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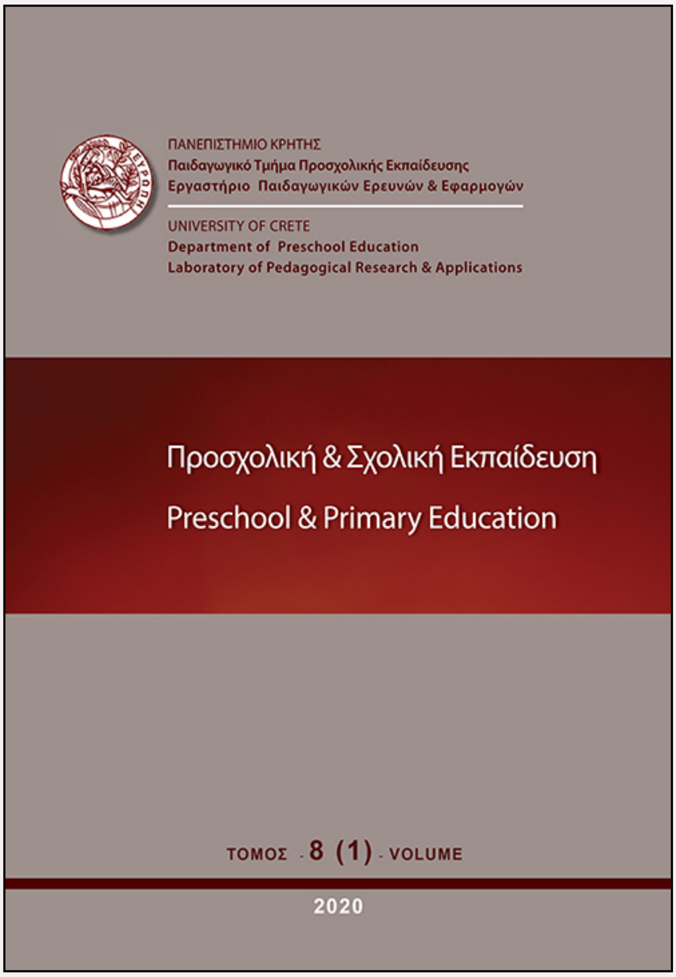

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Intervention for a visual attention span processing deficit in a Greek-speaking child with slow reading speed

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Abstract. We present the case of TN, aged 9;11, a monolingual Greek-speaking girl with accurate but slow word and non-word reading. Neuropsychological assessment revealed a selective deficit in visual attention span (VAS) tasks. TN had previously taken part in a spelling intervention targeting whole word processing and, although her spelling improved, at the end of the programme, her reading remained slow. In the present study, we assessed TN in a lexical decision task with semantic primes, and she showed reduced semantic priming in relation to typically developing readers. TN took part in an intervention aimed at mitigating the VAS processing deficit and similar to a programme previously conducted with a twelve-year-old Greek-speaking boy, RF (Niolaki & Masterson, 2013). Post-test results for TN revealed a significant improvement in letter report ability, as well as a reduction in word reading latencies; semantic facilitation was also observed in the priming task following the intervention, although pre- and post-intervention differences were not significant. The results indicate, in line with previous research, an association between visual attention span and reading speed.

Keywords: visual attention span processing; developmental dyslexia

Introduction

Research into phonological processing deficits has been prominent within the literature on developmental dyslexia (Ramus, 2003; Snowling, 2000; Vellutino et al., 1996). However, there are indications that a phonological deficit is not the only underlying cause of developmental dyslexia (see for a review, Parrila, Dudley, Song, & Georgiou, 2019; Parrila & Protopapas, 2017).

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Valdois, Bosse and Tainturier (2004) and others have reported that some dyslexics have a deficit of visual attention span (VAS), as measured in tasks assessing report of letters from briefly presented multi-letter arrays. VAS has been defined as the number of elements that can be processed in a visually presented multi-element array (e.g., Bosse, Tainturier, & Valdois, 2007), and a selective deficit of VAS was previously identified in TN, the ten-year-old Greek-speaking child who is reported in the present paper, when she took part in a group study conducted by Niolaki, Tersopoulos and Masterson (2014). In the current study, the aim was to replicate and extend findings of an intervention carried out with a Greek-speaking boy, RF, who had a VAS deficit (Niolaki & Masterson, 2013). The two objectives of the present research were, first to see whether the same intervention would be effective for TN, in terms of improving reading speed, and second, to see whether there might be evidence of a qualitative change in TN's reading as a result of the intervention, based on results from a semantic priming task.

A single-subject intervention design was used for this research. It has been argued that intervention studies can lead simultaneously to theoretical and educational insights (Nickels, Best, & Howard, 2015; Nickels, Rapp, & Kohnen, 2015). Theoretical insight is achieved since evidence can inform theories of cognitive processing when improvement in untrained processes is observed, and educational insight is achieved because the intervention can inform teaching practices. Prior to outlining the steps taken in the current investigation, we present first the key features of the Greek writing system that are relevant to the identification of reading and spelling difficulties in Greek-speaking children.

The orthographic system in Greek is very transparent and the distinction between regularly and irregularly spelled letter strings that exists for reading in English is not present (Protopapas, 2016). However, spelling is less consistent, as for other languages/orthographic systems. Irregular words for spelling in Greek are those in which the body vowel should be spelled with a grapheme that is not the usual phoneme-grapheme correspondence (for example, the <υ>/i/ in <τυρί> /tiri/ (cheese) and the <ω>/o/ in <άρωμα> /aroma/ (scent) - the most common phoneme-grapheme correspondence for the /o/ phoneme is <ο>, Zipf frequency = 7.22, the least common is <ω>, Zipf frequency = 4.55 (Terzopoulos, Niolaki, & Masterson, 2018). Several studies in the past have demonstrated that due to the transparency of Greek orthography children primarily exhibit a reading speed deficit and difficulty in spelling rather than a difficulty in reading accuracy (Terzopoulos, et al., 2018; Georgiou, Protopapas, Papadopoulos, Skaloumbakas, & Parrila, 2010; Papadopoulos, Georgiou, & Kendeou, 2009). However, in the Greek orthography, only a few studies have explored the effect of visual attention span as an alternative to a phonological deficit, especially in children who seem to have a selective deficit in lexical processes, as outlined next (Niolaki & Masterson, 2013; Niolaki, et al., 2014; Terzopoulos, et al., 2018).

A difficulty in reading irregular words for English dyslexic children and adults has been interpreted as a deficit of lexical processes (e.g., Shallice, 1981), while a difficulty reading nonwords has been interpreted as a deficit of sub-lexical processes. Children identified as having a selective deficit in lexical processes were termed surface dyslexic, whereas children with a selective deficit in sub-lexical processes were characterized as phonological dyslexics (Castles & Coltheart, 1993). Douklias, Masterson and Hanley (2009) looked for the characteristics of developmental surface and phonological dyslexia in a large group of Greek-speaking poor readers aged 9 to 12 years old. They employed word reading latency as a measure of lexical skill, on the assumption that slow reading of familiar words is an indication of reliance on resource-demanding sub-lexical processes, and nonword reading accuracy was considered the measure of sub-lexical skill. The researchers used the regression-outlier technique, previously employed by

Castles and Coltheart (1993) in a study with English-speaking dyslexic children and identified two children with slow word reading relative to control children, and two with inaccurate nonword reading relative to controls. According to their findings 50% of the poor reader population they tested with a dissociated deficit had surface dyslexia.

Niolaki et al. (2014) attempted to replicate and extend the study of Douklias et al. (2009) by including assessments of a range of literacy-related processes in addition to reading and spelling assessments and including only children who had a diagnosis of dyslexia. The tasks included tapping phonological processing, visual memory and VAS. In a group of nine Greek-speaking children, Niolaki et al. (2014) found two with a primary lexical deficit, three with a primary sub-lexical deficit, and four with combined lexical and sublexical difficulties. The rate of occurrence of dyslexic students with a primary lexical difficulty reported in this study was 40% of the total dyslexic population. This figure corresponds fairly closely to the 46% reported by Castles and Coltheart (1993) for English-speaking dyslexics in their study, and the percentage of 50% reported by Douklias et al. (2009), as noted above. Niolaki et al. (2014) further found that the children with primary lexical difficulties had a selective deficit of VAS, and those with a primary sub-lexical deficit had a selective difficulty in phonological processing, assessed with blending and spoonerism tasks. The four children with combined difficulties had deficits in both VAS and phonological ability.

In previous studies investigating possible underlying causes of surface dyslexia, Valdois et al. (2003), Dubois, Lafave de Micheaux, Noël and Valdois, (2007) and others also reported an association between a VAS deficit and lexical difficulties, and the interpretation has been in terms of impairment in the ability to process large orthographic units. Ans, Carbonnel and Valdois (1998) proposed the multi-trace memory model of multi-syllabic word reading to explain the VAS deficit hypothesis. Within this, the ability to process words is via a global reading procedure, which requires a wide visual attentional window that will process printed words as wholes, and not break them into smaller components, which is the focus of the analytic reading procedure. Ans et al. suggested that the visual attentional window can be located in the orthographic input lexicon.

However, some researchers argued that performance in VAS letter report tasks is related to phonological processing (Ziegler, Pech-Georgel, Dufau, & Grainger, 2010). Ziegler et al. claimed that the deficit in VAS derives from deficient visual to phonological recoding. In contrast, the results of Lobier, Zoubrinetzky and Valdois (2012) revealed that dyslexic children were impaired in VAS tasks with nameable and non-nameable stimuli. Findings in a similar vein were reported by Pammer, Lavis, Hansen and Cornelissen, (2004) and Pammer, Lavis, Dooper, Hansen and Cornelissen (2005). The researchers found that performance in a non-nameable symbol-string task predicted lexical decision task scores independently from scores in measures of phonological memory. The findings argue against a (solely) phonological explanation of VAS (see also Lobier, Dubois, & Valdois, 2013).

Apart from VAS, semantic overt priming has been employed as a means for investigating the integrity of lexical processes for reading. Meyer and Schvaneveldt (1971) conducted a study with high school students who were asked to decide if letter strings were real words or non-words. They found faster and more accurate responses when a semantically associated word was presented with the target word (e.g., BREAD-BUTTER) rather than when a nonword was paired with the target item (e.g., BREAD-LUFFER). The same visual lexical decision task with semantic primes was used with children with dyslexia by Pring and Snowling (1989) and Betjemann and Keenan (2008), and with Greek-speaking dyslexic children by Niolaki, Terzopoulos and

Masterson, (2015). These studies revealed evidence of semantic priming for typically developing children, but a lack of semantic priming in children with reading difficulties.

In the current study, we examined whether semantic priming would be found for TN before and after the intervention. Lack of semantic priming could indicate reliance on sub-lexical processes for reading due to a deficit in lexical processes. If evidence for semantic priming were to be observed following the intervention, this could suggest a change to use of lexical processes (although alternative potential explanations are outlined in the next section).

Intervention studies targeting VAS deficits

We next discuss single case training studies that have targeted a VAS deficit. Valdois et al. (2014) carried out an intervention study with a dyslexic child with a selective deficit of VAS. MP was a seven-year-old bilingual French and Spanish speaking child. Valdois et al. reported that training in visual search, parsing, matching and discrimination tasks resulted in significant improvement in MP's reading fluency and reading times, especially in opaque French. In a study with an older child Niolaki and Masterson (2013) reported RF, a monolingual Greek-speaking twelve-year-old boy who had impaired VAS, and no apparent difficulties with phonological processing. He had slow word reading latencies and impaired irregular word spelling, as in the two cases with a primary lexical impairment in the study of Douklias et al. (2009). Intervention for RF involved training in report of letter arrays of increasing length (from three up to five letters), with the aim of investigating whether any improvement observed in letter report would generalise to reading speed. Improvement in letter report was observed, as well as in word reading accuracy and latency. However, gains were not observed for text reading speed. The results leave open the question of why improvement in single word reading was observed but not in text reading, as had been reported for MP in the study of Valdois et al. (2014). Apart from differences in the training regimes used and age of the children across the two studies, it could be the case that, as argued by Valdois et al., interventions focusing on VAS will be more effective for opaque orthographies than transparent ones (such as Greek), since reading in the latter type of writing system relies more on smaller orthographic units.

Niolaki and Masterson (2013) also noted that the results from their study were ambiguous in that they were not able to tell whether the intervention had resulted in change from reliance on sub-lexical processes to lexical processes. The assumption underlying the training had been that improvement in VAS would lead to the use of larger orthographic units for reading, and thereby reduce the need to rely on sub-lexical processes. However, the reduction in single word reading latencies observed for RF following the intervention could potentially have been achieved through increased efficiency of sub-lexical processes, and the training may have inadvertently caused this. Niolaki and Masterson (2013) suggested that evidence indicating a qualitative change in the nature of reading processes as a result of the intervention might be obtained from performance in tasks such as semantic priming, which was employed in the current investigation.

The current investigation

A deficit in VAS, assessed by means of letter report tasks, has been associated with lexical difficulties in opaque (Bogon et al. 2014; Dubois et al. 2010; Peyrin et al. 2012; Valdois et al. 2003) and transparent scripts (Niolaki & Masterson, 2013; Niolaki et al. 2014; Germano, Reilhac, Capellini, & Valdois, 2014). The present study involved a replication and extension of the intervention study carried out by Niolaki et al. (2013) that involved targeting RF's letter report difficulty. In the *Case Study* section that follows we present results (from Niolaki et al. 2014; Terzopoulos, et al. 2018) that revealed TN had a similar profile to RF in terms of literacy difficulties and VAS deficit. We then describe the intervention conducted in the present study, that was aimed at mitigating TN's VAS deficit. We also assessed TN in lexical decision tasks with semantic priming before and after the intervention, to see whether there might be evidence for a change in reading processes following the intervention.

Method

Description of the Case Study

TN is a monolingual Greek-speaking girl aged 9 years and 11 months when assessment began for the present study. Greek was the only language spoken by her family. According to parental report, TN's developmental history was uneventful, and milestones were attained at appropriate ages. TN's mother and father were state employees. Her father reported that he had, and still has, spelling difficulties and that when he was young, he was a slow reader. TN was attending a mainstream school and learned to read and write when she was in the first grade, but her reading was slow in comparison to her peers, according to her teacher's report. At the end of Grade 2, she was still reading by means of syllabifying words, a technique typically used by children in the very initial stages of learning to read in Greek (usually by the end of first grade children can read words and pseudowords fluently) (Georgiou, Torppa, Manolitsis, Lyytinen, & Parrila, 2012).

TN had previously taken part in a group study when she was aged 9 years (please see Niolaki et al., 2014 for details). For the purposes of that study, TN's scores were contrasted with those of nine typically developing readers who were selected to form a comparison group. The children in the comparison group came from a mainstream morning inner-city school and their teacher reported that they all were typical readers and spellers. The school the comparison children were recruited from was in the same catchment area where TN attended school and had a similar composition to her school. The mean age of the comparison children was 9 years 2 months (*SD*=.03). Non-verbal ability was assessed with the Matrix Analogies Test (Naglieri, 1985) and the mean raw score was 18.9 (*SD*=5.2) (max. correct= 34). TN's non-verbal ability raw score was 24, which was not significantly different from the mean for the comparison group (modified[1] t-test $t(9)=0.9$, $p=.17$, $r^2=.28$). In addition, her scores for receptive vocabulary, digit span, author recognition and arithmetic assessments were not different from those of the comparison group.

TN's text reading rate was assessed using the test of Panteliadou and Antoniou (2007, please see *Assessment* section below for details) and was found to be impaired, with a standardised score of 76 (95% Confidence Interval (CI) = 69–83) which is well below average (mean=100). Word and nonword reading were assessed using stimuli from Loizidou-Ieridou, Masterson, and Hanley (2010). Results revealed that TN was as accurate in single word reading as comparison children, but her reading latencies were slow (TN mean=1536ms, comparison group mean=911ms, *SD*=160). Nonword reading latencies were also slow (TN mean=1592ms, comparison group mean=1103ms, *SD*=176).

Assessment with the standardised single word spelling to dictation test of Mouzaki, Protopapas, Sideridis, and Simos (2007, see *Assessment* section below for details) revealed that TN had a standard score of 74 (95% Confidence Interval (CI) = 67–81) which is well below average (mean=100). The comparison group mean standard score in the test was 102 (*SD*=15.3). For irregular word spelling, using stimuli from Loizidou-Ieridou et al. (2010), TN only scored 3 out of 20 correct (comparison group mean=10.4, *SD*=3.2), while for nonword spelling, TN's performance was unimpaired (39/40 correct, comparison group mean=36, *SD*=2.7). In tasks of phonological ability, rapid automatized naming, visual memory, and VAS TN was found to be impaired only in VAS. On the basis of the pre-intervention assessment results, Niolaki et al. suggested that TN may have difficulties in both lexical (impaired word reading latencies and irregular word spelling) and sub-lexical processes (impaired non-word reading latencies), however, good levels of accuracy in nonword reading and spelling indicated a primary lexical deficit.

Following participation in the Niolaki et al. (2014) group study, TN took part in a spelling intervention programme reported in Terzopoulos et al. (2018). The intervention involved presentation of words on flashcards for TN to copy and then spell following a 10-second delay. Scores in post-intervention assessment conducted one-month post-test and then four months later revealed a significant improvement in spelling of treated words that was sustained over time. In addition, TN showed an increase in score in the standardized spelling assessment, at post-test, her score was no longer significantly different from that of the comparison group. Reading accuracy, latency and text reading speed were also re-assessed. There was an improvement in reading accuracy but not reading speed. Therefore, for the present study, we decided to carry out a VAS intervention to see whether TN would show improvement in reading latencies, as RF did in the study of Niolaki and Masterson (2013).

Assessment

The assessments carried out for the present study prior to the VAS intervention are presented below. Data before the intervention were collected at two different Baseline assessments (Pre-test 1 and 2). We included two baseline assessments in order to look for any improvement due to test-re-test effects, and to investigate whether there was stability in performance prior to the start of intervention (Howard, Best, and Nickels, 2015). Pre-test 1 data were collected when TN was 9 years and 11 months old and Pre-test 2 data were collected when she was 10 years old. Results for the Pre-test 1 assessments are given in the first section of the *Results (Pre-intervention findings)*, and those for Pre-test 2 and post-intervention testing are reported in the *Intervention* section. We recruited a group of 35 typically developing children who were comparable to TN in age and non-verbal ability scores in the Matrix Analogies Test (Naglieri, 1985). All children were reported to have typical reading and spelling development and they all came from inner-city mainstream schools in the same area that TN attended school. Comparison children were assessed when TN was 10 years, at Pre-test 2. The mean age of the comparison group children was 9 years and 9 months (*SD*=0.29), and the mean correct score for the group in the Matrix Analogies test was 20.8 (*SD*=3.57). For age and non-verbal ability, no significant difference was found, $t_{age}(35)=1.1$, $p=.15$, r=.18 and $t_{n\text{-}vability}(19)=0.87$, $p=.19$, r=.19.

Reading assessments

Standardized measures

The Reading Test Alpha (Panteliadou & Antoniou, 2007) is a standardized reading test and was used to provide a measure of reading comprehension, text reading rate, and single word reading accuracy. Test– retest reliability for all tasks in the test ranges between .74 and .87. The reading comprehension measure involves reading texts and responding to multiple choice questions. Reading rate is assessed using a text and involves recording the total number of words read correctly in one minute. Reading accuracy involves two subtasks: reading aloud words and nonwords and lexical decision. The lexical decision subtask involves silent reading of a row of items (words and nonwords intermixed) and the testee has to report the real words only. As the test proceeds the number of items per row increases. Reading aloud words and nonwords involves the presentation of a printed list of 53 words (mean number of letters: 10.5, *SD*=3.3) and 24 nonwords (mean number of letters: 9.6, *SD*=3.1). The words and nonwords are intermixed and of increasing difficulty, according to the test manual. We report both accuracy and reading latencies in the *Results* section. To obtain reading latencies, we used the CheckVocal software developed by Protopapas (2007). Only correct responses were included in calculating the means.

Reading words and nonwords (accuracy and latencies)

a. *Test Alpha (Panteliadou & Antoniou 2007)*

For assessment of lexical and sublexical reading processes we used the results from the single word and non-word reading subtask in Test Alpha (described in the previous section).

b. *Reading words and nonwords from Loizidou-Ieridou et al. (2010)*

We decided to assess TN's reading of words and non-words further, using stimuli from Loizidou et al. (2010), in order to provide results from multiple tasks tapping the same skills (cf. Huguenin, 2012) as this could ensure construct validity. The Loizidou-Ieridou et al. (2010) stimuli consist of 40 words and 40 non-words.

Spelling assessments

Standardized measures

For spelling the Mouzaki et al. (2007), single word spelling test was administered and for spelling in text the assessment of Porpodas, Diakogiorgi, Dimakou and Karantzi (2007) was used. Single words in the Mouzaki et al. test are chosen from primary school reading primers (mean number of letters=7.6, *SD*=2.9). These reflect a wide range of morpho-syntactic rules. Words included are prone to morphological and orthographic errors, in case the participant does not know the appropriate spelling. In the Porpodas et al. test, children produce a written text according to a series of four related pictures.

Spelling regular and irregular words, and nonwords (Loizidou-Ieridou et al. 2010)

The Loizidou-Ieridou et al. reading test was also administered at a separate testing session as a spelling test. Twenty of the real words were regular in terms of phoneme-grapheme correspondence, and 20 were irregular (for reading all 40 words are regular). The stimuli were presented in blocks, with regular words displayed first followed by non-words and then irregular words.

Non-reading assessments

Visual attention span tasks

The VAS tasks of global, sequential and partial report are typically used to measure difficulties or strengths in multi-character array processing (Bosse et al. 2007; Bosse & Valdois, 2009; Valdois et al. 2011). In global report, on each trial, the testee is asked to report a briefly presented five-letter array (correct order of items is not required). Specifically, spaces between letters were increased to minimize potential crowding effects (following previous studies using the paradigm), the letter string is presented for 200 ms, so that all letters are simultaneously processed – a short duration prevents useful eye movements with extraction of new information from the string. Last, the stimuli are not random letter strings: each letter appears the same number of times in each position and adjacent letters never form frequent bigrams.

During the sequential letter report task, TN was asked to report the arrays of letters as in the global report task with the only difference that the letters are presented sequentially. The task was used to control for a possible verbal short-term memory deficit (Valdois et al., 2011). The same consonants employed previously for global report were used, Γ /g/, Δ /d/, Θ /t^h/, Λ /l/, Ξ /ks/, Π /p/, Σ /s/, Φ /p^h/, Ψ /ps/. TN looked at the central fixation point for 1000msec, then a blank screen appeared for 50 ms and finally the five uppercase consonant letters appeared one after the other at the centre of the computer screen (Dell Inspiron, Windows 7) for 200 ms each (ISI=0).

In partial report, on each trial, the testee is asked to report only one letter, indicated by a cursor presented for 50 ms, placed 1.1° under the target letter as soon as the letter string disappears from the screen. Partial report is used as a measure of VAS controlling for the memory load imposed by the global report task (Bundesen, 1998).

We also assessed TN in a control single-letter naming task used by Valdois et al. (2011). The single letter report involved the nine letters used in the letter report tasks and it was administered to control for possible visual processing difficulties for letters (Valdois et al. 2011). In this task, Valdois et al. (2011) used naming times and not accuracy. We also used naming times as the aim was to assess the duration for accurate identification of individual letters. The letters were presented singly in the centre of the computer screen. For a description of the Greek adaptation of the tasks, please refer to Niolaki and Masterson (2013). The DMDX software (Forster & Forster, 2003) was used to run the experiments.

Lexical Decision with 'active priming'

Two different lexical decision tasks were prepared (Experiment 1 and 2, respectively). The aim of using two different tasks was to check if a similar outcome would be obtained in both. The tasks involved different sets of stimuli that were comparable in printed word frequency (all psycholinguistic variables were taken from HelexKids http://www.helexkids.org/home, Terzopoulos, Duncan, Wilson, Niolaki, & Masterson, 2016). There were four prime-target conditions in each task: identity match (prime and target were the same, e.g., νερά /nera/water), phonological/orthographic association (e.g., γερά /gera/ strong), semantic association (e.g., βροχή /brohe: /rain), and unrelated (e.g., μπάλα /bala/ ball). The number of items per condition was 12. Each target appeared only once in the list. One list was constructed within which each target and each prime appeared only once. This means that the comparison of conditions was based on different prime-target pairs that however were carefully matched for length, frequency, Contextual Diversity (CD, the number of different contexts a word appears in), and Orthographic Levenshtein Distance (OLD20, a measure of orthographic neighbour based on OLD20).

For the semantically associated condition, prime-target pairs were rated by twelve primary school teachers for their semantic association using a Likert scale of 1 to 5 (not associated to strongly associated). Items with an average rating of below three were removed from the list; a total of nine items were removed from the initial list of 105 items. Primes (per condition) were matched in frequency, length, CD, and OLD20 with the targets (see Table 1 and Appendix A1 and A2). For Experiment 1 the orthographic overlap for the phonological/orthographic association condition was 61.8 (*SD*=22.6), and the phonological was 67.1 (*SD*=22.5), and for Experiment 2 the orthographic overlap for the phonological/orthographic association condition was 66.3 (*SD*=11.5), and the phonological was 71.7 (*SD*=9.1).

Table 1 Mean for conditions in the different psycholinguistic variables for the lexical decision experiments (standard deviations are in parentheses)

Experiment 1									*t*-test
Condition	*Prime*				*Target*				
	Frequency[a]	Length	CD[b]	OLD20[c]	Frequency	Length	CD	OLD20	
Identity	4.8(.97)	7(2.7)	.39(.34)	2.5(.87)	4.8(.97)	7(2.7)	.39(.34)	2.5(.87)	-
Phon./Orth.	4.7(.73)	5.6(1.2)	.23(.31)	2.1(.38)	5.6(.48)	5.8(2)	.39(.21)	2.1(.58)	*Ns*
Semantic	5.1(.65)	6.3(1.6)	.44(.23)	2.1(.39)	5(.9)	6.1(1.7)	.42(.26)	2.1(.58)	*Ns*
Unrelated	4.8(.97)	5.5(1.3)	.34(.32)	1.9(.36)	4.9(.89)	5.8(1.6)	.42(.31)	1.9(.37)	*Ns*
Experiment 2									
Identity	4.9(.71)	7.3(1.6)	.37(.27)	2.5(.50)	4.9(.71)	7.3(1.6)	.37(.27)	2.5(.50)	-
Phon./Orth.	5(.87)	6(1.8)	.45(.33)	2(.56)	4.8(.64)	6.3(1.8)	.36(.24)	2(.51)	*Ns*
Semantic	5.1(.67)	6.3(1.7)	.43(.26)	2.2(.43)	5.1(.56)	6.5(1.8)	.47(.26)	2.2(.57)	*Ns*
Unrelated	4.8(.84)	6.4(1.4)	.37(.28)	2.1(.55)	4.7(.82)	5.9(1.7)	.35(.31)	2.2(.45)	*Ns*

Note: [a] Zipf, *ns*=non-significant; [b]Contextual Diversity (CD, the number of different contexts a word appears in); [c]Orthographic Levenshtein Distance (OLD20, a measure of orthographic neighbour based on OLD20)

The task was adapted from that used by Betjemann and Keenan (2008) and was programmed using the DMDX software (Forster & Forster, 2003). According to Betjemann and Keenan (2008) 'active priming' (meaning that the child must make a lexical decision both to the prime and target) ascertains that the child surely has identified the prime. If this procedure was not used, the researcher could not ensure that the child with literacy difficulties had enough time to identify the item. A schematic representation of the procedure is provided in Figure 1. On each trial, participants were first presented, for 500ms, with a central fixation point. The prime then appeared and remained on the screen until the child pressed the left or right shift key on the computer keyboard to indicate that the item was a word or a nonword, respectively. Next, a row of hash marks, of the same length as the prime, appeared for 500ms. When the hash marks disappeared, the target was presented until the child made a decision regarding word or nonword status. Finally, a blank screen was presented for 1000ms.

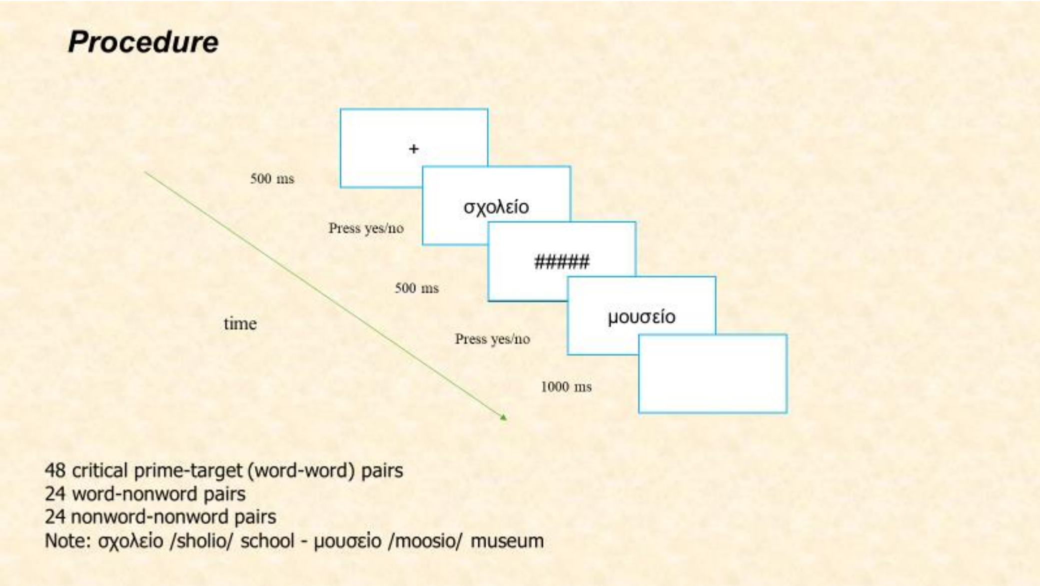


Figure 1 A schematic representation of the semantic priming task

Arithmetic skill

In order to ascertain whether any improvements as a result of the remediation programme may be selective, we assessed TN in the arithmetic subtest of WISC-III (Georgas, Paraskevopoulos, Bezevengis, & Giannitsas, 1997). The assessment was administered prior to the start of intervention (see for relevant arguments Broom and Doctor, 1995).

Results

Pre-intervention findings (Pre-Test 1)

In this section, we present the results from the pre-intervention assessments of literacy, and VAS and visual lexical decision outlined above.

Reading assessments

Standardized measures

A summary of the scores for TN and the comparison children in the standardized reading Test Alpha for the three measures, reading comprehension, reading rate and reading accuracy, is given in Table 2. Reading accuracy was not impaired for word (p=.36) and nonword reading (p=.32), however, TN showed a deficit relative to the performance of the comparison group in word and nonword reading latency: word latencies $t(11)$=2.1, p=.027, r=.53 and non-word latencies $t(8)$=2.2, p=.028, r=.57and in text reading rate, $t(17)$=2.2, p=.019, r=.47.

Table 2 Pre-intervention results in the standardised reading and spelling assessments for TN and the comparison group children (scores in bold are raw scores, standard deviations are in parentheses)

	TN	Comparison group mean	*t*-test
Reading comprehension (SS)[a]	112	112 (6.6)	*ns*
Text reading rate (SS)[a]	86*	109.9 (10.3)	*t*(17)=2.2, *p*=.019
Reading accuracy (SS)[a]	104	108.2 (14.2)	*Ns*
Single-word spelling (SS)[b]	82	101 (11.6)	*Ns*
Spelling based on written text (SS)[c]	82**	109.7 (6.9)	*t*(9)=3.8, *p*=.003
Single-word reading latency (ms)[a]	1628.5*	1118 (min.919, max.1582) (226)	*t*(11)=2.1, *p*=.027
Single-word reading accuracy (max correct = 53)[a]	49	47(min. 35, max. 53) (5.3)	*Ns*
Nonword reading latency (ms)[a]	1636*	1159.7 (min. 874, max.1376) (197.3)	*t*(8)=2.2, *p*=.028
Nonword reading accuracy (max correct = 24)[a]	19	17.2 (min. 11, max.22) (3.7)	*Ns*

Note: [a]= Reading Test Alpha (Panteliadou and Antoniou, 2007) [b]= Single word spelling to dictation test (Mouzaki et al. 2007) [c]= Diagnostic test of difficulties in written production (Porpodas et al. 2007), SS= standard scores (mean=100), * = *p*<.05, **= *p*<.01, *ns*=non-significant

Reading words and nonwords from Loizidou-Ieridou et al. (2010)

TN's accuracy in reading words and nonwords from Loizidou-Ieridou et al. (2009) was high (for non-word reading it was significantly higher than the comparison group mean, *t*(12)=2.1, *p*=.03, *r*=.53), but her reading latencies were extremely slow relative to those of the comparison children: word latencies *t*(10)=23.9, *p*<.001, *r*=.99, non-word latencies *t*(11)=4.1, *p*<.001, *r*=.78, confirming the results from the Test Alpha. TN's scores are presented in Table 3.

Spelling assessments

Standardized measure

Table 2 provides a summary of the results for the standardised spelling assessment. When TN's score in the single word spelling test (Mouzaki et al., 2007) was compared to the mean for the comparison group the difference was not significant, *t*(10)=1.5, *p*=.076, *r*=.42. However, her performance in text spelling (Porpodas etal., 2007) was significantly below that of the comparison children, *t*(9)=3.8, *p*=.003, *r*=.78.

Spelling regular and irregular words, and nonwords (Loizidou-Ieridou et al. 2010)

In Table 3 scores for spelling the Loizidou-Ieridou et al. items are presented. TN's score was not significantly different from that of the comparison group for any of the letter string types. This indicates that the beneficial result of the spelling intervention was still apparent Terzopoulos et al., 2018).

Table 3 Pre-intervention accuracy scores in reading and spelling words and nonwords from Loizidou-Ieridou et al. (2010) for TN and comparison children (standard deviations are in parentheses)

	TN	Comparison group mean	*t*-test
Word reading latencies (ms)	2995***	850 (min.672, max. 963.5) (85.6)	*t*(10)=23.9, *p*<.001
Word reading accuracy (max correct=40)	38	37.9 (min. 33, max. 40) (2.2)	*ns*
Nonword reading latencies (ms)	1689***	1084 (min. 917, max. 1318) (139.6)	*t*(11)=4.1, *p*<.001
Nonword reading accuracy (max correct=40)	40*	35 (min. 31, max.39) (2.3)	*t*(12)=2.1, *p*=.03
Irregular word spelling (max correct=20)	10	11.56 (min.8, max.15) (2.4)	*ns*
Regular word spelling (max correct=20)	19	16.64 (min.13, max.20) (2)	*ns*
Nonword spelling (max correct=40)	40	36.3 (min.30, max.39) (2.7)	*ns*

Note:*** = *p*<.001, * = *p*<.05, *ns*=non-significant

Non-reading assessments

Visual attention span tasks

Results of modified t-tests indicated a deficit for both measures of global report - correct report of all letters in the array (number of arrays), and total letters correct, *t*(13)=2.1, *p*=.03, *r*=.50 and *t*(13)=4.3, *p*<.001, *r*=.79, respectively. TN was significantly more accurate than comparison children in partial report, *t*(14)=2.1, *p*=.029, *r*=.48. Her performance in sequential report (arrays and total letters *t*(7)=1.4, *p*=.1, *r*=.54 and *t*(7)=1.1, *p*=.13, *r*=.38, respectively) and single letter report did not differ significantly from that of the comparison group (accuracy and latency *t*(6)=0.6, *p*=.28, *r*=.23 and *t*(6)=1.5, *p*=.09, *r*=.52, respectively).

The results for TN in the sequential report task, in combination with age equivalent performance in digit span (Niolaki et al., 2014), indicate that she did not have a memory impairment. Similarly, TN's unimpaired performance in the single letter report task and in rapid automatized naming (see results for rapid naming of digits and letters in Niolaki et al. (2014)) would seem to exclude visual processing difficulties for letters. Table 4 provides a summary of correct scores in the four tasks for TN and the comparison children.

Table 4 Pre-intervention results for TN and the comparison group in the letter report tasks (standard deviations are in parentheses)

	TN	Comparison group mean	*t*-test
Global report arrays (max. correct = 20)	0*	8.2 (min. 3, max13) (3.8)	$t(13)=2.1$, $p=.03$, $r=.50$
Global report letters (max. correct = 100)	61***	84.5 (min.75, max. 91) (5.2)	$t(13)=4.3$, $p<.001$, $r=.79$
Partial report (max. correct = 45)	42*	36.2 (min. 32, max. 41) (2.7)	$t(14)=2.1$, $p=.029$, $r=.48$
Sequential report arrays (max. correct = 20)	3	5.3 (min.2, max.8) (1.8)	*ns*
Sequential report letters (max. correct= 100)	69	78.7 (min.69, max.86) (6.3)	*ns*
Letter identification (accuracy)	45	43.3 (min.38, max.45) (2.6)	*ns*
Letter identification (ms)	587	710 (min.622, max. 816) (73.2)	*ns*

Note: * = $p<.05$, *** = $p<.001$, *ns*=non-significant

Lexical Decision with 'active priming'

TN took part in Experiment 1 and then Experiment 2 was conducted two weeks later. The results for TN and the comparison children are presented in Table 5. The comparison group for Experiment 1 consisted of 19 children and for Experiment 2 22 children, as some children were absent at the time of testing. Please see earlier comment about the selection of the comparison groups. For Experiment 1 the comparison group had mean age 10 years 1 month (*SD*=.94) and non-verbal ability (Matrix Analogies test, Naglieri, 1985) score 20.7 (*SD*=5.1). For Experiment 2 the comparison group mean age was 10 years 1 month (*SD*=.93) and mean non-verbal ability score was 20.5 (*SD*=5.1). No significant differences were found in age and non-verbal ability between TN and the comparison groups. For nonverbal ability TN's score was higher than the mean score of both comparison groups, group 1 $t_{n\text{-}vability}(19)=.63$, $p=.26$, $r=.14$ and group 2 $t_{n\text{-}vability}(22)=.67$, $p=.25$, $r=.14$, respectively.

We first present analyses of the results for reaction times and then for error rates. In calculating response times, only correct responses were used. Overall, in both experiments, the identity condition was the fastest for both TN and the comparison group. The unrelated condition was the slowest for the comparison children, and the related conditions fell between the unrelated and the identity match condition. However, this pattern was not found for TN who did not show facilitation from semantic priming in comparison to the unrelated condition. Wilcoxon signed-rank test was used to investigate whether there was a significant difference in latencies in the unrelated and semantically related conditions for TN and the comparison group. For TN, in Experiment 1 the difference was significant, indicating an inhibitory effect (of 1600ms-1233ms=367ms) for the semantically associated condition ($Z=2.1$, $p=.036$). However, in Experiment 2 the difference was not significant, although TN was slower in the semantically related condition (2004ms-1940ms=60ms). In both experiments, the difference was significant for the comparison group, indicating facilitation for semantically related items (Experiment 1: $Z=3.02$, $p=.003$ and Experiment 2: $Z=3.23$, $p<.001$).

Table 5 Pre-intervention lexical decision reaction times (RTs) and error rates (percentages) for TN and the comparison group in Experiment 1 and 2 (standard deviations are in parentheses)

	Experiment 1			*Experiment 2*		
Condition	TN	Comparison group mean	*t*-test	TN	Comparison group mean	*t*-test
Identity RT	996	864.8 (min. 534-max.1255) (254.7)	*Ns*	1194	850.2 (min.474-max. 1603) (287.1)	*ns*
P/O RT	1142	937.5 (min.529-max1401) (287.8)	*Ns*	1415	981.5 (min.524, max. 1807) (351)	*ns*
Semantic RT	1600*	892.3 (min. 524-max. 1394) (312.3)	$t(19)= 2.2$, $p=.02$	2004***	919.6 (min. 532, max. 1702) (324)	$t(22)=3.3$, $p< .001$
Unrelated RT	1233	953.1 (min.569-max. 1408) (314.8)	*Ns*	1940**	1018.9 (min. 547, max. 1889) (354.4)	$t(22)=2.5$, $p=.009$
Error in Identity Condition	16.7*	6.4 (min.0-max.20.8) (5.4)	$t(19)=1.8$, $p=.039$	8.3	5.7 (min. 0, max.9.1) (4)	*ns*
Error in P/O Condition	25**	8.8 (min.0-max.20.8) (6.3)	$t(19)=2.5$, $p<.01$	16***	3.8 (min. 0, max.16.7) (5.6)	$t(22)=2.1$, $p<.0001$
Error in Semantic Condition	25***	8.5 (min.4.2-max.20.8) (4.8)	$t(19)=3.3$, $p<.001$	25***	2.7 (min. 0, max.9.1) (4.1)	$t(22)=5.3$, $p<.0001$
Error in Unrelated Condition	25***	4.1 (min.0-max.16.7) (5.5)	$t(19)=3.7$, $p<.001$	25*	8.1 (min. 0, max.25) (8.6)	$t(22)=1.9$, $p=.03$

Note: * = $p<.05$, ** = $p<.01$, *** = $p<.001$, , P/O= phonological/orthographic *ns*=non-significant

We also used Monte Carlo simulations and revised tests for dissociations (Crawford & Garthwaite, 2005) to look at comparisons of the critical conditions for TN and the comparison children. For Experiment 1 there was a significant difference for TN and the comparison group when we looked at RTs for the semantic vs. unrelated conditions, $t(18)=3.6$, p(one-tailed)=.001 Z-DCC = 3.98 (95% CI = 2.53 to 5.62). A significant difference was not observed for TN and the comparison children, for the phonological/orthographic vs. unrelated conditions, $t(18)=0.6$, p(one-tailed)=.28, Z-DCC=-0.63 (95% CI=-1.25 to -0.02). For Experiment 2, findings were partially replicated. In the semantic vs. unrelated and phonological/orthographic vs. unrelated conditions a significant difference was found for both, $t(21)=1.9$, p(one-tailed)= 029, Z-DCC = 2.15 (95% CI = 0.72 to 3.65) and $t(21)=4.4$, p(one-tailed)= .00012 Z-DCC = -4.83 (95% CI = -6.65 to -3.22), respectively. Finally, modified t-tests revealed a significant difference in reaction times between TN and the comparison group for the semantic condition in both experiments ($t(19)=2.2$, $p=.02$, Z-DCC=2.26 (95% CI=1.39 to 3.12) and $t(22)=3.3$, $p<.001$, Z-DCC= 3.35 (95% CI =2.25 to 4.42) respectively) and for the unrelated condition in Experiment 2 only ($t(22)=2.5$, $p=.009$, Z-DCC=2.59 (95% CI=1.71 to 3.47)).

Analysis of error rates for the comparison children, using Wilcoxon Signed Ranks Test, revealed that the level was significantly less in the semantically associated condition than in the unrelated condition in both experiments (Experiment 1: $Z=2.37$, $p=.018$ and Experiment 2: $Z=2.39$, $p=.017$). McNemar tests were used to analyse error rates for TN. The analyses did not reveal a difference in accuracy for the semantically associated condition and unrelated condition (Experiments 1 and 2 both $p=.1$). Comparison of error rates for TN and the comparison group using modified t-tests revealed a significant difference for both experiments and for all conditions, except for the Identity condition in Experiment 2 (Experiment 1: Identity condition, $t(19)=1.8$, $p=.039$, Z-DCC=1.907 (95% CI=1.134 to 2.662), Phon./Orth. condition, $t(19)=2.5$, $p<.01$, Z-DCC= 2.571 (95% CI=1.617 to 3.510), Semantic condition $t(19)=3.3$, $p<.001$, Z-DCC=3.438 (95% CI= 2.230 to 4.631), Unrelated condition $t(19)=3.7$, $p<.001$, Z-DCC=3.800 (95% CI=2.483 to 5.103) and Experiment 2: Identity condition, $t(22)=0.63$, $p=.265$, Z-DCC=0.650 (95% CI= 0.182 to 1.105), Phon./Orth. Condition $t(22)=2.1$, $p<.0001$, Z-DCC=2.179 (95% CI=1.394 to 2.947), Semantic condition $t(22)=5.3$, $p<.0001$, Z-DCC=5.479 (95% CI=3.778 to 7.171) and Unrelated condition $t(22)=1.9$, $p=.03$, Z-DCC=1.965 (95% CI=1.234 to 2.680).

Arithmetic skill

In the arithmetic subtest of WISC-III (Georgas et al. 1997) TN gained a standardised score of 109.

Summary of Pre-intervention findings

Pre-intervention testing revealed that TN's reading performance was characterized by slow word and non-word reading, and poor irregular word spelling. Neuropsychological assessment revealed good phonological skills and no impairment of rapid automatized naming. She was administered tasks of VAS and showed very poor global report but preserved partial report performance. The selective deficit of global report was observed despite good single letter and good sequential multi-letter processing. A VAS deficit is considered to be associated with whole word recognition processes (c.f Niolaki & Masterson, 2013; Niolaki et al. 2014; Bogon, Finke, & Stenneken, 2014; Bosse et al. 2007; Bosse and Valdois, 2009; Lallier et al. 2014; Valdois et al. 2004). Location of TN's deficit in lexical processes was also indicated by the lack of semantic priming in the lexical decision experiments, evident in analyses comparing TN's performance to that of the comparison group and also comparing TN's results in the semantic versus unrelated conditions.

Intervention

TN's parents expressed concern about her slow reading and consequent disengagement from reading-related activities. Since our assessments had revealed that TN had a VAS deficit (in the global report condition), we decided to conduct the intervention targeting global letter report, since this had resulted in improvement in reading speed in the study reported with RF (Niolaki & Masterson, 2013). RF had a similar profile to TN in terms of slow reading and a selective deficit of global letter report. We also aimed to examine whether following the intervention there might be evidence for semantic priming. We, therefore, re-assessed TN in the lexical decision tasks at the end of the intervention.

The intervention involved practice at reporting arrays of increasing length. The procedure was the same as the one used with RF in Niolaki and Masterson (2013) study. TN practised the first set of 195 two-to-four-letter arrays, then the second, consisting of 195 three- to five-letter arrays, and finally a set of 104 four- and five-letter arrays. The arrays were presented on the computer as in the assessment of global letter report described in the *Assessments* section. Practice sessions lasted approximately 10 minutes, and the intervention took place over nine weeks. TN spent two weeks on each set, during which time she practised almost every day depending on her school assignments and after-school activities. During each practice session for the first two sets, there were rest periods after 65 arrays. For the third set, there was just one rest period (after 52 arrays). Practice took place always under the supervision of an adult (TN's mother or father).

The aim was for TN to practice the three sets until she could reach a comparable level of performance to RF. However, the threshold she reached was lower that RF's, as outlined below. RF practised Set 1 for six days, Set 2 for ten days and Set 3 for eight days, at which point he reached the target level of performance of 50%+ correct. TN on the other hand, for Set 1 and Set 2 reached the target accuracy of 85%+ after 11 days for each set, but for Set 3 after eight days she was only able to reach 25%+ accuracy. Although the amount of practice was similar, the level of success was not comparable to that achieved by RF. Table 6 provides scores obtained by TN for each array length at the end of practice with each set.

Table 6 Number of practice sessions per set and score (percent correct) achieved by TN for strings of different lengths

	Total sessions	2 Letters	3 Letters	4 Letters	5 Letters
Set 1	*11*	100	100	80	-
Set 2	*11*	-	100	84.6	22.2
Set 3	*8*	-	-	87.5	26.1

Post-intervention findings

In this section, we present the results from the post-intervention assessments (literacy tests, and VAS and lexical decision tasks). Data for the post-intervention assessments were collected by a tester blinded to the investigation's aims.

Global and partial letter report

The post-intervention assessment was carried out immediately at the end of the intervention (Post-test 1) and four months later (Post-test 2). The results are presented in Table 7. At pre-intervention assessment, TN's performance in global report had been significantly worse than that of the comparison group. However, at Post-test 1 and Post-test 2 TN's score was not significantly different from that of the comparison group. Comparing TN's Pre-test 2 score[3] and Post-test 1 score, we found that there was a significant increase for both arrays correct, $\chi^2(1)=7.11$,

p=.007, and total letters correct, $\chi^2(1)$=14.1, p=.0002. Between Post-test 1 and Post-test 2 there was no significant difference in either measure, indicating that improvement was maintained.

Table 7 Pre- and Post-intervention accuracy scores in the global letter report tasks for TN and the comparison group (standard deviations are in parentheses)

	Pre-intervention				Post-intervention		Comparison group Mean
	Pre-test 1	*t*-test	*Pre-test 2*	*t*-test	*Post –test1*	*Post-test 2*	
Global report arrays (max. = 20)	0*[1]	$t(13)$=2.1, p=.03	0*	$t(13)$=2.1, p=.03	9	5	8.2 (min. 3, max13) (3.8)
Global report letters (max. = 100)	61***	$t(13)$=4.3, p<.001	62***	$t(13)$=4.3, p<.001	79	78	84.5 (min.75, max. 91) (5.2)

Note: *=p<.05, ***=p<.001, [1]Comparisons reported are between TN and the comparison group's performance on the tasks

Reading and spelling assessments

Standardized measures

Table 8 gives scores for TN for the assessments of reading and spelling at Pre-test 1 and 2, and Post-test 1 and 2, as well as the mean for the comparison group (N=35) who were assessed when TN was 10;00.

At the pre-test assessments TN's score in text reading rate differed significantly from that of the comparison group, however at both post-test assessments, which involved reading the same text, her performance did not differ significantly from that of the comparison group (Post-test 1: t (11)=1.5, p=.073, r=.41 and Post-test 2 t (11)=0.9, p=.189, r=.26). However, one should acknowledge that at Post-test 1 the difference approached significance. Further analyses of the results for reading rate indicated a significant increase for TN between Pre-test 2 and Post-test 1, $\chi^2(1)$= 12.1, p=.0005, and between Post-test 1 and Post-test 2: $\chi^2(1)$= 16.05, p<.0001.

For the standardised spelling tests, we were only able to conduct assessments at Post-test 1. In the Mouzaki et al. test no significant differences were detected between TN's score and that of the comparison group at either Pre-test 1 and 2 or Post-test 1. For spelling based on written text, TN's score was significantly below that of the comparison group at both pre-tests (Pre-test 1&2: t (9)=3.8, p=.003, r=.78) and Post-test 1 (t(9)=3.5, p=.003, r=.75).

Latencies for reading words and nonwords

Word reading latencies

For word reading, the difference in latencies for Test Alpha (Panteliadou & Antoniou, 2007) and the Loizidou-Ieridou et al. (2010) stimuli was not significant at Post-test 2 in comparison to the comparison group's performance (see Table 8). However, for the Loizidou-Ieridou et al. test the difference in word latencies was significant at Post-test 1, t(11)=3.4, p=.003, r=.76. We used Wilcoxon signed-rank tests to investigate whether there was a significant difference in latencies between Pre-test 1 and Pre-test 2 initially and then between Pre-test 2 and Post-test 1 and between Post-test 1 and Post-test 2 for Test Alpha and the Loizidou-Ieridou et al. items. For the Test Alpha, between Pre-test 1 and 2 the difference in TN's latencies was not significant Z=1.7, p=.80. However, between Pre-test 2 and Post-test 1 and between Post-test 1 and Post-test 2 significant differences were detected, indicating that TN's latencies became significantly shorter, Z=2.1, p=.04 and Z=4.7, p<.001, respectively. Similar, results were obtained for the Loizidou-Ieridou et al. items. In the comparison between Pre-test 1 and Pre-test 2 the difference in TN's latencies was not significant Z=.83, p=.40. However, between Pre-test 2 and Post-test 1 and between Post-test 1 and Post-test 2 significant differences were detected, indicating that TN's latencies became significantly shorter, Z=3.32, p<.001 and Z=4.33, p<.001, respectively.

Non-word reading latencies

For non-word reading latencies, the difference for TN and the comparison group in both Test Alpha (Panteliadou & Antoniou, 2007) and the Loizidou-Ieridou et al. (2010) stimuli was not significant at Post-test 1 and Post-test 2 (see Table 8). We also used the same assessments as for word reading latencies to investigate whether there was a difference between Pre-test 1 and Pre-test 2 and between Pre-test 2 and Post-test 1 and between Post-test 1 and Post-test 2. For Test Alpha nonwords, between Pre-test 1 and 2 the difference in TN's latencies was not significant Z=.34, p=.73, however, between Pre-test 2 and Post-test 1 a significant difference was found, indicating that latencies became significantly shorter, Z=3.5, p<.001. Finally, between Post-test 1 and Post-test 2 the difference in non-word reading latencies was not significant, Z=1.1, p=.27. Results for the Loizidou-Ieridou et al. non-words revealed that between Pre-test 1 and Pre-test 2 and Pre-test 2 and Post-test 1 the difference in TN's latencies was not significant Z=.47, p=.64 and Z=.03, p=.97. However, between Post-test 1 and Post-test 2 a significant difference was detected, indicating that TN's latencies became shorter, Z=4.8, p<.001.

Spelling regular words, irregular words and nonwords (Loizidou-Ieridou et al., 2010)

For irregular word, regular word and nonword spelling, no significant differences were detected between the scores of TN and those of the comparison group.

Lexical decision

We reassessed TN with the two lexical decision tasks at Post-test 1 and 2. A summary of the reaction times and percentage error rate is given in Table 9.

Experiment 1

At pre-test, there had been no indication of an effect of semantic priming for TN (comparison of latencies in the semantically related and unrelated priming conditions revealed -367 msecs inhibition). At post-test 1 there was a facilitation effect of 53 msecs and at Post-test 2 the facilitation was 24 msecs. Wilcoxon signed-rank test was used to investigate whether there was a significant difference in latencies in the unrelated and semantically related conditions. The difference was not significant at either post-test, $Z_{\text{Post-test 1}}$=.90, p=.36, $Z_{\text{Post-test 2}}$= 58, p=.55. Similarly, McNemar tests did not reveal a significant difference in errors between the semantically associated condition and unrelated condition at either time point (both ps=1).

Experiment 2

The same analyses were conducted with the results from Experiment 2. At pre-test, there was no indication of an effect of semantic priming (comparison of latencies in the related and unrelated priming conditions revealed -64 msecs inhibition). At post-test, there was a facilitation effect of 89 msecs at Post-test 1 and 230 msecs at Post-test 2. Wilcoxon signed-rank test was used to analyse the latencies in the unrelated and semantically related conditions. Results reealed that the difference was not significant Z=.53, p=.59 for Post-test 1 or Post-test 2, Z=1.4, p=.15. McNemar tests did not reveal a difference in errors between the semantically related and unrelated conditions at either time point (p=1 and p=.5, respectively).

In summary, although TN's latencies at post-test in both experiments showed that there was facilitation for the semantically associated condition in comparison to the unrelated condition the difference failed to reach significance (see also Figure 2). As can be seen from Table 9, TN's errors across conditions at Post-test 1 and 2 were comparable to those of the comparison group, and similar results were observed for latencies, at least at Post-test 2.

Table 8 Pre- and post-intervention performance in reading and spelling assessments for TN and the comparison group (numbers in bold are raw scores, standard deviations are in parentheses)

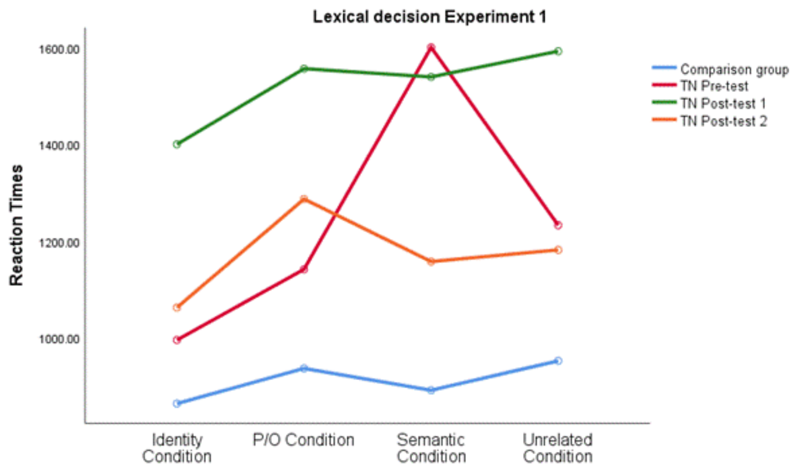
	TN								Comparison group mean
	Standardised measures								
	Pre-test 1	*t*-test	*Pre-test 2*	*t*-test	*Post-test 1*	*t*-test	*Post-test 2*	*t*-test	
Reading comprehension (SS)[a]	112	*ns*	112	*ns*	112	*ns*	112	*ns*	112 (6.6)
Text reading rate (SS)[a]	86*	$t(17)=2.2 p=.019$	87*	$t(17)=2.2 p=.023$	93	*ns*	100	*ns*	109.9 (10.3)
Reading accuracy (SS)[a]	104	*ns*	104	*ns*	104	*ns*	104	*ns*	108.2 (14.2)
Single word spelling (SS)[b]	82	*ns*	81	*ns*	81	*ns*	-[1]		101 (11.6)
Spelling based on written text (SS)[c]	82**	$t(9)=3.8, p=.003$	82***	$t(9)=3.8, p=.003$	84**	$t(9)=3.5, p=.004$	-		109.7 (6.9)
Word reading latency(ms)[a]	**1628.5***	$t(11)=2.1$ $p=.027$	**1695.5****	$t(11)=2.4 p=.017$	**1402**	*ns*	**1032.8**	*ns*	**1118 (min.919,max.1582) (226)**
Word reading accuracy (max correct=53)[a]	**49**	*ns*	**49**	*ns*	**49**	*ns*	**50**	*ns*	**47 (min. 35,max. 53) (5.3)**
Nonword reading latency (ms)[a]	**1636***	$t(8)=2.2, p=.028$	**1632***	$t(8)=2.2, p=.029$	**1528**	*ns*	**1084**	*ns*	**1159.7(min. 874, max.1376) (197.3)**
Nonword reading accuracy (max correct=24)[a]	**19**	*ns*	**19**	*ns*	**19**	*ns*	**19**	*ns*	**17.2 (min. 11, max.22) (3.7)**
	Experimental measures								
	Pre-test 1	*t*-test	*Pre-test 2*	*t*-test	*Post-test 1*	*t*-test	*Post-test 2*	*t*-test	
Word reading latency (ms)[d]	**2995*****	$t(10)=23, p<.001$	**2743*****	$t(10)=21$ $p<.001$	**1156****	$t(10)=3.4$ $p<.003$	**977**	*ns*	**850 (min.672, max. 963.5) (85.6)**
Word reading accuracy (max correct=40)[d]	**38**	*ns*	**38**	*ns*	**39**	*ns*	**39**	*ns*	**37.9 (min. 33, max. 40) (2.2)**
Nonword reading latency (ms)[d]	**1689*****	$t(11)=4.1$ $p<.001$	**1629*****	$t(11)=3.7$ $p<.001$	**1185**	*ns*	**1007**	*ns*	**1084 (min. 917, max. 1318) (139.6)**
Nonword reading accuracy (max correct=40)[d]	**40***	$t(12)=2.1$ $p=.03$	**40***	$t(12)=2.1$ $p=.03$	**40***	$t(12)=2.1, p=.03$	**40***	$t(12)=2.1, p=.03$	**35(min. 31, max.39) (2.3)**
Irregular word spelling (max correct=20)[d]	**10**	*ns*	**10**	*ns*	**9**		**-**		**11.56(min.8. max.15) (2.4)**
Regular word spelling (max correct=20)[d]	**19**	*ns*	**19**	*ns*	**20**		**-**		**16.64(min.13, max.20) (2)**
Nonword spelling (max correct=40)[d]	**40**	*ns*	**40**	*ns*	**40**		**-**		**36.3 (min.30, max.39) (2.7)**

Note: [a]= Reading Test Alpha (Panteliadou and Antoniou, 2007) [b]= Single word spelling to dictation test (Mouzaki et al. 2007) [c]= Diagnostic test of difficulties in written production (Porpodas et al., 2007), [d]= Reading of words and non-words (Loizidou-Ieridou et al., 2009), SS= standard scores, [1] Data were not collected at Post-test 2. * = $p<.05$, **= $p<.01$, *** = $p<.001$

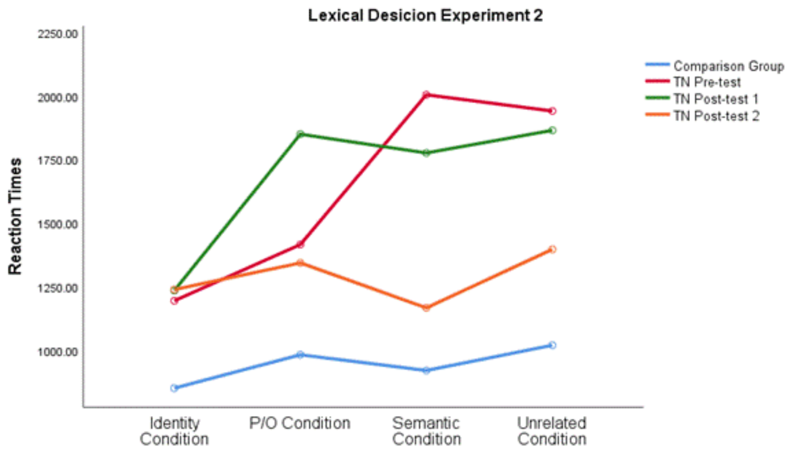
Table 9 Mean lexical decision latencies and error rates (percentages) for TN at pre- and post-intervention, and results for the comparison group (standard deviations are in parenthesis)

	Experiment 1						*Experiment 2*					
Condition			TN			Comparison group mean				TN		Comparison group mean
	Pre-test	*t*-test	Post-test 1	*t*-test	Post-test 2		Pre-test	*t*-test	Post-test 1	*t*-test	Post-test 2	
Identity latency	996	*ns*	1400*	$t(19)=2$, $p=.03$	1063	864.8 (min. 534-max.1255) (254.7)	1194	*ns*	1234	*ns*	1238	850.2 (min. 474, max. 1603) (287.1)
P/O latency	1142	*ns*	1556*	$t(19)=2.1$, $p=.03$	1287	937.5(min.529-max1401) (287.8)	1415	*ns*	1849*	$t(22)=2.4$, $p=.01$	1343	981.5 (min. 524, max. 1807) (351)
Semantic latency	1600**	$t(19)=2.2$, $p=.02$	1539*	$t(19)=2$, $p=.02$	1158	892.3(min. 524-max. 1394) (312.3)	2004***	$t(22)=3.3$, $p<.001$	1775**	$t(22)=2.5$, $p=.009$	1166	919.6 (min. 532, max. 1702) (324)
Unrelated latency	1233	*ns*	1592*	$t(19)=1.9$, $p=.03$	1182	953.1(min.569-max. 1408) (314.8)	1940**	$t(22)=2.5$, $p=.009$	1864*	$t(22)=2.3$, $p=.01$	1396	1018.9 (min. 547, max. 1889) (354.4)
Error in Identity Condition	16.7*	$t(19)=1.8$, $p=.039$	0	*ns*	0	6.4(min.0-max.20.8) (5.4)	8.3	*ns*	8.3	*ns*	0	5.7 (min. 0, max. 9.1) (4)
Error in P/O Condition	25**	$t(19)=2.5$, $p<.01$	8.3	*ns*	4.2	8.8 (min.0-max.20.8) (6.3)	16***	$t(22)=2.1$, $p<.0001$	6.7	*ns*	8.3	8.3 (min. 0, max. 16.7) (5.6)
Error in Semantic Condition	25***	$t(19)=3.3$, $p<.001$	8.3	*ns*	8.3	8.5 (min.4.2-max.20.8) (4.8)	25***	$t(22)=5.3$, $p<.0001$	8.3	*ns*	0	2.7 (min. 0, max. 9.1) (4.1)
Error in Unrelated Condition	25***	$t(19)=3.7$, $p<.001$	0	*ns*	0	4.1 (min.0-max.16.7) (5.5)	25*	$t(22)=1.9$, $p=.03$	6.7	*ns*	0	8.1 (min. 0, max. 25) (8.6)

Note: P/O= phonological/orthographic



Note: P/O= phonological/orthographic



Note: P/O= phonological/orthographic

Figure 2 Lexical Decision performance for TN and comparison groups at Pre-test and Post-test assessments

Specificity of the effect of intervention

Finally, in order to examine whether the effects of intervention might be specific to literacy processes, the arithmetic subtest of WISC-III (Georgas et al. 1997) was re-administered. At the pre-intervention assessment, TN's standardised score was 109, and this did not change at the post-intervention assessment.

Summary of post-intervention findings

The post-intervention assessment indicated a significant improvement in global letter and array report for letters presented simultaneously. In addition, significant improvement in reading latencies was observed for both real words and non-words, as well as improvement in text reading rate. Finally, semantic facilitation was observed in the priming task following intervention, although, the changes did not reach significance.

General discussion

The study involved an intervention conducted with a ten-year-old Greek-speaking child who had the characteristics of surface dyslexia, which according to Douklias et al. (2009) is slow reading of real words and nonwords whereas accuracy of single word reading is relatively unimpaired. TN was a laborious reader. There was no evidence of a deficit in phonological ability, rapid automatized naming or visual memory. According to the current results the only difficulty detected was in VAS (in the global report task). However, it is surprising to observe TN's superior performance on the partial report task. One possible explanation is that letter position coding is necessary in the partial but not the global report task. According to Grainger and Ziegler (2011) it has been suggested that exact letter position coding could in fact be related to sub-lexical processing and fine grain coding and less useful in lexical processing[2].

The first intervention conducted with TN targeted spelling of irregular words (Terzopoulos et al., 2018). At the end of this intervention TN's spelling of irregular words was observed to have improved significantly, as well as her reading accuracy. However, no improvement was observed in VAS tasks, or in reading latencies. Indeed, latencies for words and nonwords were observed to increase at both immediate and delayed post-testing. These results indicate that TN had a primary lexical difficulty and she relied on the laborious sub-lexical route which had a detrimental effect on reading latencies.

In the present study, TN took part in an intervention targeting VAS. If VAS is linked to lexical processes, then training could result in a change from reliance on sub-lexical to lexical reading processes. Indeed, post-test results indicated a significant improvement in TN's reading latencies for words and non-words and in text reading rate, which could suggest that TN now uses lexical processes more effectively. The semantic priming effects observed at both post intervention assessments (although not reaching statistical significance) could also indicate a shift to reliance on lexical processes (but see below for an alternative possible explanation).

The findings for VAS and single word reading are in line with those found for RF (Niolaki & Masterson, 2013) who received the same intervention as TN. RF showed significant improvement in VAS as well as reduced word reading latencies. However, RF did not show improvement in text reading rate, as we found for TN. This difference in the results observed between RF and TN for text reading rate could be because TN (aged 10;00) was younger than RF (aged 12;08), and so literacy processes may be more amenable to change. Our findings are comparable to those of Valdois et al. (2014) who found improvement in text reading rate for French (but not Spanish) in the bilingual participant MP, following an intervention targeting visual search.

The accumulated findings indicate that VAS is associated with reading speed. Lobier, Dubois and Valdois (2013) reported that reading speed is related to visual processing speed and this relationship is mediated by VAS processing, whereas reading speed is not related to visual short-term memory. In line with this, assessment of visual memory conducted with TN did not indicate a deficit. The accumulated findings also suggest that there is a subsample of children with atypical reading who have a selective deficit in VAS processing (Niolaki & Masterson, 2013; Lobier et al. 2013; Peyrin et al. 2012; Valdois et al. 2003; Valdois et al. 2004).

In the current study, we also aimed to look for evidence of qualitative change in TN's reading processes, using a lexical decision task with semantic primes. Prior to the intervention TN did not show any evidence of semantic priming. At the end of the intervention she showed signs of semantic priming, but the effect was not significant. However, her accuracy and response times in the lexical decision tasks improved and at post-test were comparable to those of comparison children. Therefore, changes in performance were observed despite the absence of significant semantic facilitation effects for TN (see Figure 2 for a visual depiction of the improvement). It is evident that the semantic inhibition observed at pre-test was not observed at post-test. These results could indicate that following the intervention TN was using lexical processes more effectively. This result should be attributed to the VAS intervention as this was the sole support TN received at school according to her teachers. Alternatively, however, the semantic facilitation effects observed post-intervention could be due to the VAS intervention leading to larger sublexical strings being used than previously, allowing for more efficient processing of prime and target. The current findings do not allow us to adjudicate between the alternative possible explanations.

It is notable that most improvements in TN's reading speed occurred at Post-test 2. Similar findings were reported for RF by Niolaki and Masterson (2013), as they observed improvement in literacy assessments sometime after improvement in VAS was found. A possible explanation could be that as VAS is a distal cause of literacy difficulties it takes time to generalize to reading skill.

An additional issue that should be mentioned is the association between a VAS deficit and orthographic transparency. In the Greek orthography there have been several reports of children with a profound VAS deficit and characteristics of surface dyslexia. The improvement in lexical processes found for TN after the VAS intervention could be associated with more effective coarse-grain coding. According to Grainger and Ziegler's (2011) multiple-route model, coarse-grain coding is necessary for the mapping between orthography to semantics and it optimizes the selection of letter combinations which are informative of the word's identity.

As with every piece of research limitations exist. One should acknowledge that the comparison group children did not all come from the same classroom that TN attended and also their mean age when data were collected was 9 years and 9 months, some of them were slightly younger than TN but the difference was not statistically significant. Another limitation of the current study is the fact that for the VAS tasks we only used measures of accuracy and not reaction times. Recording of the latter could have provided further evidence that improvement occurred. This is something that future studies might wish to address.

Notwithstanding this, our findings contribute to the literature suggesting different effects for different types of intervention. At the end of the word-specific intervention targeting spelling (Terzopoulos et al., 2018) TN's spelling and reading accuracy were found to improve, but not reading latencies, which were found, on the contrary, to increase. The word specific training may have led TN to be more attentive to spellings of words and this could have had a detrimental impact on reading latencies. Targeting VAS in the present study appeared to bring about improvement in reading speed, and there was some evidence for qualitative change in reading processes as indicated by the results from the lexical decision experiments.

There are educational implications of this type of intervention, targeting a frequently deficient mechanism (i.e., reading speed) in transparent orthographies. The intervention we used is relatively easy to administer, and the positive effects are direct as in only a set number of weeks the children's reading speed improved (please also see RF's intervention results and results reported by Valdois et al., 2014). A VAS deficit seems to limit the number of letters correctly identified at each fixation, therefore an intervention targeting this specific process might be more or equally effective as other reading speed interventions, such as repeated reading (Therrien, 2004). It would be informative to compare the effectiveness of a VAS intervention and a reading speed intervention in Greek-speaking children with slow reading speed. However, as was noted in Niolaki and Masterson (2013) the VAS intervention might not be successful in improving spelling skill. In this case tailored interventions focusing on the child's difficulty and targeting accuracy and not speed may be effective (Terzopoulos et al., 2018).

To summarise, reading speed is important for reading comprehension and automaticity (Perfetti & Stafura, 2014). The intervention conducted in the present study resulted in improvement in TN's reading speed and engagement with reading for pleasure. We would like to conclude with an observation made by TN's parents who reported that after the completion of the intervention TN felt more confident with her reading and that she started enjoying reading to herself at bedtime, which she had avoided prior to the intervention.

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Endnotes

[1] Modified *t*-tests were used for statistical analyses since they control for Type I error in studies with small comparison groups and when we treat the case study as a sample of *N*=1 (Crawford & Howell, 1998; Crawford & Garthwaite, 2002). Where there was a significant difference between the score of TN and mean for the comparison group, this is indicated in the table of results (*p* values reported are one-tailed). We also report the effect size correlation denoted as $r_{Y□}$, or the Effect Size (Z-CC) for difference

between TN and controls, which estimates the percentage of the population that would obtain a lower score (together with a 95% confidence interval).
[2] r represents the effect size correlation, rYλ, using independent groups t-tests values and *df*
[3] TN's second baseline score was used in all pre- and post-test analyses of VAS performance as it was the most recent score and can carry over any test-retest effects

Appendix

Appendix A.1 Stimuli used in priming experiments

Experiment 1					
Prime			*Target*		
Identity match					
τετράποδο	tetrapotho	quadruped	τετράποδο	tetrapotho	quadruped
σώμα	soma	body	σώμα	soma	body
δραστηριότητα	thrastiriotita	activity	δραστηριότητα	thrastiriotita	activity
παιδί	pethi	child	Παιδί	pethi	child
αγάπες	ayapes	loves	Αγάπες	ayapes	loves
φράση	frasi	phrase	Φράση	frasi	phrase
ανακωχή	anakohi	truce	Ανακωχή	anakohi	truce
φούστα	foosta	skirt	Φούστα	foosta	skirt
ήχος	ixos	sound	Ήχος	ixos	sound
εικόνες	ikones	pictures	Εικόνες	ikones	pictures
δουλειά	thoolia	work	Δουλειά	thoolia	work
μοναστηριού	monastirioo	monastery	μοναστηριού	monastirioo	monastery
Phonological/orthographic association					
χρώμα	hroma	color	χρονιά	hronia	year
ζουμερό	zoomero	juicy	νούμερο	noomero	number
δίσκος	thiskos	disc	Δυσκολίες	diskolies	difficulties
φορά	for a	trend	Φόρα	fora	impetus
φοίνικα	finika	palm	Πίνακα	pinaka	table
φέτα	feta	slice	Φυτά	fita	plants
γατιά	yatja	cats	Ματιά	matja	look
δοκιμές	thokimes	tests	Τιμές	times	prices
παγωτά	payota	ice creams	Φαγητά	fayita	foods
αγαθά	ayatha	goods	Αγαπά	ayapa	loves
μερίδες	merithes	servings	εφημερίδες	efimerithes	newspapers
φύσα	fisa	blow	Ίσα	isa	equal
Semantic association					
σημερινός	simerinos	of today	τωρινός	torinos	current
φίλοι	fili	friends	παρέα	parea	company
κράτος	cratos	state	Χώρα	hora	country

λέξεις	lecsis	words	Προτάσεις	protasis	sentences
συγγραφέας	sigrafeas	author	Βιβλίο	vivlio	book
ήλιος	iljos	sun	Φως	fos	light
μήκος	mikos	length	Μέτρο	metro	measure
κεφάλι	kefali	head	Κρανίο	cranio	skull
τρίγωνο	triyono	triangle	ορθογώνιο	orthoyonio	rectangle
δυνατή	thinati	possible	Σκληρή	skliri	tough
κινητό	kinito	mobile	Μήνυμα	minima	message
πλοία	plia	ships	Καράβια	caravia	ships
Unrelated					
μπάλα	bala	ball	νερά	near	waters
στοιχεία	stixia	data	Κείμενο	kimeno	text
τσάντα	tsanta	bag	οικία	ikia	house
κλάματα	clamata	tears	Περιοχή	periohi	region
μέσα	mesa	within	Ώρα	ora	time
μορφή	morfi	form	Σειρά	sira	series
πίστη	pisti	faith	Γάλα	yala	milk
αυγά	avya	eggs	σκίουρος	skiooros	squirrel
τσάι	tsai	tea	Αρχαίοι	arhei	ancients
θρόνος	thronos	throne	Αγαθά	ayatha	goods
κόκκαλο	cocalo	bone	Κέρασμα	kerasma	treat
τρίχα	triha	hair	Αδύνατος	athinatos	weak

Experiment 2					
Prime			*Target*		
Identity match					
τεμπελιά	tempelia	laziness	Τεμπελιά	tempelia	laziness
τοποθεσία	topothesia	location	Τοποθεσία	topothesia	location
μπογιές	mpojes	paints	Μπογιές	mpojes	paints
γνωστή	jnosti	known	Γνωστή	jnosti	known
εκδήλωση	ekthilosi	manifestation	Εκδήλωση	ekthilosi	manifestation
ιδιότητες	ithiotites	properties	Ιδιότητες	ithiotites	properties
ιερέας	iereas	minister	Ιερέας	iereas	minister
εποχής	epoxis	seasonal	Εποχής	epoxis	seasonal
περιβάλλον	perivalon	environment	περιβάλλον	perivalon	environment
εκκλησία	eklisia	church	Εκκλησία	eklisia	church
λέξη	lecsi	word	Λέξη	lecsi	word
σχολείο	sxolio	school	Σχολείο	sxolio	school
Phonological/orthographic association					

αφήγηση	afigisi	narration	Οδήγηση	othigisi	driving
κέρματα	kermata	coins	Δέρματα	thermata	skins
κλαδιά	clathia	branches	Βράδια	vrathia	night
μας	mas	us	Μάχης	mahis	battlefield
άλλες	alles	other	Μπάλες	bales	balls
διάθεση	diathesi	disposal	Σύνθεση	sinthesi	composition
παράθυρα	parathira	windows	Παραμύθι	paramithi	fairy tale
παρέα	parea	company	Παρά	para	than
χέλι	heli	eel	Χέρι	heri	hand
αποτύπωμα	apotipoma	imprint	αποτέλεσμα	apotelesma	apotelsma
φύση	Fisi	nature	Λύση	lisi	solution
συνέχεια	sinexia	continuity	Συνήθεια	sinithia	habit
Semantic association					
ψωμάκι	psomaki	roll	Κουλούρι	coulouri	pretzel
μαρούλι	marooli	lettuce	Σαλάτα	salata	salad
χρόνια	hronia	years	Αιώνας	eonas	century
πολλά	pola	a lot	πληθυντικός	plithintikos	plural
αυτοκίνητο	aftokinito	car	Δρόμος	thromos	road
κόρες	cores	daughters	Κορίτσι	coritsi	girl
ελιά	Elja	olive	Λάδι	lathi	oil
δέντρο	thentro	tree	Φύλλα	fila	leaves
μαμά	mama	mama	Μητέρα	mitera	mother
τρίγωνο	trigono	triangle	Σχήμα	shima	shape
γυναίκες	yinekes	women	Άνθρωπος	anthropos	man
τραγούδι	tragoothi	song	Μουσική	moosiki	music
Unrelated					
ταύρος	tavros	bull	Οίνος	inos	wine
παιχνίδι	pehnithi	game	Κομήτης	comitis	comet
πεπόνια	peponia	melons	Ύψωμα	ipsoma	elevation
αγώνας	ajonas	fight	Πιπέρι	piperi	pepper
βουνά	voona	mountains	Ψυγείο	psigio	refrigerator
καλοκαίρι	calokeri	summer	πληροφορία	pliroforia	information
γλώσσα	ylosa	language	Αλάτι	alati	salt
κλάσματα	clazmata	fractions	Σημασία	simasia	significance
μήνας	minas	month	Σχέση	shesi	relationship
ναός	naos	temple	Γης	yis	land
καρδιά	carhja	heart	Υλικά	ilica	materials
καντίνα	cantina	canteen	αρχηγός	arhiyos	chief

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