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Word spelling assessment using ICT: The effect of presentation modality

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Abstract

Up-to-date spelling process was assessed using typical spelling-to-dictation tasks, where children's performance was evaluated mainly in terms of spelling error scores. In the present work a simple graphical computer interface is reported, aiming to investigate the effects of input modality (e.g. visual and verbal) in word spelling. The software was constructed with the view to measuring both spelling error and production time scores. The main purpose was to not only to examine spelling strategies used by primary school children, but also to provide educators with a useful tool that incorporates ICT technology. Within this framework, teachers could exploit the benefits of computerised spelling assessment and adjust their teaching methods towards a more effective approach of helping children master spelling skills. The results indicate that the presentation format has no impact on accessing abstract word representations, yet it accounts for variations in both time production scores and spelling errors. Spelling in Greek, albeit being a relatively consistent orthographic writing system, seems to pose difficulties to young spellers. Our data suggest that the particularities of the Greek orthography may need to be tackled using other than the standard spelling-to-dictation task used in primary schools. Computer-assisted teaching methods could exploit their flexibility in presenting different input modalities and therefore serve as a useful tool in teaching spelling.

Introduction

Writing is a method of representing language in visual or tactile form addressed in all domains of everyday life. In order to convey meaning through writing someone must be able to spell words accurately. Many theoretical models have been developed, which outline the cognitive components of the spelling process. These models have been referred to as cognitive neuropsychological interpretations and have evolved over the past two decades.

Classical dual-route theory assumes that spelling process involves two “routes” for translating phonology to orthography (Caramazza, 1988; Ellis & Young, 1988; Tainturier & Rapp, 2000). These processes are referred to as the sublexical and lexical route. The lexical route is thought to contain information on relating phonological, semantic and orthographic representations of words to one another. The sublexical route, on the other hand, is assumed to encode the systematic relationships between phonemes and graphemes (Rapp et al., 2002).

Barron (1980) has suggested that in order for a person to spell, he has to follow either a phonological or a visual-orthographic strategy. The first strategy generates the spelling pattern of a word using the sound-to-spell correspondence rules and thus assembles spellings for unfamiliar words. On the other hand, the visual-orthographic strategy constitutes a holistic spelling procedure, whereby a person has to retrieve the exact form of the word stored in his lexical memory. Bishop and Robson (1989) use the terms “direct” and “indirect” to describe these two different spelling routes. Evidence about the distinction between two sets of processes applied to spelling is derived from impaired spelling performances studied by neuropsychologists (Goodman & Caramazza, 1986). The two best known studies in this field are reported by Beauvois and Derouesné (1981), as well as by Shallice (1981). Beauvois and Derouesné (1981) describe a patient who could spell novel (sublexical route), but not irregular words (lexical route). In contrast, Shallice’s patient could spell irregular words accurately, but not novel words. These two performances suggest that spelling is processed by two distinct and independent routes.

The phonological strategy (or sublexical route) is considered to be not only economical, due to the partial processing of words (Henderson & Chard, 1980), but also more rapid (Kang & Simpson, 1996). It is worthwhile mentioning that this sequential process depends heavily on auditory coding. This indirect spelling route is activated when a spelling task involves unfamiliar words for which there is no orthographic specification available in lexical memory (Bishop & Robson, 1989) and is regarded as very important during the first years of learning to spell (Marsh et al., 1980; Stage & Wagner, 1992). Nevertheless, others believe that the visual-orthographic strategy also helps novice spellers to select the correct spelling of a word (Treiman, Cassar & Zukowski, 1994). The phonological strategy requires awareness of the fact that there is a connection between orthography and phonology, the development of which will allow mapping between these two levels (Brown & Ellis, 1994). The sublexical route concerns the segmentation of words into their constituent phonemes (Bryant & Bradley, 1980; Nelson, 1980). The “assembled” route makes use of the phoneme-grapheme correspondence rules and involves activation of the phoneme-grapheme conversion buffer proposed by Ellis and Young (see also Goswami & Bryant, 1990). The correspondences between the sound and orthographic patterns of words are encoded in order to produce the correct spelling (Brown & Ellis, 1994). Finally, the sublexical route is assumed to output phonologically plausible spellings, especially for common words that have simple phoneme-to-grapheme correspondences (Rapp et al., 2002).

The visual-orthographic strategy (or lexical route) depends on the function of the grapheme output lexicon. A speller has to retrieve whole graphemic word forms from his memory. This presupposes the existence of a significant number of different visual word representations or chunks stored in the grapheme output lexicon. Kang and Simpson (1996) suggest that this route seems to be a rather slow process relative to the phonological strategy. The holistic strategy presupposes access to the word's "envelope"; which refers to the retrieval of words as distinctive orthographic patterns from memory (Brown & Ellis, 1994; Barry, 1994). The lexical route seems to handle inconsistent words and homophones, high frequency or irregular words that cannot be translated via the grapheme-phoneme conversion buffer. Furthermore, it can be accessed only through activation of specific orthographic characteristics of individual words in the grapheme output lexicon, activating also the semantic system (Bishop & Robson, 1989; Weekes, 1994; Barry, 1994; Holligan & Johnston, 1991).

Barron (1980) assumes that both strategies can be used when spelling regular words. The difference between them lies in the fact that only the visual-orthographic strategy is suitable when a spelling task concerns irregular words. Substantially growing evidence supports the notion that the phonological and the orthographic processing routes are distinct but *"... reciprocal related components of word recognition and spelling*" (Manis et al., 1993, p. 64).

When spelling to dictation, spellers who use the lexical route assemble orthographic representations from lexical phonological representations to lexical semantic representations (Rapp et al., 2002). Some theorists assume that there is actually another lexical route that maps directly from phonology to orthography without semantic intermediation (Patterson, 1986).

For many years, the lexical and sublexical spelling procedures were considered as separate routes for producing acceptable spelling patterns. Recently, Rapp and her collaborators (2002) have suggested that the sublexical process in spelling acts as a strengthening factor of a target word's constituent graphemes. Based on their data, the same group of theorists point out that there is interaction between lexical and sublexical processes in spelling. Since these two routes utilize different representations (e.g. phonological vs visual-orthographic) for producing word spellings, an important question should be addressed i.e., whether stimulus modality affects the production of acceptable spelling patterns.

Early models of language processing have proposed that auditory and visual inputs partially converge during word processing (Geschwind, 1965; Patterson & Shewell, 1987). Despite the fact that spelling utilizes primarily auditory information, recent research highlights the benefits of exploiting visual inputs in word spelling. The role of phonemic analysis in spelling of words with consonant clusters, or sound-to-spelling consistent words in general, is of crucial importance (Bosman & Van Orden, 1999). Yet, phonology cannot facilitate spellers when tackling inconsistent words. Thereby, visual information would be particularly implemental in learning words with ambiguous sound-spelling relations (van Hell et al., 2003).

Another key factor involved in the process of converting phonology into orthography is syllabic structure which is considered to play a significant role (Sanders and Caramazza, 1990). As they report: *"... a phoneme (or syllable) will be converted into a particular grapheme (or graphosyllable) with a probability that is equal to the relative frequency of occurrence of that phoneme-to-grapheme mapping in written language*" (Sanders & Caramazza, 1990, p. 62). Baxter and Warrington (1987) differentiate their view stating that the phoneme-to-grapheme mapping that someone selects is not always the most frequent option in the written language (Baxter & Warrington, 1987). In Sanders and Caramazza's (1990) viewpoint, a highly irregular (or a low frequency) mapping, like "yacht", is less likely to be spelled correctly, since the graphosyllabic unit "cht" has a C-C-C structure on the graphemic level, whereas on the phonological level it is represented by a single consonant phoneme (e.g. /t/). Consistency is a well known factor that accounts for variation in spelling performance. An issue raised at this point is whether input modality (e.g. auditory, visual or both) contributes to or partials out consistency effects in spelling performance. This study aims to explore potential effects of stimulus modality (e.g. auditory, visual) and word consistency (regular, irregular) when spelling in a shallow orthography like Greek.

"*Modern Greek language is the sole descendant of ancient Greek ...*" (Mackridge, 1985, p. 2) and has undergone evolutionary changes over the centuries. These changes mainly occurred on the phonological level. In contrast, the written form of modern Greek language has remained essentially the same since antiquity (Porpodas, 1990). The term "*historic orthography*" is used to describe the aforementioned phenomenon (Porpodas et al., 1990). Greek words are spelled the way they were pronounced 25 centuries ago and not the way they are pronounced today. Thus, Greek spelling reflects the phonetic etymology of words rather than their phonetic condition. This is the main reason why spelling in Greek is a far more complex cognitive process than reading (Mackridge, 1985; Chliounaki & Bryant, 2003). Greek orthography, as in most languages (Smith, 1980), indicates information other than purely phonemic. It is more consistent with a word's meaning (semantic identity). Thus, vowel phonemes can be represented with different vowel graphemes. For example, the vowels /o/ and /e/ can be spelled in two ways ('ο' and 'ω' - 'ε' and 'αι'). The same pattern can be observed for spelling the phoneme /i/ ('ι', 'η', 'ει', 'οι', 'υ', and 'υι'). Selecting the right spelling poses great difficulties to children (Bryant et al., 1999; Chliounaki & Bryant, 2003). It is often the case that children choose single-letter representations (e.g., they use 'ι' and 'η' to represent /i/ over diagraphs 'ει' or 'οι').

In alphabetic orthographies, novice spellers must learn the underlying relationships between phonemes (sounds) and graphemes (spellings) (van Hell et al., 2003). In Greek, both reading and spelling development set out as a sequential process, termed "*alphabetic process*", according to Seymour's model of foundation literacy (Seymour, 1990; 1997; 1999). It is a strategy of converting phonology to orthography in a serial manner. Later on, children adopt a visual-orthographic strategy that process larger units than single phonemes.

The theoretical background of spelling research, reported so far, provides teachers with a theoretical framework for effectively teaching children how to spell. Within a modern educational context though, the use of computer technology is suggested to have beneficial effects on learning. This claim is supported by a growing body of research evidence that the application of Information and Communication Technology (ICT) motivates pupils, improves their performance and raises educational standards (Torgerson & Elbourne, 2002). The term "*technological literacy*" is used to describe this trend and is defined as the ability to incorporate computers for improving learning, productivity and performance (Breuch, 2002; Bybee, 2003). The notion of literacy has changed. Nowadays, literate is someone who is able to exploit technology and use it for increasing his academic performance (Smolin & Lawless, 2003). As they mention "*... technology can also help students organize and synthesize information in different ways, facilitating their ability to construct and refine their knowledge*" (Smolin & Lawless, 2003, p. 572).

The computer is an increasingly used learning tool within all levels of formal education (Dickhäuser & Stiensmeier-Pelster, 2002). Steele and his collaborators (2002) mention a number of reasons for employing educational software in teaching practice, such as efficiency, portability, consistency and effectiveness. As Kerawalla and Crook (2002) argue, computers can extend students' learning opportunities, not to mention the increased preference that students dislpay toward a computer-based instruction (Steele et al., 2002; Saunders & Klemming, 2003) over conventional teaching. Torgerson and Elbourne (2002, p. 140) mention that "*... an ICT intervention may be preferable if it is seen as more enjoyable for the participants"*, adding that the implementation of ICT to teach spelling was found to be effective on students performance (Torgerson & Elbourne, 2002).

The use of computers allows stimuli control over testing requirements. The software used was constructed to coerce participants into employing a sequential spelling strategy and therefore exploit a simple graphical computer interface for evaluating three different testing sessions in spelling performance. The rational behind this design was to examine the effects of visual and auditory information when spelling in a shallow orthography. A key factor in our approach is that of taking into account reaction and duration time scores in spelling production. To the writers' knowledge, research on the field mainly focuses on spelling error analysis. This study integrates time measurements, which despite being rough, provide us with insights of recording processes.

Methodology

This research was conducted from January to May 2008. One experimenter gathered the data in order to control variations in testing. An ordinary small office with abundant light and no external noises was selected for conducting the experiments. During the procedure only the experimenter and the subject were in the office. Subjects sat in an ergonomic, height adjustable office chair, approximately 80 cm away from the screen, so that the visible screen surface was within their optical field. It should be stressed here that the light had no disruptive effect whatsoever, e.g. reflections on the computer screen.

Software and Hardware

For the needs of this research, specific software was constructed. Specifically, object based, high level programming language Microsoft Visual Basic 6.0, and an IBM compatible computer were used. The software runs under Microsoft Windows XP Professional Edition and consists of three modules. Each one of these enables the experimenter to administrate up to 50 databases with words, pictures and sounds.

Users can enter each module by typing an identification name (username). During testing sessions a log file records subject's actions (e.g. mouse clicks, typing behavior, reaction and duration time).

The desktop PC used consisted of a microprocessor P4 / 2,8 MHz / 1GB RAM with a display adapter 17''. The screen resolution was 1024x768 pixels with 32 bit depth colour. A typical wired optical two-button + wheel with USB connection, Microsoft Intellimouse type mouse was used for controlling the software with Microsoft Windows default settings. A typical dark blue mouse pad was also used.

The software involved a simple user interface. Any use of icons or features that might have misled subjects or have attracted their attention were avoided. Thus, subjects could focus on the tasks undistracted. Figure 1 displays the flowchart of all three software's modules.

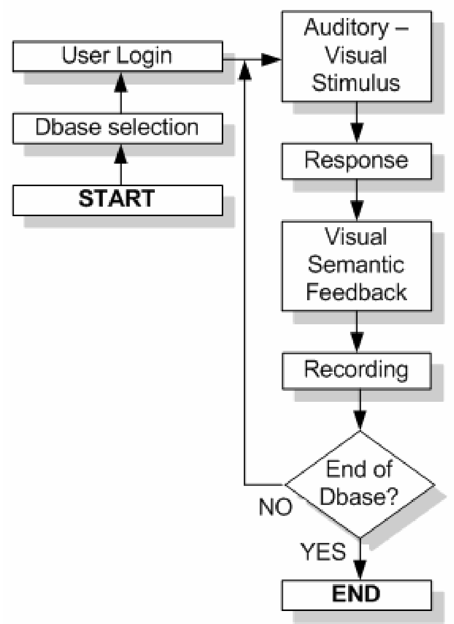

Figure 1. The data flow structure of every module

A content management system (cms) was incorporated in the software, which allowed the administrator to insert any word in a preset database, as well as its interconnections with the corresponding picture or sound. Via the content management system the administrator was able to correct or erase any word (and its interconnections) from the database, to create a new database for future use or to delete an existing one. Therefore, the software could serve as either a diagnostic tool for educational assessment, in order to evaluate children's spelling performance on a specific set of words, or as a post-test method to estimate potential gains of an already applied spelling intervention programme. It should be noted here that the software, without any changes to its structure, could be applicable to support English language courses in both primary and secondary education. Another feature of the specific software was the possibility to record all system-user interactions (e.g. the elapsed time between a stimulus presentation and the user's response). As illustrated in Fig. 2, the software could produce in a sequential format, thoroughly described outputs containing all the steps that were taken by each user.

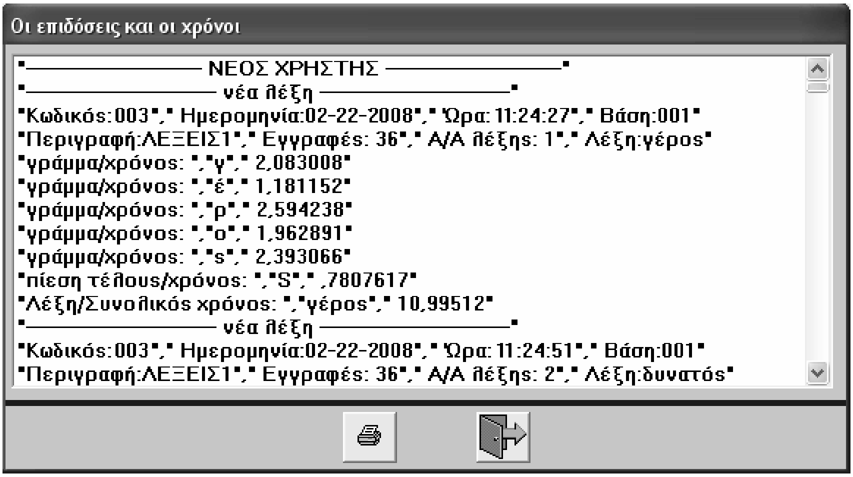

Figure 2. The window displaying the output with all subjects' responses

Experimental Procedure

Before the main experimental procedure, the experimenter prompted the subject to begin the familiarisation process. Each experiment incorporated a subprogram in order for the subject to become acquainted with the software and especially with the mouse move and click tasks involved in the experiments.

Right after the familiarisation process the experimental procedure started. For each subject this session did not exceed a 20 min time limit. The experimenter used exactly the same verbal instructions for guiding subjects throughout the experiments. The sequence of the three procedures was rotated across the testing sessions. A two-week interval time between testing sessions was employed in order to avoid any warm up effects.

Under the auditory conditions, all speech sounds were digitized (16 bit; the normal audio cut-off, 22050 Hz) by means of digital audio production software, whilst the auditory stimuli were presented binaurally to the subjects through headphones.

Sample

Overall, 26 subjects participated in this research, thirteen girls and thirteen boys. Their mean age was ($\bar{x} = 11{,}5$). Individuals with special needs (learning or physical) were excluded from the sample. Participation was voluntary. All subjects had normal or corrected to normal vision, were right-handed and were attending the 6th grade of Elementary School. All participants had computer experience, either through courses in school or at home.

Corpus

Thirty six word items (nouns and adjectives) were totally selected for this study (see appendix). All items were middle frequency words, drawn from a personal database containing all words used in the elementary grammar books (for all 6 grades). The rate used was 0,324 (e.g. 3.24 per 1000 words). Items were classified as consistent if they had a simple CV syllabic pattern and a 1:1 grapheme to phoneme mapping, as consonant cluster words with complex CV syllabic patterns and 1:1 grapheme to phoneme mapping. The other two categories comprised inconsistent words. The first one included words with vowel diagraphs and spelled relying upon the historic orthography rules of the Greek language (Porpodas et al., 1990). Finally, the second category comprised words with double consonants that violate simple 1:1 phoneme-to-grapheme correspondence rules. Word items were controlled for length.

All testing items were presented in the visual-only condition (test 3) in lower case letters (Arial 18 pt.).

Pilot test

Two months before the main experimental procedure a pilot test had been conducted. Overall, 5 subjects took part in the pilot test. None of them participated in the main experimental procedure. Data from the pilot test and the obtained results led to revisions on the software in terms of function processes.

Experiments, Description

Each subject completed three main tests. These were presented in rotation for each subject. Thus, the first subject started with the first test, the second subject with the second test and so on. The circle rotation was also sustained within each test - for all testing items.

As it has already been mentioned, apart from the software and the hardware, coloured cards were also used in this research. These cards represented the interface of each experiment using words that were not employed in the testing sessions. That strategy was regarded as crucial, since the experimenter could prepare the subjects for the appropriate actions to be taken. In that way, subjects were very well aware of what they were about to see. The experimenter answered questions or gave instructions when necessary. The tests were the following:

Test 1

The first test was a simple simulation of the typical spelling-to-dictation task often used within a normal classroom setting and constitutes a combination of the next two experimental procedures, as shown in Fig. 3. Participants were required to press the "*sound button*" and hear the uttered testing item.

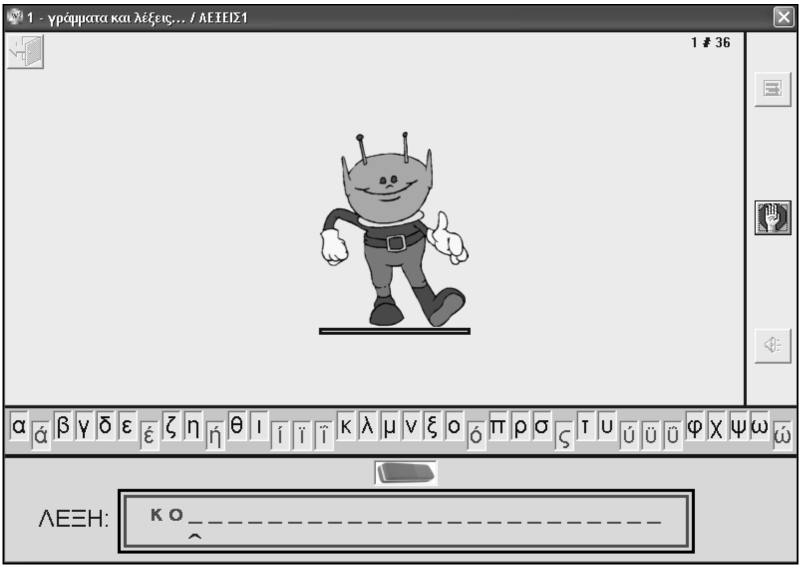

Figure 3. Screen shot of the first module, used for the first test

It should be noted here that a female voice was recorded for this purpose. Then children tried spelling the target word pressing the correct "*letter buttons*" using a mouse. Different buttons were used for stressed vowel graphemes. Participants had the opportunity to correct their spellings by pressing the relevant "rubber button". The rationale behind this experiment was to give children the chance to combine both verbal and visual stimuli in order to complete the spelling task. When a child pressed the first letter button the reaction time was recorded. After the completion of the first target item subjects had to press the "*stop button*" and duration time was recorded. The procedure continued with the next word item.

Test 2

The second test was a modification of the first spelling to dictation task, as displayed in Fig. 4. The participants were instructed to press the "*sound button*" and hear the uttered testing item. A female voice was also used for this purpose. Then children tried to spell the target word pressing the correct "*letter buttons*" making use of the mouse. Different buttons were used for stressed vowel graphemes. As in the first experiment, participants were given the opportunity to correct their spellings by pressing the relevant "*rubber button*".

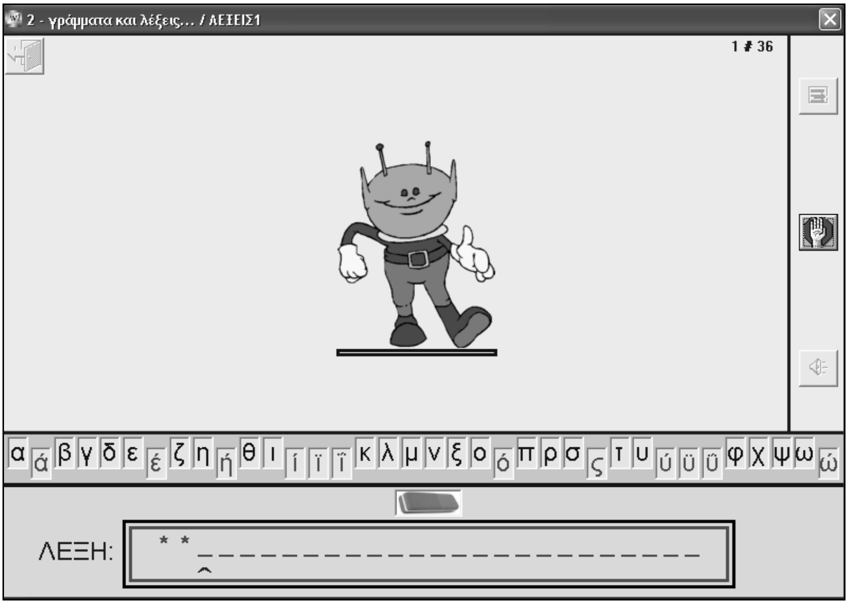

Figure 4. Screen shot of the second module, used for the second test

The difference here is that children could not use visual information regarding their spellings, since the selected graphemes were not visible on the screen. Instead, an asterisk was used for representing graphemes. This was considered to be essential as it ensured avoidance of omission errors that were observed in the pilot study. Consequently, spelling could only be based on the use of verbal information. When a child pressed the first letter button the reaction time was recorded. After the completion of the first target item subjects had to press the "*stop button*" and duration time was recorded. The procedure continued with the next word item.

The purpose of this design was to ensure that subjects could not have visual feedback. Their spelling was entirely based on phonology. Actually, subjects could neither check their spellings using a word's visual familiarity, nor employ reading knowledge when spelling. The above described procedure presupposes phonological access to a word's orthographic identity in the lexical memory.

It has been suggested that at this age spelling begins to rely less on phonological rules. It rather appears to employ more of a visual strategy. Stage and Wagner (1992) put forward that children often check their spellings by resorting to visual word representations. These representations, or orthographic images (Ehri, 1980) are controlled in this test. Concluding, this technique was used to examine the effects of an isolated phonological route in spelling words with different syllabic structures (e.g. different C-V-C patterns).

Test 3

The third test was a multiple choice spelling task, as shown in Fig. 5. Participants had to press the "*picture button*" and observe the four potential spelling patterns. All possible spellings were presented simultaneously. It should be noted that only one of the presented spelling patterns was the correct. The other three alternatives comprised different phonologically plausible phoneme-to-grapheme mappings. The given alternatives included a variety of spelling errors (different vowel graphemes to represent a vowel phoneme). At least one of the alternatives was a phonologically implausible visual representation of the target item. After completing the "visual scan" participants had to select the last presented spelling pattern. This was the starting point for measuring reaction time scores. Then children tried to spell the target word pressing the correct "letter buttons" using a mouse. Different buttons were to be chosen for stressed vowel graphemes. The participants had the opportunity to correct their spellings via the "rubber button".

Figure 5. Screen shot of the third module, used for the third test

The rationale behind this experimental session was to allow children to exploit a visual pathway for lexical access, as well as to enable them to exploit visual feedback about their spellings. When a child pressed the first "*letter button*" the reaction time was recorded. After the completion of the first target item subjects had to press the "*stop button*" and duration time was recorded. The procedure continued with the next word item.

The above mentioned procedure was designed to address several questions. First, our primary interest was to find out how a word spelling is produced while using only visual informational units. Subjects could only identify the correct spelling by direct access to lexical memory. Subvocal rehearsal was possible only via a lexical route that first presupposes word identification in lexical memory. Moreover, test 3 may address another question. That is the use of reading knowledge when we spell.

Results

As it has already been mentioned, both reaction and duration times were recorded. Reaction time scores was the time that intermediated from the presentation of a target word since the selection of its first grapheme. Classical dual-route theory of spelling postulates that this is the imperative time for retrieving words' abstract forms form lexical memory. Recording these scores was thought to be crucial for obtaining a rough measure of the time needed to access a candidate spelling pattern for a given target item.

Subjects of this age are considered to have mastered the ability to spell using a visual-orthographic strategy, a holistic process, which enables spellers to retrieve an exact representational word form stored in lexical memory. All three experimental procedures employed in this study aimed at enforcing participants to resort to a serial spelling process. Thus, duration time scores served as an indication for evaluating presumable input modality effects on spelling process.

Reaction time

A repeated measures 3x4 ANOVA was calculated with input modality as the within-subjects variable (verbal and visual stimuli, verbal stimuli, visual stimuli) and consistency (consistent, consonant cluster, vowel diagraphs and double consonants words) as the between-subjects factor. Since the result of the Mauchly's Test of Sphericity for homogeneity of covariance was significant (W= .51; df=2; p<.001) we resorted to the more conservative option of the Greenhouse-Geisser test for adjusting the degrees of freedom in the ANOVA test in order to produce a more accurate significance (*p*) value (Grieve & Ag, 1984). Thus, there was a significant main effect of input modality $F_{(2,1858)}$= 573.79; p< .001. Test 3 (visual stimuli) was proved to be more demanding in terms of reaction time than the other two testing sessions, as expected. It is important to note that the time needed to complete the evaluation for all given alternative spellings was 50% of the actual overall reaction time. The F value obtained in the ANOVA output can be attributed to the particularities of test 3 (time consuming).

A further analysis was performed in order to check the hypothesis that reaction times do not differ across testing sessions. Even though there is a marked difference between test 3 and the other two testing sessions, as demonstrated in Fig. 6, this differentiation is on account of the visual scan of all the alternative spellings that are provided in test 3. A preliminary analysis was carried out for testing the hypothesis that there is no effect of testing in reaction time scores. Thus, an independent samples t-test was calculated between sessions 1 (auditory and visual stimuli) and 2 (auditory stimuli). The mean difference was 0.16 sec and thus not significant: t(1867)= 1.8; p> .05. The results to support our hypothesis were found after taking into account the "visual scan" scores, recorded only for test 3. Abstracting the "visual scan" scores from the total reaction time scores creates a new picture. In the novel

ANOVA model the effect of testing was partialled out: $F_{(2,2801)}$= 1.84; p> .05. Our results support the idea that input modality has no effect on lexical access in spelling.

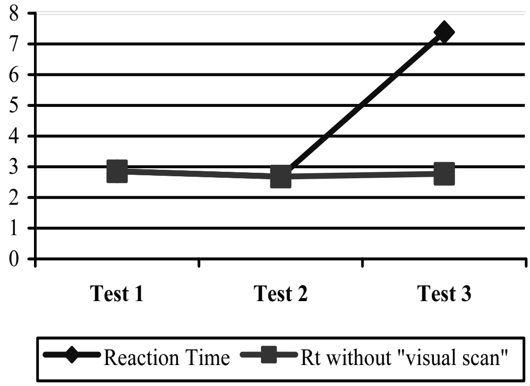

Figure 6. Reaction times (in seconds)

The repeated measures 3x4 ANOVA revealed a significant main effect of consistency: $F_{(3, 929)}$= 11.19; p< .001 (Fig. 7). Tukey's HSD post hoc comparisons showed that inconsistent words (both vowel diagraphs and double consonants) differ significantly on the level of < .05 from all other words for test 1. The consistency effect reached statistical significance also at test 2 for double consonant words (p< .05) and at test 3 for inconsistent words (both vowel diagraphs and double consonants) on the level of < .05. Tests 1 and 3 appear to share common features that associate reaction time scores and consistency in respect to spelling.

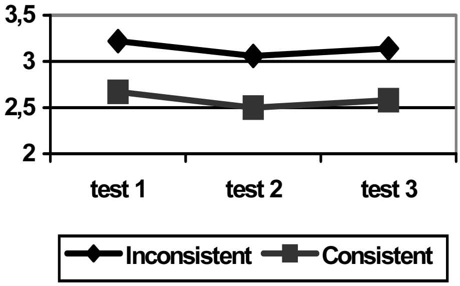

Figure 7. Reaction time scores (in seconds)

Duration time

Duration times that entered the analysis were calculated from the total time minus the reaction time. Specifically, it is the time consumed from the selection of a word's first grapheme to the selection of the last grapheme. This option was preferred in order to eliminate the reaction time effect.

A repeated measures 3x4 ANOVA was calculated with input modality (verbal and visual stimuli, verbal stimuli, visual stimuli) as the within-subjects variable and consistency (consistent, consonant cluster, vowel diagraphs and double consonants words) as the between-subjects factor. Since the Mauchly's Test of Sphericity was significant (W= .91; df=2; p<.001) we once more select the more conservative option of the Greenhouse-Geisser test. Thus, there was a significant main effect of input modality $F_{(2,1850)}$= 338.72; p< .001. Test 2 was proved to be less demanding in terms of duration times than the other two testing sessions. Another important finding was that duration scores on tests 1 and 3 were almost identical as illustrated in Fig. 8.

There was also a significant main effect of consistency: $F_{(3,\ 929)}$= 11.23; p< .005. Tukeys's HSD post hoc comparisons for test 1 revealed that inconsistent words (historic orthography) differ significantly on the level of < .05 from all other words, forming a separate subset with a mean difference of 1.4 sec. The consistency effect failed to reach statistical significance at test 2 and 3, although inconsistent words were spelled more slowly than consistent ones. It is important to stress here that vowel inconsistent words achieved the lowest mean difference (less than 0.6 sec) at test 2. Results from the duration time scores duplicate those observed in the reaction time scores analysis. The auditory only session (test 2) seems to have formed different specifications for spelling.

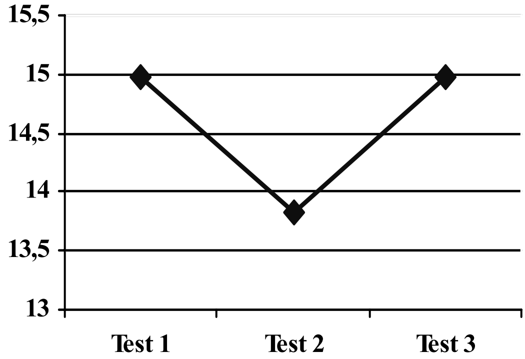

Figure 8. Duration times (in seconds)

Error analysis

In an effort to examine if testing method (tests 1, 2, 3) and spelling errors (visual vowel, visual consonant and phonological implausible errors) inter-relate, we used a crosstabulation analysis. Visual vowel errors refer to errors occurring in diagraphs, where subjects alter the correct letter string with a phonologically plausible single vowel grapheme (e.g. σ**ει**ρά, /sira/ - σ**ι**ρά, /sira/). Visual consonant errors refer to errors occurring in double consonants (e.g. φύ**λλ**ο, /filo/ - φύ**λ**ο, /filo/), where participants omit one consonant without changing the word's phonological identity. Finally, phonological implausible errors refer to responses that violate the word's phonological identity (e.g. πέτρα, /petra/ - πέρα, /pera/). Our main objective was to search for patterns of interaction between these two variables.

The analysis demonstrated that there is a significant association between testing method and error types: x^2 = 28.51; df= 4; p< .001. The strength of the association observed was measured with Cramér's V correlation coefficient: Cramér's V= .21; p< .001.

As shown in Fig. 9, the typical spelling-to-dictation method provided an increased number of errors compared to the other two conditions, especially for inconsistent words (visual vowel and visual consonant error types). As expected, utilizing visual information prevent spellers from performing grapheme alternation errors. What is more important is that spelling-to-dictation is more sensitive to phonologically implausible errors. The pattern observed in test 3 was intriguing, since participants could use veral information through subvocal rehearsal to check their spellings.

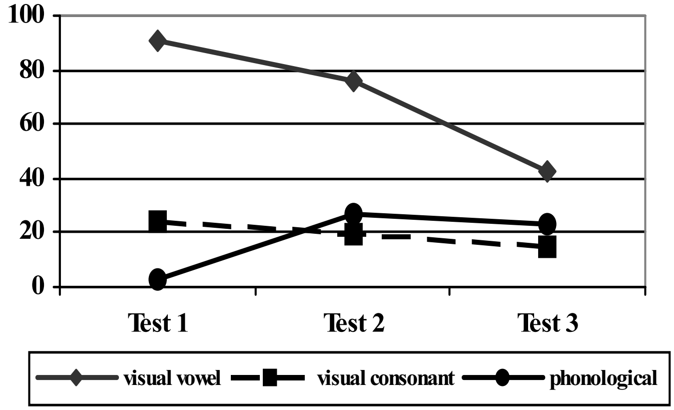

Figure 9. Error types across testing sessions

A further crosstabulation analysis was carried out between error types (visual vowel, visual consonant and phonological implausible errors) and word consistency (consistent, consonant cluster, vowel diagraphs and double consonants words). The analysis disclosed that there is a significant association between word consistency and error types for test 1: $x^2 = 101.63$; df= 6; p< .001. The strength of the association observed was measured with Cramér's V correlation coefficient: Cramér's V= .66; p< .001.

As displayed in Fig. 10, vowel selection is the interesting factor. Vowel graphemes pose major difficulties to children for all word types and not just for those belonging to the historic orthography category.The same analysis was conducted for test 2, which made it clear that there is a significant association between word consistency and error types: $x^2 = 81.68$; df= 6; p< .001. The strength of the association observed was measured with Cramér's V correlation coefficient: Cramér's V= .58; p< .001. As shown in Fig. 11, vowel selection still remains the crucial factor. What is odd here is that the visual input only condition does not differentiate error frequency among vowel inconsistent, consonant cluster, and consistent words.

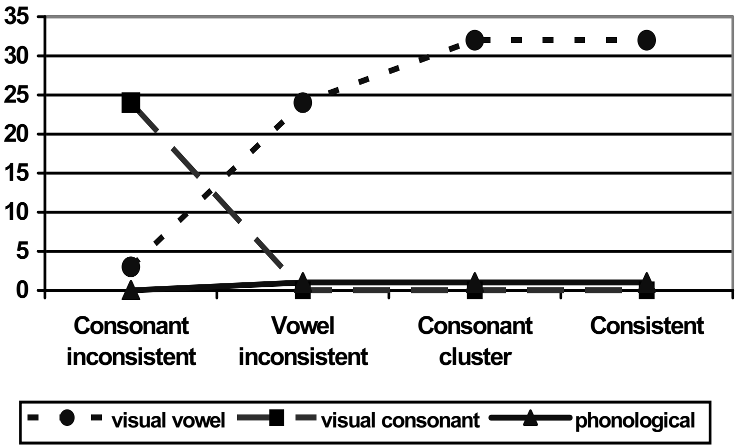

Figure 10. Error types and consistency for test 1

Finally, a crosstabulation was performed for test 3, which revealed that there is a significant association between word consistency and error types: $x^2 = 48.84$; df= 6; p< .001. The strength of the association observed was measured with Cramér's V correlation coefficient: Cramér's V= .55; p< .001.

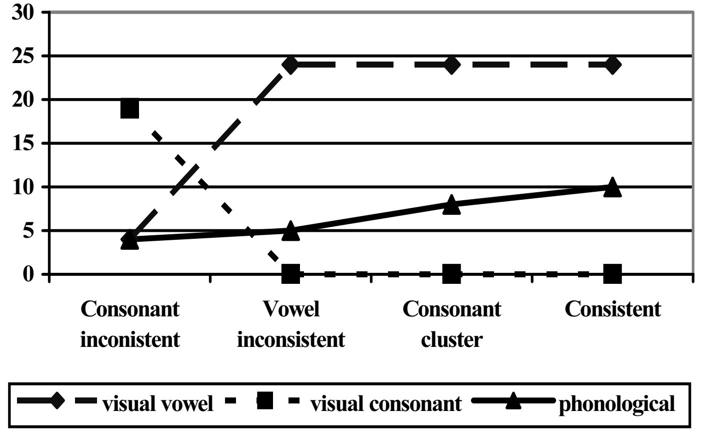

Figure 11. Error types and consistency for test 2

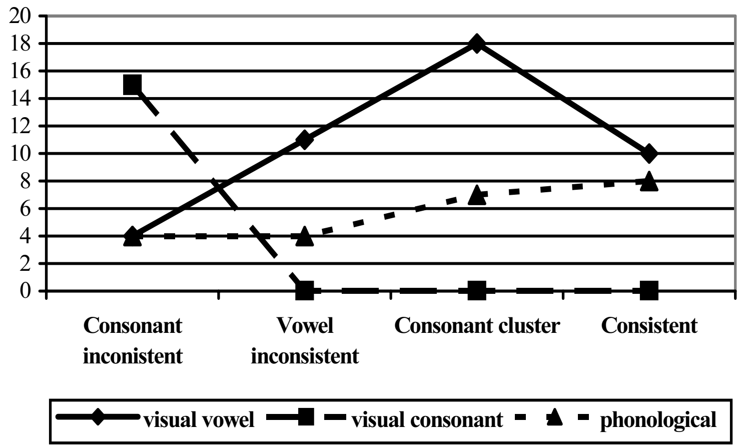

Figure 12. Error types and consistency for test 3

As shown in Fig. 12, vowel selection follows the same pattern. Although participants could actually use verbal information consonant cluster words posed a much greater difficulty to them. Vowel inconsistent and consistent words presented equal results in terms of error frequency. Another point that needs to be further explored is the occurrence of phonologically implausible spelling errors. Words with simple phoneme-to-grapheme correspondences were prone to this type of errors.

Discussion

The data from this study present a different view regarding the effects of input modality in children's spelling. The design of the current research enables us to investigate the role and the degree of engagement of various factors involved in the process of spelling using a transparent alphabetic system.

First, the effects of auditory, visual and both auditory and visual information were manipulated using a simple computer graphical interface. The software used allowed us not only to control spelling outputs regarding spelling accuracy, but also gave us rough measures concerning the processing time needed to complete a simple word spelling task.

The results from this study revealed that presentation modality effects can be observed in the time required to produce acceptable word spellings. In particular, input modality did not contribute to variation in reaction times scores. Data support the view that lexical access is not affected by stimulus presentation. What counts significantly in lexical access is the syllabic structure. Word consistency was found to influence performance increasing reaction times scores. Spelling inconsistent words, of both types (e.g. vowel or consonant inconsistent), required more cognitive resources for accessing a word's representation for test 1. Even though consistency preserved its value as a latency predictive variable in tests 2 and 3, the engagement of pure visual inputs (test 3) weakened its strength. The gains derived from the involvement of visual inputs were capitalized on vowel inconsistent words (historic orthography). On the other hand, visual information benefits did not reflect on reaction times scores for consonant inconsistent words (double consonants), a discrepancy that was unexpected. Another important issue which emerged from the reaction time score analysis, was that tests 1 and 3 seemed to share some common features. Processing visual information requires more time when consistency is taken into account.

A further feature emanating from the current study was that the testing method did affect spelling not only in terms of duration times, but exerted influence upon spelling errors too. In relation to duration time scores, the effect of input modality was found to have a major impact on spelling duration. Test 2 was proved to be more economic. Again test 1 and 3 produced the pattern observed in the reaction time scores analysis.

The involvement of auditory information seems to predominate over visual information, diminishing thus gains from applying visual-orthographic knowledge. A quite interesting question arising here therefore is why spellers could not benefit, in terms of production time required, from the auditory-visual session. It could be argued that the time lag observed between tests was due to spellers' effort to combine different inputs in order to access a single correct orthographic pattern. When a word is visually presented it is reasonable to speculate that access will rely on an orthographically based code, which is compatible with the visual characteristics of the word. Relevant literature, however, holds that words are recoded phonologically (Taft, 1991). Thus, after the initial lexical matching process, which is based on phonology, visually presented words must be phonologically recoded before gaining access to any lexical entry. Our data suggest that input modality does not militate against accessing lexical information per se, but acts upon the retrieval processes. Evidence in favor of this option has been found in the reaction time scores analysis where testing sessions revealed almost identical results, in contrast to duration time scores. This accounts for the lower time scores achieved by children in test 2 (auditory session), implying that spelling through phonological activation produces faster outputs. Nevertheless, the emerging results have failed to bring to light an answer to the question why visual orthographic mediation (test 1) increased production times.

Error analysis helped to elucidate statistically significant associations between input modality and error types. What is striking is that in the classic spelling-to-dictation task (test 1) children made more errors than any other test.

The opportunity of utilizing visual information feedback and applying reading knowledge (test 3) had a beneficial effect on spelling performance for both consistent and inconsistent words. Especially for words that retain the ancient Greek orthography, the proportion of spelling errors was significantly reduced in the visual-only inputs design, producing thus the lowest incidence of historic errors. This result is an effect of applying reading knowledge when spelling ambiguous words. Accessing orthographic word representations of irregular words stored in the graphemic output buffer via a visual route seems to help spellers when they attempt to spell inconsistent words.

Another noteworthy finding was that visual information proved to be of great importance for consistent words, as it helped reduce vowel substitution errors. As discussed earlier, vowel phonemes in Greek may be represented by more than one grapheme. Therefore, providing subjects with alternative spellings facilitates a whole visual-orthographic matching procedure and thereby enables the retrieval of correct representations. Although this pattern appears perfectly reasonable and is in step with the current dual-route spelling theory, the application of reading knowledge (visual feedback) in the spelling-to-dictation task (test 1) was proved proportionally far more beneficial when participants were presented with historic diagraphs than when they were required to spell consistent words.

Consistency seems to be the major determining factor for correct spelling. As the findings highlight, irregular words exhibited much greater difficulty for children. As discussed in the introduction, inconsistent words need to be processed via a lexical spelling route. Spelling words that do not have a 1:1 mapping from phonology to orthography using a sublexical route could lead to substitution errors.

Historic digraphs like "αι" (/e/) or "ει" (/i/) fell within this error pattern, where vowel digraphs were represented using a single phoneme (e.g. "αι" → /e/ as "ε" → /e/). The predictability of Greek orthography did predispose children towards using the most frequent grapheme mappings for the vowel phonemes. Substitutions of the vowel phonemes account also for the high proportion of the phonologically plausible (compared to implausible ones) spelling errors observed in this study.

Since phonologically implausible spellings are relatively highly correlated with deletion errors, it seems plausible that visual feedback (test 1) minimizes deletions. In the visual-only design (test 3) stimuli were constantly available to the subjects and thus phonologically implausible errors should have had equally low frequency. Surprisingly, participants produced errors of both this type in the same proportion at tests 2 and 3. In the auditory-only design (test 2) the sound trace of the heard word fades out quickly, thus this pattern of results is predictable. An interpretation of the obtained results in test 3 is difficult, however, and may reflect input modality effects.

Conclusion

In this study we investigated the effects of stimulus modality on word spelling, relying upon specific computer software. Our results highlight the significant role of presentation format in both duration time (production of acceptable word spellings) and spelling errors. On the other hand, there was no effect of testing while accessing abstract word representations from memory (reaction time scores). It is argued here that the spelling-to-dictation task, a method frequently used in classrooms, allows for visual feedback. Yet it does pose difficulties for the young spellers.

As evidenced in the present study, the syllabic structure of words had a statistically significant effect on spelling reaction and duration time scores. The particularities of the Greek alphabetic writing system, especially those concerning vowel phoneme representations on the graphemic level, were found to contribute to spelling error variation across testing. Training studies may be particularly efficient if they incorporate computer-assisted methods for teaching spelling. Hence, as it can be inferred from the emerging research results, to some extent, it could be useful to provide different presentation formats for teaching different types of words.

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Appendix

Table A1. Two syllable words

Simple		
γέρος- /geros/ - old man	δάσος - /dasos/ - forest	γύρος - /giros/ - round
μύλος - /milos/ - mill	βυθός - /vithos/ - sea bed	κήπος - /kipos/ - garden
Complex		
φύλλο - /filo/ - leaf	μαύρο - /mavro/ - black	σειρά - /sira/ - queue
κόλλα - /kola/ - glue	πεύκο - /pefko/ - pine tree	λαιμός - /lemos/ - neck
Consonant clusters		
σπίτι - /spiti/ - house	στόμα - /stoma/ - mouth	βράχος - /vraxos/ - rock
σκηνή - /skini/ - tent	βρύση - /vrisi/ - faucet	φτερό - /ftero/ - feather

Table A2. Three syllable words

Simple		
δυνατός - /dinatos/ - strong	πατέρας - /pateras/ - father	κυνηγός - /kinigos/ - hunter
σωλήνας - /solinas/ - tube	καρύδι - /karidi/ - nut	γερανός - /geranos/ - derrick
Complex		
σύννεφο - /sinefo/ - cloud	μαχαίρι - /maxeri/ - knife	γυναίκα - /gineka/ - woman
ναυτικό - /naftiko/ - navy	σειρήνα - /sirina/ - siren	μελίσσι - /melisi/ - beehive
Consonant clusters		
δάχτυλο - /daxtilo/ - finger	πρόσωπο - /prosopo/ - face	δασκάλα - /daskala/ - teacher
κλωνάρι - /klonari/ - branch	καρέκλα - /karekla/ - chair	πρόβατο - /provato/ - sheep