they did not have any accommodations because of their disabilities.

5.3. Method and procedure

All 20 students received traditional L2 and L3 instruction; additionally, the experimental groups received the specialized training with CLS outside of school. The contact sessions took place over a period of three months (five times a week for 20 minutes) in separate, distraction-free rooms at the children's homes. Three sessions per week were supervised by trained research assistants, while the parents had been previously trained to assist the subjects in the remaining two sessions.

Before the introduction of the computerized learning support in the experimental group, all 40 subjects participated in a battery of pretests. Each subject was tested separately by the experimenter in a school room. The test battery lasted approximately four hours per subject. There was no difference between the subjects regarding the time allotted for testing nor were any time limits set. Immediately after the treatment ended, the posttest was administered to the 40 students. Analogous procedure to that used during pretest administration was applied. Following Ganschow and Sparks (1995), pre- and posttest comparisons *within* groups and pre- and posttest comparisons *between* groups (dyslexic vs. non-dyslexic; CLS vs. non-CLS) were conducted. The data were analyzed in accordance with their properties by *t* tests, Wilcoxon tests, Mann-Whitney *U*-tests, and chi-square tests. In order to account for the gains made by participants, multivariate analyses of covariance (MANCOVA) were applied, taking the scores of the participants on the posttest as the dependent variables, their scores on the pretest as the covariates, and treatment and reading ability as the independent variables. In the (M)ANCOVA approach, the whole focus is on whether one group has a higher mean after the treatment. MANCOVA also allows us to see whether each of the main factors, treatment and reading ability, as well as interaction between them, are statistically significant, while at the same time we can account for variation around the posttest means that comes from the variation in where the participants started at pretest.

5.4. Measures

A full battery of tests was administered in the participants' L2 (Standard German, the language of literacy) and L3 (English). The pre- and posttest battery included four continuous rapid automatized naming tests of numbers and objects in pictures in L2 and L3; two phoneme deletion tasks in L2 and L3, respectively; three standardized measures for L2 word and pseudoword reading fluency using the Salzburg Reading and Orthography Test (Salzburger Lese- und Rechtschreibtest SLRT-I and SLRT-II, see Landerl, Wimmer, & Moser, 2006) and the Salzburg Reading Test (Salzburger Lese-Screening SLS, see Mayringer & Wimmer, 2005); one measure of L3 word and pseudoword reading efficiency/reading speed using the word reading subtest of the Test of Word Reading Efficiency (TOWRE-2, Form A, see Torgesen, Wagner, & Rashotte, 2012); one standardized L2 spelling test (Salzburg Reading and Orthography Test [SLRT-II], see Moll & Landerl, 2010); one measure of L3 controlled receptive vocabulary (see Read, 2007); and two measures of L3 productive vocabulary, that is, a picture-naming task and a stimulated vocabulary retrieval task to capture size, depths, and richness of vocabulary knowledge (see Chen, 2012; Milton, 2009; Read, 2007). According to several authors (e.g., Orosz, 2009, p. 182), vocabulary size is closely related to other language skills and it is the foundation on which later learning can be built.

The tasks are in line with the characteristic indicators of phonological deficits that may underlie reading impairments and the typical symptoms of dyslexia in the transition from L1 to FL. They are aligned to the schools, the course book, and the age of the participants. The assessed problem areas covered in the pre- and posttests were the same as those covered by CLS. All tests had been successfully pilot-tested with four members of the relevant population (one of each group described above), but not with those who will form part of the final sample (Gamper, 2013).

5.5. Results

In the presentation of the results, first an overall picture of the participants' reading speed will be discussed. Table 1 gives the pre- and posttest results of the rapid automatized (digit/picture) naming tasks (DIGRAN and PICRAN) in the L2 and L3. In general, there were significant between-group differences favoring the two nondyslexic groups on all pretest and posttest rapid naming measures (in all cases $p < .05$). While the Test Dyslexic group was able to make significant gains over time on the DIGRAN-L2 test ($z = 2.42$, $p = .02$), the DIGRAN-L3 test ($z = 2.78$, $p = .005$) and the PICRAN-L3 test ($z = 2.68$, $p = .007$), the Control Dyslexic group showed the opposite pattern, scoring significantly lower on the post-PICRAN-L2 test ($z = -2.78$, $p = .005$) and the post-PICRAN-L3 test ($z = -2.78$, $p = .005$) than on the corresponding pretests. Neither of the two nondyslexic groups (Test Nondyslexic and Control Nondyslexic) made any significant gains.

Table 1 Naming speed means (seconds) in the RAN pre- and posttests

Test	Test Dyslexic	Test Nondyslexic	Control Dyslexic	Control Nondyslexic
Pre-DIGRAN-L2	47.5	22.8	41.6	26.2
Pre-DIGRAN-L3	70.5	47.7	62.3	47.7
Pre-PICRAN-L2	56.6	40.6	59.1	48.8
Pre-PICRAN-L3	71.8	55.3	61.8	50.8
Post-DIGRAN-L2	41.8	25.6	41.4	28.0
Post-DIGRAN-L3	57.5	41.7	62.5	44.2
Post-PICRAN-L2	53.3	42.4	78.5	46.8
Post-PICRAN-L3	65.5	47.6	77.7	47.7

In the L2/L3 phoneme deletion tasks, the two dyslexic groups performed better on all measures than the control groups without dyslexia, as Table 2 illustrates. None of the dyslexic children produced any errors on the regular digraph conditions (German *Schaf*, English *ship*, German *Theater*, English *thunder*). By contrast, the learners with average reading abilities showed signs of orthographic intrusion, such as in responding to *ship* with *hip* (rather than *ip*), which corroborates previous findings (e.g., Landerl et al., 1996). There were statistically significant pre- and posttest differences for the Test Dyslexic group ($z = -2.78$, $p = .005$) and the Test Nondyslexic group ($z = -2.78$, $p = .005$), in contrast to the two control groups (in all cases $p > .05$). While statistically significant differences were observed between the results of the pre-PHON-L3, with the Test Nondyslexic group outscoring the Test Dyslexic group ($U = 76$, $p = .053$), the results of the post-PHON-L3 indicated no more differences between the two experimental groups.

Table 2 Mean scores (mean %) on the phoneme deletion tasks (maximum = 7)

Test	Test Dyslexic	Test Nondyslexic	Control Dyslexic	Control Nondyslexic
Pre-PHON-L2	7 (100%)	5.9 (84.29%)	6.9 (98.57%)	4.6 (65.71%)
Pre-PHON-L3	4.2 (60%)	4.8 (68.57%)	5.2 (74.29%)	4 (57.14%)
Post-PHON-L2	7 (100%)	6.1 (87.14%)	6.4 (91.43%)	4.9 (70%)
Post-PHON-L3	6.2 (88.57%)	6 (85.71%)	5.8 (82.86%)	4.2 (60%)

Table 3 displays the results of the SLRT-I test series. The SLRT-I task targets single word and compound reading in the L2, reading of short and long text passages, and reading of pseudowords with regular and irregular grapheme-phoneme correspondences. As illustrated in Table 3, all 20 learners without dyslexia had significantly higher reading speed than the 20 dyslexic learners on all pre- and posttest measures. The reading speed of the dyslexic learners was particularly slow for the regular and irregular pseudowords. No significant differences were found within or between the Test Nondyslexic group and the Control Nondyslexic group. Likewise, there were no significant differences between the 10 Test Dyslexic group and the 10 Control Dyslexic group participants. Finally, no significant within-group differences emerged between any pre- and posttest; in other words, the reading speed underwent no improvement as a function of the intervention.

Table 3 Mean reading times (seconds) on L2 word and pseudoword reading fluency measures (reading speed) (SLRT-I)

Test	Test Dyslexic	Test Nondyslexic	Control Dyslexic	Control Nondyslexic	*t*	*p*
Pre-SLRT-L2 words	64.20	23.86	58.62	21.17	39.2	> .001
Pre-SLRT-L2 pseudowords	102.61	32.26	99.12	33.71	57.04	> .001
Post-SLRT-L2 words	64.85	22.08	58.43	20.93	34.77	> .001
Post-SLRT-L2 pseudowords	106.57	32.71	102.30	31.30	48.12	> .001

It is also noteworthy that all four groups had very high accuracy scores (number of real words and pseudowords read correctly) on all measures in the SLRT-I test series. Statistically significant between-group differences emerged in the pre- and posttests of the reading of regular and irregular grapheme-phoneme correspondences, as the Test Dyslexic group (U = 76, p = .05) and the Control Dyslexic group (U = 79.5, p = .03) had significantly lower values with the regular pseudowords in the pretest than the respective nondyslexic groups. Their scores were also significantly lower for the corresponding posttests (U = 76, p = .053 and U = 79.5, p = .029, respectively). The results of the Pre-SLT-L2 irregular pseudowords also indicated significantly lower values for the Test Dyslexic group (U = 91, p = .002) and the Control Dyslexic group (U = 99.5, p < .001), relative to the non-dyslexic readers. For the 20 non-dyslexic learners, the difference between words and pseudowords (95.1% s vs. 98.9%) was significantly smaller than for the 20 dyslexic learners (91.6% s vs. 82.6%; χ^2 = 62.6, df = 1, p < .001), which confirms previous findings on effects of lexicality (word vs. pseudowords) (e.g., Landerl et al., 1996, 1997a). As to pre- and post-comparisons within groups, the only statistically significant differences concerning accuracy were found between the results of the SLRT-I (irregular grapheme-phoneme correspondences) pre- and posttest, on which the Test Dyslexic group made significant gains over time (z = -2.78, p = .005). They were even able to reach the performance level of the non-dyslexic groups, in contrast to the Control Dyslexic group, who still achieved significantly lower scores than the two non-dyslexic groups (in both cases U = 95, p < .001).

As Table 4 shows, the within-group differences in the SLRT-II test also indicated some enhancement in L3 decoding and word reading efficiency as a result of the training. The Test Dyslexic group showed significant pre- and posttest differences on pseudowords (z = -1.96, p = 0.05), while the Test Nondyslexic group made significant gains with real words over time (z = -2.78, p = .005). There were no statistically significant differences within the two control groups. However, the Test Dyslexic group was not able to reach the performance level of either the Test Nondyslexic group or the Control Nondyslexic group (in all post-tests U = 100, p < .001). The dyslexic learners had particular difficulty reading pseudowords, with an error pattern similar to that in the SLRT-II test (see Table 4).

Table 4 L2 word and pseudoword reading fluency measures (mean accuracy scores within 1 minute) (SLRT-II)

Test	Test Dyslexic	Test Nondyslexic	Control Dyslexic	Control Nondyslexic
Pre-SLRT-L2 words	23.2	63.2	24.8	75.0
Pre-SLRT-L2 pseudowords	18.2	44.9	17.5	44.8
Post-SLRT-L2 words	23.9	75.7	21	79.2
Post-SLRT-L2 pseudowords	24.8	41.6	18.8	46.0

Note. Because of the generally low error scores, the errors for all three syllable lengths were combined (see Landerl et al., 1997a, p. 324).

Finally, in the SLS test, where the learners had three minutes to judge the truth content of a number of sentences, statistically significant results emerged between groups but not within groups. Table 5 presents these results. Almost all the performances on sentence reading fluency decreased slightly (but not significantly) with time for all subgroups. The non-dyslexic groups significantly outscored the dyslexic learners on the pretest as well as the posttest (in all cases t = -21.2, p < .001).

Table 5 Mean scores on L2 sentence reading fluency within 3 minutes (SLS)

Test	Test Dyslexic	Test Nondyslexic	Control Dyslexic	Control Nondyslexic
Pre-SLS-L2	23.9	49.2	26.6	54.9
Post-SLS-L2	22.9	45.2	25.7	56.8

Table 6 shows that, similarly, overall the dyslexic learners produced significantly fewer correct L3 forms than the non-dyslexic readers and at the same time skipped a high number of words. However, the Test Dyslexic group (z = -2.78, p = .005) and the Test Nondyslexic group (z = -2.62, p = .009) improved significantly on the TOWRE, in contrast to the control groups. While there were no significant differences between the Test Dyslexic group and the Control Dyslexic group on the pretest (U = 65.5, p = .23), the Test Dyslexic group significantly outperformed the Control Dyslexic group on the posttest measures (U = 2, p < .001). Despite gains, however, the Test Dyslexic group did not catch up with the Test Nondyslexic group or even the Control Nondyslexic group (in both cases U = 100, p < .001). Furthermore, while the number of skipped words decreased significantly over time in the Test Dyslexic group ($z = 2.78$, $p = .005$), it remained relatively high in the corresponding Control Dyslexic group, with no pretest-posttest difference ($z = -0.74$, $p = .46$).

Table 6 Mean scores (mean %) on L3 word decoding in the TOWRE (sight word efficiency part) within 45 seconds

Test	Accuracy	Test Dyslexic	Test Nondyslexic	Control Dyslexic	Control Nondyslexic
Pre-TOWRE-L3	correct	5.3 (19.2%)	37.1 (85.89%)	6.2 (26.98%)	39.9 (88.69%)
	error	6.9 (25%)	5.9 (14.11%)	10 (39.68%)	5.1 (11.33%)
	skipped	15.4 (55.8%)	0 (0%)	8.9 (34.13%)	0 (0%)
Post-TOWRE-L3	correct	17.8 (75.11%)	51.1 (86.9%)	7.6 (29.57%)	41.2 (85.65%)
	error	4.9 (20.68%)	7.7 (13.1%)	8.5 (33.07%)	6.9 (14.35%)
	skipped	1 (4.22%)	0 (0%)	9.6 (37.35%)	0 (0%)

In the L2 spelling test, the spelling of 48 monosyllabic and polysyllabic words was measured. Table 7 summarizes the results of orthographic errors, phonological errors, and capitalization errors. None of the groups made significant gains over time in L2 spelling. The differences in the total number of errors and the total number of misspelled words between the dyslexic learners and the non-dyslexic learners was significant on the pretest as well as the posttest (in all cases $U = 0.0$, $p < .001$), mainly because the dyslexic learners produced significantly more orthographic errors than the non-dyslexic readers on all measures (pre-SPELL-L2 orthographic: $U = 0.0$, $p < .001$; post-SPELL-L2 orthographic: $U = 0.0$, $p < .001$).

Table 7 Mean numbers (mean %) of error types in the SLRT-II-L2 spelling (maximum = 48)

Test	Test Dyslexic	Test Nondyslexic	Control Dyslexic	Control Nondyslexic
Pre-SPELL-L2 orthographic errors	29.6 (61.67%)	4 (8.33%)	26.4 (55%)	2.4 (5%)
Pre-SPELL-L2 phonological errors	1.2 (2.5%)	0 (0%)	1.9 (3.96%)	0 (0%)
Pre-SPELL-L2 capitalization errors	8.9 (18.54%)	3.1 (6.46%)	7.9 (16.46%)	1.2 (2.5%)
Pre-SPELL-L2 total errors	39.7 (82.71%)	7.1 (14.79%)	36.2 (75.42%)	3.6 (7.5%)
Pre-SPELL-L2 total misspelled words	32.7 (68.13%)	9.1 (18.96%)	30.6 (63.75%)	2.6 (5.42%)
Post-SPELL-L2 orthographic errors	27.8 (57.92%)	1.9 (3.96%)	23.2 (48.33%)	3.1 (6.46%)
Post-SPELL-L2 phonological errors	1.3 (2.71%)	3.2 (6.67%)	3 (6.25%)	1.3 (2.71%)
Post-SPELL-L2 capitalization errors	7.9 (16.46%)	4 (8.3%)	8.8 (18.33%)	4.5 (9.38%)
Post-SPELL-L2 total errors	37 (77.08%)	9.1 (18.96%)	35 (72.92%)	8.9 (18.54%)
Post-SPELL-L2 total misspelled words	29.3 (61.04%)	5.5 (11.46%)	31.4 (65.42%)	6.7 (13.96%)

Note. A distinction was made between *total errors* and *total misspelled words* because some words contained more than one error.

Table 8 summarizes the main results of the L3 receptive vocabulary task. The non-dyslexic groups exhibited ceiling-level performance on both the pre- and posttest. The Test Dyslexic group made significant gains over time (pre-LISTEN-L3 vs. post-LISTEN-L3: $z = -2.78$, $p = .005$), to the extent that they caught up with the non-dyslexic readers. The Control Dyslexic group scored significantly lower than the two non-dyslexic groups on the pretest as well as the posttest (in all cases $U = 100$, $p < .001$).

Table 8 Mean error scores (mean error %) on L3 word comprehension in sentence context (maximum = 6)

Test	Test Dyslexic	Test Nondyslexic	Control Dyslexic	Control Nondyslexic
Pre-LISTEN-L3	4.1 (68.33%)	6 (100%)	4 (66.67%)	6 (100%)
Post-LISTEN-L3	6 (100%)	6 (100%)	4.3 (71.67%)	6 (100%)

Finally, as Table 9 shows, in the first test of productive vocabulary, the L3 picture naming task, the Test Dyslexic group was the only group to have significantly higher scores on the post-PICNAM-L3 than on the pre-PICNAM-L3 ($z = -2.52$, $p = .012$). However, the differences in performance between the Test Dyslexic group and the two non-dyslexic groups were still significant on the posttest ($U = 86$, $p = .007$ and $U = 81$, $p = .021$, respectively).

Table 9 Mean scores (mean %) on the L3 picture naming task (maximum = 25)

Test	Test Dyslexic	Test Nondyslexic	Control Dyslexic	Control Nondyslexic
Pre-PICNAM-L3	13.8 (55.2%)	18.4 (73.2%)	12.4 (49.6%)	18.9 (75.6%)
Post-PICNAM-L3	18 (72%)	21.8 (87.2%)	11.2 (44.8%)	20.9 (83.6%)

As to the second test of productive vocabulary, the stimulated vocabulary retrieval task, the results of the correct words, number of switches, number of clusters, mean cluster size (excluding single words), overlapping items, and phonological clusters are shown in Table 10 for L2 German and Table 11 for L3 English.[4] While there were no significant differences between the Test Dyslexic group and the Control Dyslexic group, or between the Test Nondyslexic group and the Control Nondyslexic group, the nondyslexic learners performed significantly better than the dyslexic learners on all measures (in all cases $p < .001$). In other words, the non-dyslexic learners had higher levels of associative knowledge than the dyslexic learners. In general, the learners who had higher scores on the L2 stimulated vocabulary retrieval task achieved higher scores on the corresponding L3 test (pre-RETRIEVE: $r = .86$, $p < .0001$; post-RETRIEVE: $r = .87$, $p < .0001$). Similarly, the number of overlapping items significantly correlated

[4] For ease of exposition, the results of the two semantic categories for each language (*sports* and *professions* for German and *animals* and *body parts* for English) were collapsed.

with the number of correct words (pre-RETRIEVE-L2: $r = .38$, $p = .017$; post-RETRIEVE-L2: $r = .58$, $p < .0001$; pre-RETRIEVE-L3: $r = .48$, $p = .002$; post-RETRIEVE-L3: $r = .63$, $p < .0001$). While the size and depth of lexicon of the Test Dyslexic group ($z = -2.57$, $p = .01$) and the Test Nondyslexic group ($z = -2.62$, $p = .009$) increased significantly on the RETRIEVE-L3 correct words, the gains of the Control Dyslexic group on the post-RETRIEVE-L3 task (see Table 11) were not significant.

Table 10 Mean scores on L2 stimulated vocabulary retrieval tasks within 30 seconds

Test	Test Dyslexic	Test Nondyslexic	Control Dyslexic	Control Nondyslexic
Pre-RETRIEVE-L2 total words correct	4.95	9.35	6	9.95
Pre-RETRIEVE-L2 switches	1.95	3.6	2.45	3.85
Pre-RETRIEVE-L2 no. of clusters	1.2	2.15	1.2	2.2
Pre-RETRIEVE-L2 mean cluster size	2.46	2.96	1.95	3.15
Pre-RETRIEVE-L2 overlapping items	0	0.55	0.05	0.25
Post-RETRIEVE-L2 total words correct	4.15	9.45	5.9	9.5
Post-RETRIEVE-L2 switches	1.7	3.85	2.1	3.6
Post-RETRIEVE-L2 no. of clusters	1	2.05	1.25	2.15
Post-RETRIEVE-L2 mean cluster size	1.95	2.58	1.95	3.02
Post-RETRIEVE-L2 overlapping items	0	0.59	0	0.2

Table 11 Mean scores on L3 stimulated vocabulary retrieval task within 30 seconds

Test	Test Dyslexic	Test Nondyslexic	Control Dyslexic	Control Nondyslexic
Pre-RETRIEVE-L3 total words correct	4.75	9.5	5.45	12.65
Pre-RETRIEVE-L3 switches	1.95	3.35	1.9	5.1
Pre-RETRIEVE-L3 no. of clusters	1.15	2.3	1.35	3.05
Pre-RETRIEVE-L3 mean cluster size	2.025	3.57	2.54	3.78
Pre-RETRIEVE-L3 overlapping items	0.05	0.30	0	0.45
Post-RETRIEVE-L3 total words correct	5.3	11.75	7.1	11.9
Post-RETRIEVE-L3 switches	2.35	5	2.8	5
Post-RETRIEVE-L3 no. of clusters	1.4	2.95	1.75	2.8
Post-RETRIEVE-L3 mean cluster size	2.53	3.4	2.92	3.6
Post-RETRIEVE-L3 overlapping items	0	0.45	0	0.35

Finally, further analyses were conducted in order to examine the effects of the treatment (test vs. non-test) and the participants' reading skills (dyslexic vs. nondyslexic) on their scores as well as the interaction between the two independent variables. The MANCOVA analysis clearly reveals that both the intervention as well as L2 reading skills influenced the learners' performance on the 15 dependent measures. While the impact of the participants' reading skills is hardly surprising, Table 12 shows that there were significant results for 11 of the 15 measures and consistently high effect sizes for the treatment variable. As mentioned above, rapid automatized digit naming in German (DIGRAN-L2), L2 reading speed (SLRT-I), L2 spelling (SLRT-II-S), and stimulated vocabulary retrieval in English (RETRIEVE-L3) did not change as a function of the intervention.

Table 12 MANCOVA follow-up test results for all dependent measures (*df* = 1)

Effects of treatment			
Task	*F*	*p*	η^2
DIGRAN-L2	1.85	= .183	.030
DIGRAN-L3	8.20	< .001*	.112
PICRAN-L2	32.45	< .001*	.163
PICRAN-L3	36.34	< .001*	.243
PHON-L2	30.51	< .001*	.353
PHON-L3	39.64	< .001*	.285
SLRT-I	2.38	= .143	.002
SLRT-II-R	38.31	< .001*	.333
SLS	7.95	< .001*	.139
TOWRE	57.19	< .001*	.436
SLRT-II-S	0.93	= .342	.024
LISTEN	145.92	< .001*	.440
PICNAM	15.60	< .001*	.200
RETRIEVE-L2	38.32	< .001*	.152
RETRIEVE-L3	1.74	= .197	.019
Effects of reading ability			
Task	*F*	*p*	η^2
DIGRAN-L2	23.67	< .001*	.387
DIGRAN-L3	29.7	< .001*	.407
PICRAN-L2	98.56	< .001*	.495
PICRAN-L3	71.97	< .001*	.482
PHON-L2	4.46	= .042	.052
PHON-L3	36.29	< .001*	.261
SLRT-I	12.21	< .001*	.320
SLRT-II-R	40.43	< .001*	.352
SLS	4.05	= .052	.071
TOWRE	38.88	< .001*	.297
SLRT-II-S	1.78	= .190	.047
LISTEN	4.13	= .050	.012
PICNAM	18.37	< .001*	.235
RETRIEVE-L2	178.98	< .001*	.708
RETRIEVE-L3	55.42	< .001*	.594
Interaction of treatment and reading ability			
Task	*F*	*p*	η^2
DIGRAN-L2	0.61	= .441	.001
DIGRAN-L3	0.14	= .713	.002
PICRAN-L2	33.10	< .001*	.167
PICRAN-L3	6.14	= .018*	.041
PHON-L2	16.56	< .001*	.191
PHON-L3	28.23	< .001*	.203
SLRT-I	0.34	= .214	.005
SLRT-II-R	1.22	= .276	.012
SLS	10.47	= .003*	.181
TOWRE	0.06	= .809	.000
SLRT-II-S	0.25	= .621	.006
LISTEN	148.76	< .001*	.446
PICNAM	9.04	< .001*	.116
RETRIEVE-L2	0.43	= .516	.002
RETRIEVE-L3	1.16	= .289	.013

Note. *Statistically significant at $\alpha < .05$.

5.6. Discussion

The current results are in line with multiple non-computerized intervention studies (e.g., Sparks et al., 1998; Vellutino et al., 2004) that indicate that learners without dyslexia achieve significantly higher scores on tasks that require phonemic differentiation, a challenge for individuals with dyslexia. The entry-level L2 literacy skills were uniformly deficient in the group of the impaired readers (the Test Dyslexic group and Control Dyslexic group), relative to the non-dyslexic readers, which supports Hypothesis 1. As a consequence of their poor entry-level literacy skills, the dyslexic learners had a weaker foundation for L3 learning than the non-dyslexic readers; it was found that L2 abilities at entry were highly predictive of final outcomes and of reading growth during intervention. Students with stronger L2 skills demonstrated higher L3 proficiency and achievement (e.g., in the L3 TOWRE word decoding task) than students with weaker L2 skills. In the vocabulary retrieval task, the learners who had higher scores on the L2 tests, the nondyslexic groups, achieved higher scores on the L3 tests. Since the vocabulary retrieval task works as an indicator of development because it requires online retrieval and monitoring responses and therefore captures many aspects of language that develop with time (Chen, 2012), the low scores of the dyslexic learners indicate an underdevelopment of the size and depth of German and English vocabulary. Also, the more frequent use of overlapping clusters by nondyslexic learners indicates richer semantic knowledge because in order to produce overlapping clusters, learners have to know at least two features of the item that belongs to two consecutive clusters (Chen, 2012).

Hypothesis 2 was also supported. In contrast to the control groups, significant differences were revealed for learners with or without reading difficulties (Test Dyslexic and Test Nondyslexic) in intervention outcomes or growth on the following measures: L2 and L3 phoneme deletion task, L2 (regular) pseudoword decoding (SLRT), and L3 word decoding (TOWRE). The Test Dyslexic group made even greater gains than the Test Nondyslexic group on the L2 and L3 rapid automatized digit/picture naming as well as the L3 receptive vocabulary test and the L3 picture naming task, to the extent that they were able to catch up to the performance of the Control Nondyslexic group and/or the Test Nondyslexic group (see Hypothesis 3). For the L2 word decoding and L2 sentence reading fluency tasks (SLRT-I, SLRT-II, and SLS), there was relatively little difference between the pretests and the posttests. However, the percentage of correct readings for pseudowords (irregular grapheme-phoneme correspondences) by the Test Nondyslexic group climbed significantly across most tests. Certain reading-related cognitive deficits, such as L2 reading speed and L2 spelling, were found to be difficult to remediate within such a short period of time. What is more, all groups made significant gains over time on the stimulated vocabulary retrieval task regardless of training method.

In sum, the research-based intervention proved superior to the traditional education control on a wide variety of task outcomes and rate of growth: Concerning the impacts of the treatment and the participants' reading skills, MANCOVA indicated that treatment effects were significant for 11 of the 15 dependent variables, with large effect sizes. Thus, there seemed to be some facilitation effect of the MSL training, which answers my third and last research question.

5.7. Conclusion

This study examined the effect of three months of computer-mediated MSL instruction in the phonology/orthography of English as an L3 offered to elementary school students identified as being at-risk (*n* = 20) and not at-risk (*n* = 20) of struggling with language acquisition. The training that the Test Dyslexic group and the Test Nondyslexic group underwent proved effective irrespective of the reading ability of the learners, which is in line with many previous noncomputerized intervention studies. What is more, the training tested here was more effective for the Test Dyslexic group than for the Test Nondyslexic group, which corroborates Lovett et al.'s (2008) finding that lower language-ability learners improve at a faster rate than their higher language-ability peers in intervention programs. The results of this study provide a contribution to the literature of FL interventions with MSL computerized language training for dyslexic language learners. Due to self-dependent, systematic multisensory and highly repetitive phonics practice in L3, dyslexic learners learn to map print onto speech, develop quite competent decoding abilities and phonemic awareness, and accordingly can catch up in both L2 and L3 acquisition to the non-dyslexic learners. This training has a positive impact not only on L3 but also L2 decoding skills. It has to be noted, however, that despite considerable progress and gain, the Test Dyslexic group still lagged behind the nondyslexic readers in some of the phonological/orthographic abilities measured, which confirms previous observations (e.g., Ganschow & Sparks, 1995) that at-risk learners are not likely to catch up with their not-at-risk peers in FL learning.

It goes without saying that the small sample sizes limit the power of the statistical analyses. Thus, the results must be regarded as tentative until more rigorous, controlled evaluations are undertaken. Moreover, it remains to be seen if the Test Dyslexic group is able to maintain their gains over time because the duration of the intervention effects is unclear. Without further training, the Test Dyslexic group might not be able to maintain or increase their initially achieved gains. Additional research is also needed regarding general task effects as well as differences in motivational dispositions that might influence, or emerge as a result of, the intervention (see Pfenninger, 2014). Concerning the task effects, we cannot rule out the possibility that the same results would have been obtained with any other intervention task. Nevertheless, the data offers preliminary support for the value of a computer-based learning aid outside the classroom and its influence on the L2 and L3 skills of young learners. Given the increasing number of FL programs, the absence of special help available to students with specific learning difficulties, and the reluctance of FL educators to accept the importance of explicit multisensory instruction in phonology and grammar (see, e.g., Nijakowska, 2008, p. 144), longitudinal research on the effects of after-school learning support is essential.

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