Learning to spell in a language with transparent orthography: Distributional properties of orthography and whole-word lexical processing

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We examined how whole-word lexical information and knowledge of distributional properties of orthography interact in children’s spelling. High-versus low-frequency words, which included inconsistently spelled segments occurring more or less frequently in the orthography, were used in two experiments: (a) word spelling; (b) lexical priming of pseudoword spelling. Participants were 1st-, 2nd-, and 4th-grade Italian children. Word spelling showed sensitivity to the distributional properties of orthography in all children: accuracy in spelling uncommon transcription segments emerged progressively as a function of word frequency and schooling. Lexical priming effects emerged as a function of age. When related primes contained an uncommon segment, 2nd- and 4th-graders preferred uncommon segments than common ones in spelling target pseudowords, thus inverting the response trend found in the control condition. A smaller but significant effect was present in 1st-graders, who, unlike 2nd- and 4th-graders, still preferred common segments, only slightly increasing the use of uncommon ones. A larger priming effect emerged for high-frequency primes than low-frequency ones. Results indicate that children learning to spell in a transparent orthography are sensitive to the distributional properties of the orthography. However, whole-word lexical representations are also used, with larger effects in more skilled pupils.
more regular the writing system the more children rely on sublexical processing (for an English–Italian comparison see Marinelli, Romani, Burani, & Zoccolotti, 2015). Additionally, in regular orthographies the sublexical procedure is acquired more rapidly and efficiently: First-grade children learning in transparent (e.g., Czech: Caravolas & Bruck, 1993) or intermediate orthographies (e.g., German: Wimmer & Landerl, 1997) show better pseudoword spelling skills than age-matched English-speaking children (for reviews, see Caravolas, 2004; Sprenger-Charolles, Colé, & Serniclaes, 2006). In line with cross-linguistic data, a recent study that investigated spelling acquisition in first- to eighth-grade Italian children (Notarnicola, Angelelli, Judica, & Zoccolotti, 2012) confirmed a prevalent reliance on the sublexical procedure in all grades examined (children being always more accurate on consistent items than on inconsistent ones), with a ceiling effect for stimuli with consistent transcription after only three years of schooling.

However, in Italian, as in other relatively consistent orthographies, there is a certain degree of uncertainty regarding phoneme-to-grapheme correspondences. Examples of unpredictable spelling are those cases in which a given phonological string has more than one possible orthographic solution, but only one is correct. For example, in Italian the phonemic group [kw] can be transcribed with the orthographic sequences QU or CU [e.g., QUOTA (= share) instead of *CUOTA, or SCUOLA (school) instead of *SQUOLA], and the orthographic renderings of the syllables [tʃe], [ʃe], [dʒe] may or may not require the insertion of an i—for example, [ʃena] is converted into SCENA (scene) and not *SCIENA, but [ʃentsa] is converted into SCIENZA (science) and not *SCENZA. In these instances, phonological-to-orthographic conversion rules are insufficient to obtain the correct spelling of words, and reliance on the lexical route is necessary. Lexical spelling deficits (e.g., surface dysgraphia), in fact, have been documented in both Italian brain-damaged patients (Luzzatti, Laiacona, Allamano, De Tanti, & Inzaghi, 1998) and children with learning disabilities (Angelelli, Judica, Spinelli, Zoccolotti, & Luzzatti, 2004; Angelelli, Marinelli, & Zoccolotti, 2010; Angelelli, Notarnicola, Judica, Zoccolotti, & Luzzatti, 2010; Angelelli, Putzolu, et al., 2016). Although in consistent orthographies the sublexical procedure is preponderant, evidence of lexical spelling was found to occur very early in spelling development—that is, by the end of first grade (for Portuguese, see Fernandes, Ventura, Querido, & Morais, 2008; for Italian, see Notarnicola et al., 2012), supporting the view of a parallel and early acquisition of both lexical and sublexical spelling procedures, which showed, however, differential developmental trends. Thus, in a consistent orthography such as Italian, children may early learn the sublexical phoneme-to-grapheme mappings and prevalently rely on this procedure, which allows them to spell correctly almost all words. Then children progressively acquire the orthographic representations of the few words with unpredictable transcriptions.

However, to what extent children learning to spell exploit the statistical distributions of phonology-to-orthography mapping has still been little investigated. Furthermore, we still do not know when sensitivity to the distributional properties of orthography appears. The first aim of the present study was to evaluate whether children learning to spell a consistent orthography, such as Italian, are sensitive to the distributional properties of the orthography in spelling along the sublexical procedure. We also aimed to investigate when this sensitivity develops. Studies on reading development (Sulpizio & Colombo, 2013) revealed that Italian children are sensitive to the distributional properties of the language, since they are able to successfully rely on the statistical properties of the language for stress assignment in reading. However, no parallel evidence for the spelling process is as yet available. Moreover, we aimed to investigate how the use of the sublexical regularities of the orthography interacts with the whole-word lexical procedure. Both theoretical models of spelling (e.g., Houghton & Zorzi, 2003; Rapp, Epstein, & Tainturier, 2002) and experimental studies (described further below) indicate that lexical and sublexical processes may interact. Therefore, a further interesting question is whether whole-word lexical information influences sublexical processing also in a consistent orthography such as Italian.

Several studies on English-speaking and French-speaking children showed that during literacy acquisition young children not only learn phoneme–grapheme correspondences explicitly, they also learn orthographic regularities (such as frequent or legal letter associations or positions) that reflect the statistical distribution of graphotactic patterns in their orthography through implicit mechanisms (e.g., Pacton, Fayol, & Perruchet, 2002; Pacton, Perruchet, Fayol, & Cleeremans, 2001; Treiman, 1993; Treiman & Cassar, 1997). According to Pacton, Sobaco, Fayol, and Treiman (2013, p. 8), “people use their general
knowledge about the graphotactic patterns of their writing system, even when other sources of information would logically suffice to produce correct spellings.” Starting from first grade, English- and French-speaking children demonstrated that they had acquired the orthographic regularities of their opaque orthographies; indeed, they preferred the most frequent orthographic patterns in both reading (e.g., Pacton et al., 2001) and spelling (e.g., Treiman, 1993). Additionally, this knowledge of orthographic regularities influenced the recall of newly learned orthographic representations in French-speaking children and adults (Pacton, Borchardt, Treiman, Lété, & Fayol, 2014; Pacton et al., 2013; Sobaco, Treiman, Peereman, Borchardt, & Pacton, 2015). To our knowledge, only one study (Nigro, Jiménez-Fernández, Simpson, & Defior, 2015) examined children’s ability to learn graphotactic regularities and their relation to reading and spelling skills in a transparent orthography. The authors failed to find a relationship between the learning of graphotactic regularities and the reading performance or pseudoword spelling. However, a relationship was found between the learning of graphotactic regularities and the ability to spell inconsistent words, suggesting that implicit learning mechanisms may play a role in the acquisition of lexical knowledge and, thus, in spelling proficiency.

On the other hand, several studies showed that lexical activation influences sublexical processing and that units larger than single phonemes/graphemes are also used in pseudoword spelling. A first set of studies investigated this issue examining morphological effects in pseudoword spelling. Young English- and French-speaking children showed morphological facilitation in spelling, indicating that children do not rely (at least not exclusively) on rules but use a statistical learning process of intra- and inter-word regularities (for a review, see Pacton & Deacon, 2008). Morphological facilitation in spelling was also found in orthographies with consistent phoneme-to-grapheme correspondences, such as Spanish (Defior, Alegría, Titos, & Martos, 2008) or Finnish (Lehtonen & Bryant, 2005). With regard to Italian, a recent study of third- and fifth-grade children reported a clear advantage in spelling pseudowords made up of real roots and suffixes with respect to non-morphemic pseudowords (Angelelli, Marinelli, & Burani, 2014). In developing readers, exposure to these frequently occurring chunks of sound and meaning in speech and their corresponding orthographic patterns in writing allows morphemes to become relatively independent spelling units. Overall, the reported evidence suggests that children learning to write in both opaque and transparent orthographies exploit orthographic regularities that reflect the statistical distribution in their orthography, and that they might also use large-sized processing units in pseudowords spelling.

Another series of studies addressed the relationship between sublexical and whole-word lexical processing by examining lexical neighbourhood effects in the spelling of pseudowords containing low-probability phoneme-to-grapheme mappings. Tainturier, Bosse, Roberts, Valdois, and Rapp (2013) studied French-speaking proficient adults who spelled pseudowords to dictation that had a phonological word neighbour spelled with a low-probability phoneme-to-grapheme mapping (e.g., /o/ transcribed as AUD). The authors found that low-probability phoneme-to-grapheme mappings were used significantly more often in spelling pseudowords that had a phonological lexical neighbour containing that spelling than in spelling pseudowords with no lexical neighbours. Interestingly, the magnitude of the lexical influence increased with the frequency of the neighbour. Evidence supporting the influence of whole-word lexical processing on pseudoword spelling is also present in studies on typically developing children in both opaque (e.g., Bosse, Valdois, & Tainturier, 2003; Campbell, 1983, 1985; Martinet, Valdois, & Fayol, 2004) and transparent orthographies (Angelelli, Notarnicola, Marcolini, & Burani, 2014). Bosse and colleagues (2003) dictated pseudowords to French primary school children (from first to fifth grade). Some of them were phonological neighbours of words with uncommon endings (e.g., /daby/ derived from DEBUT, /deby/). The authors found that all of the children, including the youngest ones, spelled pseudowords by analogy to known words. An analogy effect was found even in first-graders, when the children knew how to spell the reference word. In Italian children, Angelelli, Notarnicola, Marcolini, and Burani (2014) found facilitatory lexical neighbours effects on pseudoword spelling. This supported the view that, similarly to what happens in opaque orthographies, developing spellers of a transparent orthography use lexical information in pseudoword spelling.

Finally, evidence of a whole-word lexical influence on pseudowords spelling comes from lexical priming studies (e.g., Barry, 1988; Barry & Seymour, 1988; Cuetos, 1993; Folk & Rapp, 2004). In these experiments, carried out with unimpaired adults, priming
was assessed by comparing levels of responding with a target spelling in the related priming condition to those in a control condition (a free-spelling task of isolated pseudowords or an unrelated priming condition in which prime words were replaced by unrelated, control, words). Results in English-speaking adults showed that pseudoword spelling could be affected by the orthography of the previously heard word (e.g., /priːt/ was more likely to be spelled PREET following the spoken word “sweet” and to be spelled PREAT following the word “heat”). Lexical priming effects on pseudoword spelling were also found in Italian skilled adults (Barry & de Bastiani, 1997). These authors showed that participants were prone to spell pseudowords with the orthographic segment that occurred in the prime word they had previously heard. The study of Barry and de Bastiani (1997) indicates that spelling in Italian may rely on sublexical print-to-sound regularities and that whole-word lexical processes may interact with sublexical ones, at least in skilled adults. Similar results were obtain in Spanish, another transparent orthography, on adult skilled spellers (Cuetos, 1993).

The aim of the present study was twofold: (a) to investigate whether young children (first-, second-, and fourth-graders) who are learning to spell in Italian use sublexical units that reflect distributional properties of orthography and, if so, when this occurs; (b) to study how sensitivity to the distributional properties of orthography interacts with whole-word lexical processing. For this purpose, we performed two experiments. In Experiment 1, we used a spelling-to-dictation task of high- versus low-frequency words that included inconsistently spelled segments that occur more or less frequently in the Italian orthography. A word frequency effect above the segment frequency effect (higher accuracy for low-frequency segments contained in high-frequency words) was considered evidence of lexical activation, and a segment frequency above word frequency effect (low-frequency segments spelled worse than high-frequency ones irrespective of word frequency) might reveal prevalent sensitivity to the distributional properties of orthography (with preference for the segment that occurs most frequently in the language) and thus evidence of sublexical processing.

In Experiment 2, we further tested the interaction between sublexical regularities in the sound–spelling mapping and the whole-word lexical procedure by means of lexical priming on pseudoword spelling. Words of Experiment 1 were used as prime words of pseudowords containing the same inconsistently spelled segments (related priming condition). We investigated the degree of lexical priming on pseudoword spelling as a function of the frequency of the prime word and the frequency of the sublexical segment. As a control, we examined the effect of unrelated words with predictable spelling on pseudoword spelling (unrelated priming condition). If children preferred the more frequent segment transcription irrespective of the priming condition, this could be considered as absence of lexical priming (and prevalent reliance on sublexical regularities). If, by contrast, the whole-word lexical procedure interacted with knowledge and use of sublexical regularities, we could expect in the related priming conditions a segment choice significantly different from that induced by unrelated primes. In particular, a higher occurrence of uncommon mappings in pseudoword spelling (with respect to the control condition) would be caused by related primes containing uncommon segments; similarly, related primes containing common mappings might maximize the use of common mapping in pseudoword spelling, relative to the unrelated priming condition. Finally, we could expect larger lexical priming effects in the case of high-frequency than low-frequency primes, because stronger lexical activation is assumed for high-frequency prime words, and for older pupils with respect to first-graders, because the acquisition of lexical orthographic representations requires school experience.

**Experiment 1: Word spelling**

**Method**

**Participants**

We included 106 children (53 males, 53 females) with normal reading and spelling performance. Participants were 31 first-grade children (17 males, 14 females; \( M_{\text{age}} = 6.73 \text{ years, } SD = 0.45 \)), 30 second-grade children (11 males, 19 females; \( M_{\text{age}} = 7.60 \text{ years, } SD = 0.37 \)), and 44 fourth-grade children (24 males, 20 females; \( M_{\text{age}} = 9.59 \text{ years, } SD = 0.33 \)) in the areas of Rome and Bari, Italy.

To be included in the study, children had to fulfil the following criteria: (a) normal reading speed and/ or accuracy performance on a standardized reading test (MT Reading Test, Cornoldi & Colpo, 1998); (b) normal performance on a standardized spelling test (Diagnosis of Developmental Orthographic Disorder,
Table 1. Performances of first-, second-, and fourth-grade children on the reading test and the spelling test.

<table>
<thead>
<tr>
<th>Task</th>
<th>First grade</th>
<th></th>
<th>Second grade</th>
<th></th>
<th>Fourth grade</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Raven</td>
<td>0.34</td>
<td>1.1</td>
<td>0.41</td>
<td>0.88</td>
<td>0.04</td>
<td>0.74</td>
</tr>
<tr>
<td>MT Reading speed</td>
<td>−0.07</td>
<td>0.5</td>
<td>−0.52</td>
<td>0.21</td>
<td>−0.27</td>
<td>0.59</td>
</tr>
<tr>
<td>MT Reading errors</td>
<td>0.11</td>
<td>0.59</td>
<td>−0.19</td>
<td>0.47</td>
<td>0.12</td>
<td>0.64</td>
</tr>
<tr>
<td>WRT spelling</td>
<td>−0.23</td>
<td>0.87</td>
<td>0.31</td>
<td>0.47</td>
<td>0.19</td>
<td>0.74</td>
</tr>
<tr>
<td>WCS spelling</td>
<td>0.09</td>
<td>0.83</td>
<td>0.14</td>
<td>0.86</td>
<td>0.15</td>
<td>0.7</td>
</tr>
<tr>
<td>WUT spelling</td>
<td>−0.23</td>
<td>0.71</td>
<td>0.54</td>
<td>1.00</td>
<td>0.58</td>
<td>0.85</td>
</tr>
<tr>
<td>PW spelling</td>
<td>−0.26</td>
<td>0.83</td>
<td>−0.29</td>
<td>0.87</td>
<td>−0.24</td>
<td>0.85</td>
</tr>
</tbody>
</table>

Note: Performances reported as z scores. Reading test: MT reading test (Cornoldi & Colpo, 1998). Spelling test: Diagnosis of Developmental Orthographic Disorder (DDO–2; Angelelli et al., 2016). DDO = words with regular one-sound-to-one-letter correspondence; WCS = words requiring the application of context-sensitive rules; WUT = words with unpredictable transcription; PW = pseudowords with regular one-sound-to-one-letter correspondence.

DDO–2; Angelelli, Marinelli, et al., 2016); (c) normal performance on Raven’s Coloured Progressive Matrices (CPM; Prunetti et al., 1996), and (d) adequate socio-educational conditions. Screening data are presented in Table 1. Overall, 10 children were excluded from the study (leading to the present sample of 106 children), because they did not fulfill these criteria.

Groups did not differ for Raven’s CPM performance (z score), F(2, 102) = 1.96, p = .15.

Parents were informed of the screening activities and authorized their child’s participation by signing the appropriate informed consent paperwork. The study was conducted according to the principles of the Helsinki Declaration and was approved by school authorities.

Reading assessment

Reading level was assessed using a standard reading achievement test (MT Reading Test, Cornoldi & Colpo, 1998). Two meaningful text passages were given. The participant had to read aloud the first text passage within a 4-min time limit; speed (time in seconds per number of syllables read) and accuracy (number of errors, adjusted for the amount of text read) were computed. The second passage had to be read silently or aloud without a time limit, and the participant answered 10 multiple-choice questions (comprehension index). Stimulus materials and related reference norms varied depending on school grade. Children with a performance below 2 standard deviations of the normative data (Cornoldi & Colpo, 1998) for reading speed and/or accuracy were excluded.

Spelling assessment

Participants’ spelling abilities were tested with a standard spelling test (DDO–2, Angelelli, Marinelli, et al., 2016) composed of four sections:

- Section A (N = 70): words with full one-sound-to-one-letter correspondence;
- Section B: words requiring the application of context-sensitive sound-to-spelling rules (N = 10). In Italian, context-sensitive rules are required when the orthographic transcription of a consonant depends on the following sound. For example, the phoneme [k] is spelled C when followed by a consonant [e.g., in CLIMA /klima/ (climate) or by A, O, U as in CASA /kaza/ (home), CONO /kono/ (cone)] and CH when followed by E or I [e.g., in CHILO /kilo/ (kilogram)];
- Section C (N = 55): words with unpredictable phonology-to-orthography transcription [e.g., /kwo/ in /kwota/ (= share); QUOTA and not *CUOTA];
- Section D (N = 25): pseudowords with one-sound-to-one-letter correspondence.

The number of items spelled correctly in each category was computed. Children were excluded if their performance was two standard deviations below the normative data (Angelelli, Marinelli, et al., 2016) for accuracy on the total corpus of stimuli.

Experimental procedure and material

The experimental stimuli included 30 words, half of high and half of low frequency, which had to serve as primes of different types in the subsequent priming experiment (see the Supplemental material, left-hand column). Words were selected from the frequency dictionary for children based on a corpus of 1 million of occurrences (Marconi, Ott, Pesenti, Ratti, & Tavella, 1993). High-frequency words had a frequency higher than 40, low-frequency words a frequency lower than 30 (Marconi et al., 1993).

Twenty words, which had to serve as related primes, had unpredictable spellings due to the presence of one of the following inconsistently spelled segments: (a) the phonemic group [kw] sometimes transoded as CU, and other times as QU (e.g., CUOCO /’kwɔko/ (cook) vs. QUOTA /’kwota/ (share)); (b) the syllables [tʃe]; [ʃe], which are written as CIE, SCIENZA in some words and CE, SCE in other words (e.g., CIECO /’tʃɛko/ (blind) vs. CECO /’tʃɛko/ (Czech), SCIENZA /ʃɛntsa/ (science) vs. ADOLESCENZA /adoleʃɛntsa/
(adolescence)]; (c) the plosive phoneme [b], which, when followed by the liquid consonants [r] and [l], is a homophone to its doubled pair. Each segment was considered either high or low frequency depending on its occurrence in two frequency dictionaries (De Mauro, 1989; Marconi et al., 1993). Accordingly, the orthographic segments CE, SCE, QU, BL, and BR were considered high-frequency segments because they appeared in 77.2% (according to Marconi et al.’s, 1993, database) and 82.8% (De Mauro’s, 1989, database) of words including the corresponding ambiguous phoneme; by contrast, CIE, SCIE, CU, BBL, and BBR were considered as low-frequency segments because they appeared in 22.8% and 17.2% of cases in the two databases, respectively. From now on and throughout the text, we use the terms common and uncommon to refer to high- and low-frequency segments, respectively. Ten of the selected words, which had to serve as unrelated primes, had consistent spelling. In sum, the 30 prime words were subdivided as follows:

- Ten high-frequency words with unpredictable spelling: Five had the more frequent type of transcription for the critical segment [e.g., SCELTA /ˈʃɛltə/ (choice)], and five had the less frequent one [e.g., SCIENZA /ˈʃɛntsa/ (science)];
- Ten low-frequency words with unpredictable spelling: Five had the more frequent type of transcription for the critical segment [e.g., QUOTA /ˈkwɔta/ (quote)], and five the less frequent [e.g., CUOIO /ˈkwɔio/ (leather)];
- Ten words with one-sound-to-one-letter correspondence: five had high frequency [e.g., FRASE (= sentence)], and five low frequency [e.g., DIETA (= diet)].

The sets were matched for number of letters, grammatical class, word frequency, and bigram frequency (in both the children’s and the adult’s word frequency corpora: Marconi et al., 1993; Bertinetto et al., 2005, respectively), N-size (according to the Colfis database, Bertinetto et al., 2005), and the position of the critical segment in the word (in the case of unpredictable words).

A total of 30 filler words (with no inconsistently spelled segments) were added to the experimental list to prevent participants from understanding the aim of the experiment and to limit the effects of repetition of the graphomotor patterns in spelling the ambiguous segments. Filler words were matched to the experimental words for frequency, grammatical class, number of letters, and orthographic complexity.

Overall, the experimental list included a total of 30 experimental stimuli (20 related and 10 unrelated prime words) and 30 filler words. Words were presented in random order and were given to children in a spelling-to-dictation task. The experimenter read aloud each stimulus in the list without emphasizing the possible source of ambiguity, and the children were required to write each stimulus in either capital or lower-case letters (as they preferred). No feedback was provided about the accuracy of the written response. In the case of self-corrections, final responses were considered.

Children were tested individually in a quiet room. The experimental session lasted about 20 minutes.

**Data analysis**

Only accuracy on words with unpredictable spellings was computed. Only errors in the transcription of the critical segment with the complementary erroneous transcription were taken into account [e.g., SCIENZA (= science) spelled *SCENZA or SCELTA (= choice) spelled *SCIELTA]. Errors regarding the critical segment that were different in nature [e.g., SCIENZA (= science) spelled *SIENZA or SENZA] were not computed. Similarly, correct transcriptions of the critical segment of the word, with errors in other parts of the word [e.g., SCIENZA (= science) spelled *SCIENSA] were discarded from the computation of errors.

Errors on control words were not analysed because they were not relevant for the purpose of the present study. Accuracy in spelling this sub-set of words was at ceiling (96% in first-grade, 100% in second-grade, 99% in fourth-grade children).

Accuracy percentages on words with unpredictable spellings were analysed by means of analysis of variance (ANOVA) with grade (first, second, and fourth grade) as between factor and word frequency (high, low) and segment transcription frequency (high frequency vs. low frequency) as within factors. Significant interactions were explored by means of planned comparisons.

**Results**

Figure 1 reports the percentages of accuracy in spelling words as a function of grade, word frequency, and segment frequency. As can be seen in the figure, the children were more accurate in spelling critical high-frequency segments than low-frequency...
ones in each grade, especially in the case of low-frequency words. However, first-graders showed a large effect of segment frequency irrespective of word frequency, whereas the difference in accuracy for high-versus low-frequency segments decreased in second- and fourth-graders, especially in the case of high-frequency words.

The ANOVA showed a significant effect of grade, $F(2, 102) = 53.85$, $MS = 28,911$, $p < .0001$: Overall, first-graders had a lower level of accuracy (60%) in word spelling than second- (81.33%; $p < .0001$) and fourth-graders (87.85%; $p < .0001$). The difference between second- and fourth-graders was also significant ($p < .05$). The effects of word frequency, $F(1, 102) = 127.64$, $MS = 23,693$, $p < .0001$, and segment transcription frequency, $F(1, 102) = 187.40$, $MS = 81,124$, $p < .0001$, were significant, with greater spelling accuracy for high-frequency words than for low-frequency ones (84% vs. 69%) and for common segments than for uncommon ones (91% vs. 62%).

The Grade x Segment Transcription Frequency interaction was significant, $F(2, 102) = 52.55$, $MS = 22,748$, $p < .0001$: A high and comparable level of accuracy was reported in each grade for common segments (89% in first-, 89% in second-, and 94% in fourth-grade children), whereas progressively higher levels of accuracy emerged for uncommon ones as a function of schooling (31% accuracy in first grade compared to 74% and 82% in second and fourth grade, respectively, at least $p < .0001$; the difference between second and fourth grade approached significance). Note that the presence of a common segment led to fewer errors in each grade (at least $p < .001$), but this reduction was considerably larger in first grade (58%) compared to second and fourth grade (15% and 12%, respectively, at least $p < .0001$; and the difference between second and fourth grade was not significant). The reduction of errors due to the presence of a common segment did not differ in second- and fourth-grade children.

The Word Frequency x Segment Transcription Frequency interaction was also significant, $F(1, 102) = 3.96$, $MS = 660$, $p < .05$: The difference in accuracy between segments with common transcription and segments with uncommon transcription was larger for low-frequency words (31%) than for high-frequency words (26%).

The Grade x Word Frequency interaction approached significance, $F(2, 102) = 2.40$, $MS = 445$, $p = .09$: for low-frequency words, a higher level of accuracy was evident as a function of schooling (with 50%, 74%, and 82% accuracies for first-, second-, and fourth-grade children, respectively, at least $p < .001$); for high-frequency words there was a lower level of accuracy in first grade than in second and fourth grade (70%, vs. 89% and 94%, respectively; $p < .0001$), and no difference emerged in second and fourth grade.

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**Experiment 2: Lexical priming on pseudoword spelling**

**Method**

Participants were the same as those in Experiment 1.

**Experimental procedure and material**

For this experiment, the words tested in Experiment 1 were used as primes. For each prime word, a target pseudoword with an ambiguous segment along the phonological-to-orthographic conversion routine was created (see the Supplemental material, right-hand column). Target pseudowords were comparable to prime words for length (number of letters), type and position of the critical segment, and orthographic complexity (presence of geminates or consonant clusters). For example, for the prime word SCELTA, /ˈʃɛlta/ (choice), the pseudoword /ʃɛrco/ was created; for COSCIENZA, /ˈkɔʃɛnza/ (consciousness), the pseudoword /ˈmaʃɛrda/ was created. All pseudoword sets were controlled for bigram frequency (according to both the children’s and the adults’ word frequency corpora; Bertinetto et al., 2005; Marconi et al., 1993) and N-size (http://dpss.psy.unipd.it/claudio/vicini2.php), all $F_s < 1$. Target pseudowords were also paired to filler prime words; they had the same number of letters.

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Figure 1. Percentages of accuracy in spelling words with unpredictable spelling as a function of grade, word frequency, and segment frequency. HF = high frequency; LF = low frequency.
and same degree of orthographic complexity as the filler prime words.

In sum, the experimental list consisted of 60 pairs of word primes and pseudoword targets: 30 experimental pseudoword targets preceded by a related or an unrelated prime word (20 related and 10 unrelated) and 30 pairs of filler word primes and pseudoword targets.

The experiment of lexical priming on pseudowords was run at a distance of one week from the word spelling experiment. The 120 stimuli (the same for each participant) were presented in random order, with each prime word being followed by its paired target pseudoword. The experimenter read each item aloud in a neutral tone, and the children were instructed to spell the pseudowords only and to write a hyphen for words. As in the word spelling experiment, children could write in capital or lowercase letters, and only final responses were considered. A brief practice session preceded the priming experiment. The stimuli were divided into three blocks so that the young children did not have to make too great an effort. Participants performed each block on a different day (with at least one week between test sessions). Each experimental session lasted about 20 min. The order of presentation of the three blocks was balanced across participants; no detectable differences in accuracy were found among the three groups who performed the blocks in different order ($F_{s}$ < 1).

**Data analysis**

First, we counted the percentages of times children chose the high- versus low-frequency transcription of the critical segment in pseudoword spelling, for each priming condition (unrelated, related with a common segment, related with an uncommon segment). In the related prime conditions we excluded all target pseudoword spellings where the corresponding prime word had been misspelled in Experiment 1. Then a multivariate analysis of variance (MANOVA) was carried out in order to compare pseudoword spelling in the three priming conditions. Grade (three levels: first, second, and fourth grade) was entered as between factor and condition (three levels: unrelated, related primes with common segments, and related primes with uncommon segments) and word frequency of the prime (high, low) as within factors. The dependent variable was the percentage of target pseudowords spelled with common or uncommon segments. This analysis was meant to capture the lexical priming effect on pseudoword spelling, thus disclosing in what measure related prime words would produce an effect different than expected without their influence. In each analysis, significant interactions were explored by means of planned comparisons.

**Results**

The lexical priming effect was evaluated by comparing pseudoword spellings following either unrelated or related prime words. Table 2 reports the percentages of common and uncommon segment transcriptions in spelling pseudowords preceded by unrelated—for example, FIUME /fiume/ (river)—or related prime words—for example, CIELO [ˈtʃelo] (sky)—which included either a common or an uncommon segment.

The MANOVA showed the significance of the main effects of grade, $F(4, 202) = 20.47$, Wilks = .51, $p < .0001$, and condition, $F(4, 99) = 105.74$, Wilks = .19, $p < .0001$. The main effect of word frequency was not significant, $F(2, 101) = 0.07$, ns, but word frequency interacted significantly with condition, $F(4, 99) = 7.98$, Wilks = .76, $p < .0001$. Also the interaction Grade $\times$ Condition was significant, $F(8, 108) = 10.68$, Wilks = .49, $p < .0001$.

The Word Frequency $\times$ Condition interaction was significant also in univariate analysis on both the percentages of pseudowords spelled with the common segment, $F(4, 204) = 12.24$, $MS = 2529$, $p < .0001$, and those with the uncommon one, $F(4, 204) = 12.45$, $MS = 2181$, $p < .0001$. The exploration of the interaction (Figure 2) highlights that word frequency did not influence the choice of common or uncommon segments in the case of pseudowords preceded by unrelated prime words. In contrast, a frequency effect was present in the case of related primes, with larger priming effects for high-frequency primes than for low-frequency ones. Pseudowords preceded by a related prime containing a common segment were spelled more frequently with a common segment when preceded by high-frequency primes than when preceded by low-frequency ones ($p < .001$); in this priming condition, uncommon segments occurred rarely and were more frequent in the case of low-frequency primes, which resulted in their being less effective primes than high-frequency ones ($p < .01$). Similarly, when pseudoword targets were preceded by a related prime containing an uncommon segment, children used uncommon segments
more frequently in the case of high-frequency primes than for low-frequency ones ($p < .05$); unprimed common segments occurred more frequently with low-frequency primes, which again resulted in their being less effective primes than high-frequency ones ($p < .01$). Note that this pattern did not interact with grade, indicating that prime frequency modulated spelling performance in a similar way for all groups.

The Grade × Condition interaction is represented in Figure 3. Univariate results confirmed the significance of the interaction for pseudowords spelled with common segments, $F(4, 204) = 33.09$, $MS = 10,716$, $p < .0001$, and uncommon ones, $F(4, 204) = 32.55$, $MS = 9937$, $p < .0001$. Exploration of the interaction showed that lexical priming effects emerged as a function of age. With related primes containing common segments, second- and fourth-grade children but not first-grade children increased the use of common segments (at least $p < .001$) and decreased the use of uncommon ones (at least $p < .0001$) with respect to the unrelated (control) condition. In first-grade children the use of common segments was maximized, and the related priming condition with common segments did not further increase children’s tendency to use the most common segments. On the other hand, when a related prime containing an uncommon segment preceded the target pseudoword, second- and fourth-grade children inverted their response trend with respect to the control condition: The percentages of uncommon segments in pseudoword spelling largely increased (at least $p < .0001$), while the use of common segments considerably decreased (at least $p < .0001$). A smaller but significant effect was

![Figure 2](image)

**Figure 2.** Percentages of choice of common versus uncommon segment for each priming condition as a function of prime word frequency. hf = high frequency; lf = low frequency.

<table>
<thead>
<tr>
<th>Segment choice</th>
<th>First grade</th>
<th>Second grade</th>
<th>Fourth grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Word prime frequency</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Related prime with common segment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unrelated prime</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>SE</td>
<td>M</td>
<td>SE</td>
</tr>
<tr>
<td>Unrelated prime</td>
<td>89.68</td>
<td>3.06</td>
<td>93.55</td>
</tr>
<tr>
<td>Related prime with common segment</td>
<td>91.67</td>
<td>2.90</td>
<td>97.00</td>
</tr>
<tr>
<td>Related prime with uncommon segment</td>
<td>8.39</td>
<td>2.75</td>
<td>3.11</td>
</tr>
<tr>
<td>Unrelated prime</td>
<td>8.39</td>
<td>2.96</td>
<td>7.74</td>
</tr>
</tbody>
</table>

Note: SE = standard error; hf = high frequency; lf = low frequency. Experimental condition: high- and low-frequency prime, unrelated versus related prime.
present also in first-grade children who, contrary to second- and fourth-grade children, continued to prefer common segments, but slightly increased the use of uncommon ones with respect to the unrelated condition (p < .01). In the related priming condition with uncommon segments, effects in first-grade children were smaller than those in second- and fourth-grade children on both common (at least p < .001) and uncommon (at least p < .0001) segments.

General discussion

In the present study we had two main aims: (a) to investigate whether young children (first-, second-, and fourth-graders) who are learning to spell in Italian, a language with a very consistent orthography, adopt spelling units that reflect sensitivity to the distributional properties of the orthography and to determine when this sensitivity appears; (b) to study how sensitivity to the distributional properties of orthography interacts with whole-word lexical processing.

Both experiments clearly showed that sensitivity to the distributional properties of orthography is an early acquisition in a language with a very consistent orthography, such as Italian. Specifically, at the end of the first year of school the children showed that they were affected by the statistical distribution of phonology to orthography mappings when spelling both words and pseudowords. In word spelling, children in first grade benefited as much as second- and fourth-graders from the presence of segments with very common transcription, which showed they had learned the distributional properties of orthography and were able to use this probabilistic knowledge for spelling. In the case of uncommon segments, higher levels of accuracy were obtained in higher grades, probably when whole-word lexical representations start to be established. These data indicate that sensitivity to the distributional properties of orthography is acquired very early—that is, before children optimize the acquisition of lexical orthographic representations. The early sensitivity to regularities was found also for pseudoword spelling in an unrelated prime condition, in which children preferred the most common spelling transcription in proportions that mirrored the occurrence of that transcription in the orthography of their language. In the case of unrelated prime words the children spelled target pseudowords exclusively using the distributional properties of the orthography and preferred the high-frequency transcription to the low-frequency one in 79% of cases. This effect did not interact with schooling: Similarly to second- and fourth-grade children, first-grade children were sensitive to the distributional properties of orthography. Thus, it can be concluded that sensitivity to the distributional properties of orthography is acquired very early and is already mastered by first-graders; indeed, further exposition to orthography with age, school experience, and book reading seemed not to increase this ability.

Our data are consistent with those collected in inconsistent orthographies, such as English, which show that already in first grade, children acquire orthographic regularities and prefer more frequent orthographic spelling patterns (e.g., Treiman, 1993). In the case of uncommon segments, higher levels of accuracy were obtained in second- and fourth-graders than in first-graders. As suggested by Treiman and Kessler (2006), people probably store the most common spellings and individually memorize the spellings of words with less common mappings. According to connectionist models, children modify the connections between phonological and spelling units in response to exposure to a substantial number of examples (Brown & Loosemore, 1994; Seidenberg, 1997) and progressively learn to adopt the most frequent orthographic solution in spelling. By using these connections it is possible to generate plausible spellings even for items that have never been encountered thanks to the statistical regularities.

Figure 3. Priming effects. The figure reports the percentages of common versus uncommon segment transcriptions in pseudoword spelling as a function of grade, in the unrelated and related prime (with both common and uncommon segment) conditions.
of the orthography on which the model has been trained. To our knowledge, cross-sectional studies on the emergency of sensitivity to distributional properties of the orthography are lacking. However, a study on spelling acquisition in a relatively consistent orthography such as Portuguese (Fernandes et al., 2008) concluded that spelling initially involved sublexical processing but was increasingly influenced by lexical processing as literacy acquisition progressed. Thus, our results are consistent with the view of a progressive expansion of the orthographic lexicon as a function of school experience.

Our study also highlights that sensitivity to the distributional properties of orthography interacts very early with whole-word lexical information in pseudoword spelling. In the second experiment we examined the effect of a prime word containing either high- or low-frequency segments to determine whether the activation of a lexical representation containing a given segment influences the spelling of the following pseudoword. Results showed that second-grade children were already sensitive not only to the frequency of the critical segment but also to the presence and frequency of related prime words. In particular, with related primes containing common segments, second- and fourth-grade children increased the use of common segments and decreased the use of uncommon ones. In first-grade children the use of common segments was maximal, and the priming condition with related primes containing common segments could not further increase children’s tendency to choose most common segments. On the contrary, a related prime including an uncommon segment largely affected pseudoword spelling of second- and fourth-grade children who preferred more frequently uncommon segments than common ones, thus inverting the response trend with respect to the unrelated condition. A smaller but significant effect was present also in first-grade children who, contrary to second- and fourth-grade children, continued to prefer common segments, but slightly increased the use of uncommon ones.

Our data highlight the presence of a lexical priming effect and the use of distributional knowledge in spelling in a very consistent orthography such as Italian. Findings are consistent with those reported in recent studies on reading acquisition in Italian children, which showed that children use distributional cues to assign stress to new and low-frequency words (e.g., Colombo, Deguchi, & Boureux, 2014). Moreover, the presence of many stress friends (i.e., a high proportion of words in the language that share the stress pattern and the final orthographic–phonemic sequence) influenced reading times and accuracy, outweighing any effect of stress dominance (Burani, Paizi, & Sulpizio, 2014; Paizi, Zoccolotti, & Burani, 2011). Sulpizio and Colombo (2013) examined stress assignment in reading aloud in Italian second- and fourth-grade children and found that both item-specific knowledge (as demonstrated by the frequency effect) and general information about stress distribution (as demonstrated by the stress neighbourhood effect) were relevant in children’s reading.

Overall, the present study supports the view that lexical and sublexical processes share information during the spelling of both known words and new stimuli. In their study on skilled English-speaking spellers, Barry and Seymour (1988) proposed that the sublexical process consisted of a set of probabilistic phoneme-to-grapheme mappings, weighted according to their frequency, and the selection of a particular phoneme-to-grapheme mapping from the weighted lists was open to lexical influence, but the mechanism was not specified. Following Folk and Rapp (2004), in skilled spellers the interaction between lexical and sublexical spelling consists in a “dynamic” updating of probabilistic sound–spelling correspondences, thanks to the fact that word primes activate orthographic lexemes that co-occur with grapheme selection. The “simultaneous activation” hypothesis (Rapp et al., 2002) foresees that both lexical and sublexical routines are simultaneously engaged by a phonological stimulus and activate candidate graphemic elements at the level of the graphemic buffer where information is integrated. In this vein, a cooperative interaction takes place when both routines agree on a given spelling, as in the case of pseudowords with common segments preceded by a related prime containing the same segment. When they do not agree, position-based competition takes place between candidate graphemes, and the most strongly activated candidates are selected for output. In this framework, school experience makes the difference between the most active outputs. In the present study, the poor lexical processing in first-grade children made word and pseudoword spelling was determined prevalently by sublexical probabilistic phoneme-to-grapheme mappings. However, already by second grade, the lexical output co-occurred with the sublexical procedure, to determine the spelling of both pseudowords (when preceded by a related prime words) and words.
Present results are important for two main reasons. First, they extend evidence of reliance on sublexical orthographic regularities to spelling in transparent orthographies. Perry and Ziegler (2004) showed that English-speaking skilled spellers exploited large-sized sound-to-spelling relationships as well as purely orthographic factors. However, their findings referred to adults learning an opaque orthography. The present series of experiments shows that from first grade Italian typically developing children not only learn the grapheme-to-phoneme mapping rules, but also acquire and use sound-to-spelling regularities that reflect statistical distributions in their orthography. Present data suggest that the sublexical spelling procedure may be based on implicit learning of intra- and inter-word regularities, along with explicit learning of phoneme-to-grapheme correspondences.

The second main finding is that lexical activation modulates pseudoword spelling even at the earliest developmental levels and in a transparent orthography. Interaction between lexical and sublexical information in spelling has been documented in both children (Bosse et al., 2003; Martinet et al., 2004) and adult spellers (e.g., Barry & Seymour, 1988; Folk & Rapp, 2004; Tainturier et al., 2013) of opaque orthographies. However, in opaque orthographies, such as English or French, the high degree of inconsistency in sound-to-spelling mappings induces strong reliance on lexical knowledge in spelling unlike what occurs in more consistent orthographies such as Italian (e.g., Marinelli et al., 2015). In transparent orthographies, the orthographic lexicon may be expected to have a less influential role than in opaque orthographies. However, the present data clearly show parallel processing of lexical and sublexical information in Italian young spellers, in line with lexical priming studies conducted in skilled adults (for the Italian see Barry & de Bastiani, 1997; for the Spanish see Cuetos, 1993) and in children learning Polish (Kaminska, 2003), another relatively transparent orthography. In the Polish study, lexical priming of pseudowords was used in two different experimental conditions: when pseudowords contained ambiguous phonological segments and the more adverse conditions when its specification was in conflict with that of the lexical prime. The study found that lexical orthography not only influences the resolution of phonology in cases of ambiguity, but overrides phonology when resolution is unambiguous. Similarly, in the present study we found that already in second grade, lexical activation influences probabilistic choices in determining the orthographic solution for spelling pseudowords containing phonological segments that can be spelled in more than one way. Similar conclusions were drawn in a recent study on Italian third- and fifth-grade typically developing children in which the effects of lexical neighbours on regular unambiguous pseudoword spelling were investigated (Angelelli et al., 2014).

In conclusion, our results indicate that young learners of a transparent orthography—that is, Italian—are sensitive to the distributional properties of orthography when they spell along the sublexical procedure already in the first year of school and that sublexical units and whole-word lexical knowledge interact very early.

**Notes**

1. In these experiments the target spelling of a pseudoword referred to the particular spelling of the pseudoword’s vowel that corresponded to the spelling of the same vowel in the prime word.
2. Stress assignment to polysyllabic words is the only aspect of the pronunciation of written Italian that cannot be predicted by rules.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

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