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Exploring the Influence of Letter Encoding on Motor Execution in English Word Writing: A Linguistic Analysis Compared to Italian

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Abstract

The study aims to explore the influence of double letters on handwriting in English compared to Italian. A methodological approach was applied, involving 20 English-speaking participants from Harvard University and 20 Italian-speaking participants from the University of Grenoble. The experiment utilized the Ductus software to analyze handwriting data, including inter-letter intervals and individual letter durations. The study concluded that words with double letters are written faster than other words, with significant differences between the two languages. The effect of double letters was more pronounced in Italian, highlighting the role of linguistic features in influencing motor processes during writing.

Keywords: English word writing, double-letter effect, comparative linguistics, handwriting, linguistic analysis, motor efficiency, doublet words, Italian words.

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Introduction

Proficiency in writing is a necessary life skill. In order to write a word, we first determine its spelling before using a pen or pencil keyboard to produce hand movements that correspond to the letters. In order to investigate the processes that are in motion prior to writing, experimental research on spelling processes typically measures reaction time. (Teulings et al., 1983)Movement kinematics is examined in the research on the motor components of written production. We retrieve the letter's shape and motor program when we write it, according to this viewpoint, the movements to produce it will be determined by this information. Thus, this perspective holds that writing words requires the linear activation of their letter components (Van Galen, 1991). This implies that, regardless of its linguistic equivalent, we should always write letters in the same manner. However, it is unlikely that we will automatically write a word one letter at a time without using any sort of

mnemonic device to help us remember the correct spelling. We propose that in order to maximize word production, spelling and motor processes interact. This cross-linguistic English-Italian study shows that the way the orthographic representations encode information affects the timing of motor production in addition to the shape of the letters we must write.

Studies on a range of cognitive processes have revealed that we often combine smaller units into larger chunks when we need to retrieve multiple elements in a sequence. Multiple studies ىproposed that multiple-element strings are especially effective at being remembered and retrieved using this processing method. Because we give each element a meaning that becomes a mnemonic cue, it is more efficient to chop them up into larger units. Phonological cues can influence how the writing system puts letters together in writing. Kandel and Spinelli (2010), for instance, found that the letter A is processed as a single unit when it is pronounced /a/, as in the word CLAVIER (keyboard), in French. However, because it is a part of the complex grapheme AI, it is pronounced /e/ when related to I, as in PRAIRIE (meadow). The AI will be processed in chunks by the writing system. In CLAVIER, the motor production timing for writing the letter A is shorter than in PRAIRIE. As a result, the way the orthographic representations encode the phonological counterpart of a letter, such as the shape of the letter A, affects when it is produced.

The issue of letter doubling is the focus of this investigation. Are double letters combined into a single, larger unit? Most of us have written a double letter in a word that isn't the letter that needs to be doubled at least once (e.g. A. MISSING? *misinng: we show the correct spelling in upper case and the production in lower case after the arrow; the * denotes that the letter sequence is not a word. We may be aware that a letter in the word needs to be doubled, but we may not be able to recall which letter it is. When writing a word, how do we know that we must double a letter? Do orthographic representations have a special coding for double letters? Neuropsychological data on spelling errors of dysgraphic patients who speak Italian and English indicate that this occurs because orthographic representations code letter identity and quantity independently (McCloskey et al., 1994).

According to the earliest research on the production of written language, the orthographic representations we use to write word code information on letter identity and order (Caramazza et al., 1987; Wing & Baddeley, 1980). For instance, the word "missing" would be represented as M1I2S3S4I5N6G7. This linear understanding of orthographic representations was quickly refuted by neuropsychological research based on dysgraphic patients' spelling performance. according to Caramazza and Miceli (1990) Orthographic representations are multi-dimensional structures that encode information on different levels of linguistic processing .Spelling mistakes made by a dysgraphic patient who speaks English suggest that letter identity and quantity are represented at different levels of representation (McCloskey et al. in 1994). Studies of typing behavior have provided further evidence that digraphs function as a single, integrated unit. This reduces the time between keystrokes when typing two letters as opposed to other sequences (Sternberg et al., 1990). Such a segmentation strategy is consistent with linguistic structure and influences the processing of motor skills in handwriting and typing, for example in handwriting French participants displayed longer gaps between letters when crossing letter boundaries. This indicates that they have adjusted

their speed (Kandel et al., 2006). These predicted motor adjustments support van Gaalen's (1991) idea of a nonlinear model for word representation in Produce motors.

Research on handwriting production indicates that the type of letter chunks we activate when retrieving a word's spelling, in addition to the spatial or geometric parameters of a letter, constrain movement production. Using a digitizer, French participants wrote words in capital letters (Kandel, Alvarez, and Valle´e, 2006). The length of time between letters was measured by the authors, just like in the typing studies. They examined the spacing between words that had the same initial letters but distinct syllable boundary positions (e.g. G. PRI. PRIS and SON. ME, the syllable boundary is indicated by the dot. The findings showed that the syllable boundary (IS) in PRI is the length of time that separates the letters. SON) was longer than the corresponding interval in a position within a syllable (IS in PRIS). ME). Because the motor system expected the subsequent syllable to be produced, the IS intervals were longer when they were situated at the syllable boundary. There was no need for additional processing at this level because the movement to produce the syllable for within-syllable IS intervals had already been programmed before writing began. As a result, letters are put together into larger pieces rather than being created sequentially, one after the other—i.e. e. syllables—which control motor programming when writing by hand. The anticipatory nature of movement production, as suggested by Van Galen's (1991) handwriting mod, can explain these variations in duration.

Further developments in this area were carried out by Kandel et al. (2011), who proposed an improved model based on van Galen's work. They argued that orthographic representations involve multidimensional encoding. The unique integration of letters, sequences, and syllable structures into coherent and retrievable units. This model reveals the phonological organization of the information retrieval process. This facilitates the production of smoother and more efficient motors. The findings from this study add valuable insights into the interaction of spell retrieval and motor processes in written language production in different languages.

Methods

Participants

the study included 20 English-speaking participants, all of whom were enrolled in a summer course at Harvard University. This part of the experiment was previously validated in a study by Kandel et al. (2013) and approved by the Harvard Institutional Review Board (IRB). In addition, 20 Italian-speaking participants were recruited. People from the Erasmus exchange program at the University of Grenoble Their participation complies with the ethical guidelines outlined for cognitive science experiments at the University of Grenoble. All participants were right-handed. Have normal or correct vision and do not have any hearing or mobility impairments These people are not aware of native speakers' goals in using English or Italian.

Materials

For experiments in Italian Most of the stimuli were paired with English words used in previous research by Kandel et al. (2013), respectively. Each language group was given a target word that contained pairs in the third and fourth syllables, such as “DISSIPATE” in English and "DISSIPARE" in Italian. These doublet words are paired with control words that

have the same first three letters but do not have a doublet (e.g. "DISGRACE" in English and "DISGRAZIA" in Italian) and allow for Default character structure This alignment is especially important for Italian Sm, where vowel duration is reduced in closed syllables. As noted in previous studies (Maddison, 1984; Chang, 2000).

Procedure

Experiments were conducted using Ductus software (Guinet & Kandel, 2010). Each trial began with an auditory signal and a fixation point displayed on the screen. This was followed by presentation of the words in Times New Roman font, size 18. Participants were instructed to immediately write the sight words at normal speed using an Intuos Inking Pen, lined paper with a Wacom Intuos 2 digitizer involved. It has a sampling frequency of 200 Hz and a precision of 0.02 mm. Participants were asked to write each word in uppercase letters and hold a pen between each letter. In order for the operation to go smoothly They wrote their names and practiced picking up a pen before the actual experiment. Twenty-eight target words were presented in two blocks. Each block contained 14 words. Additionally, 10 fillers were included to balance the stimuli. Each participant completed the task individually in a quiet room. And the whole session lasts 10 to 15 minutes.

Data Processing and Analysis

Data collected using the ductus were analyzed to measure latency. Duration of syllables and the distance between syllables Delay refers to the time that elapses between the appearance of words on the screen and the beginning of the writing activity. The motion data was processed using a Finite Impulse Response filter with a cutoff frequency of 12 hertz to smooth the signal. Syllable duration was normalized based on the number of beats per syllable for consistency. The letter interval refers to the time between two letters separated by a lift of the pen. The number of strokes was also analyzed. This is consistent with previous studies (e.g., Spinelli et al., 2012). For information in English Linear mixed effects models were used to account for participant and item variance. Statistical analyzes were performed on interval duration (I1 to I3) and letter stroke duration (L1 to L4), with word type (Doublet vs. Control) treated as a fixed effect. “DISSIPATE/DISGRACE” should be compared with “DISSIPARE/DISGRAZIA ”… etc. to find out the variation in fourth syllable recognition in situations like There is further analysis. Model selection was based on Bayesian Information Criterion (BIC) and p values for fixed effects were obtained from Type III ANOVA.

Results

Inter-letter Interval Duration

Figure 1 shows the average duration of the syllable difference (1–3) between the words Doublet and Control in English and Italian. There is a slight data exemption: 2.3% for English and 3.1% for Italian. Random affects variables such as participants, items, and fourth letter choices. This resulted in significant variance in both languages ($p < .001$).

Italian language

The analysis revealed noteworthy mixed effects. Specifically, there was an interaction between item and interval position ($\chi2(5) = 21.38$, $p < .001$), with interval duration for doublet words shorter than for control words ($F(1, 14.05)) = 5.36$, $p = . 036$) There was also

a significant effect of time period condition (F(2, 29.89) = 7.68, p = .002). The interaction between the two factors was also statistically significant. (F(2, 29.89) = 4.58, p = .041) Follow-up analysis revealed that the duration of the interval was 2.5 times longer than the control words in period 2 (t(1215) = -2.

English

The study explored the effects of word type and position on letter spacing and stroke duration in English and Italian, revealing interesting patterns in both languages. In English, no significant mixed effects were observed overall, suggesting that the type of word used did not notably influence letter spacing. Statistical analysis supported this, with no substantial effect of word type on letter spacing (F(1, 14.98) = 2.37, p = .144). However, the position of spacing within a word was found to be highly significant (F(2, 1614.39) = 7.49, p < .001). This indicates that where spacing occurs in the word influences how letters are spaced. Additionally, the interaction between word type and spacing position was significant (F(2, 1614.37) = 8.77, p < .001), suggesting that the impact of word type is more nuanced when considering specific positions within words.

A deeper investigation revealed differences in the duration of control words and paired words during period 3. Control words exhibited significantly longer durations (t(22.00) = -2.12, p = .046), which could imply greater complexity or processing effort for these words. These findings emphasize the importance of contextual and positional factors in understanding letter spacing and timing in English writing.

The analysis of letter stroke durations provided further insights. Figure 2 of the study highlighted the average stroke durations for the first four letters in both English and Italian words. The results showed that English control words excluded less information compared to Italian control words, with a negligible difference of 0.4% for English and 0.8% for Italian. These findings suggest slight variations in processing efficiency between the two languages. Random effect variables, including participant differences, item characteristics, and letter choice, significantly influenced the variance (p < .001). However, no significant mixed effects were found for either language in certain comparisons, underscoring the complexity of letter stroke dynamics.

Italian language

In the Italian language analysis, syllable stroke duration displayed a notable pattern. Paired words consistently showed shorter syllable stroke durations compared to control words (F(1, 17.25) = 5.32, p = .034). This suggests that paired words may be processed more efficiently in Italian, potentially due to phonological or structural features of the language. Letter position within words also had a significant impact on stroke duration (F(3, 2133.05) = 197.98, p < .001), indicating that specific positions within a word influence writing dynamics.

The interaction between word type and letter position was particularly significant in Italian (F(3, 2133.05) = 31.55, p < .001). This interaction revealed that stroke times were consistently shorter for paired words across all four letter positions, suggesting a robust relationship between word pairing and writing efficiency. These findings highlight the influence of linguistic structure and positional dynamics on writing behaviors in Italian.

Further exploration showed that stroke times for paired words were consistently shorter across all four letters compared to control words. This pattern underscores the efficiency of paired words in the Italian language, which may reflect the interplay of phonological and orthographic factors. The consistency of these results across letter positions emphasizes the structural advantages of paired words in Italian writing.

In conclusion, this study provides valuable insights into how word type and letter position influence letter spacing and stroke duration in English and Italian. While English exhibited notable positional effects on letter spacing, Italian revealed a consistent efficiency advantage for paired words in stroke duration. These findings contribute to a deeper understanding of cross-linguistic differences in writing processes and highlight the nuanced interplay between linguistic structure, word type, and positional dynamics. The results also underscore the significance of contextual factors, such as word type and letter position, in shaping writing behaviors across languages.

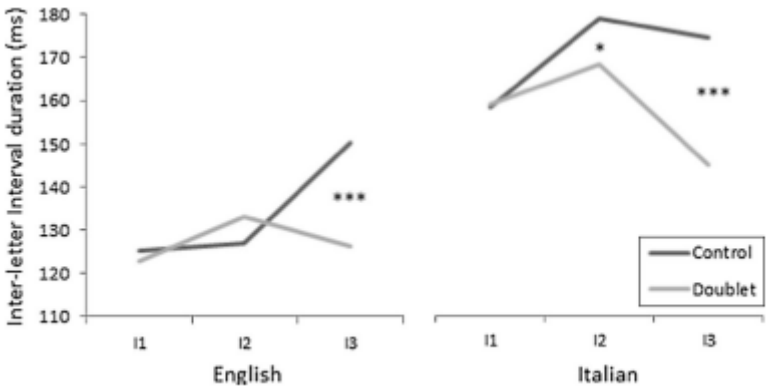

Figure 1: Average duration of 1-3 intervals between English and Italian words (e.g. DISSIPATE - DISSIPARE for Doublet words and DISGRACE - DISGRAZIA for control words). The intervals are as follows: interval 1 (I1) = DI, interval 2 (I2) = IS, period 3 (I3) = SS/SG

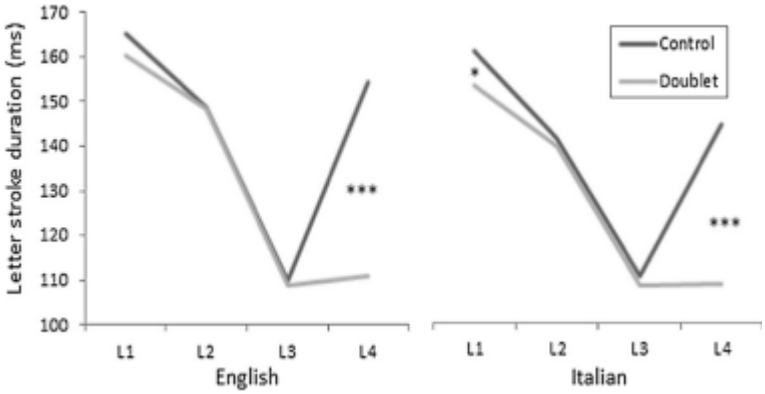

Figure 2: Average syllable stroke duration for 1-4 letters in English and Italian words (e.g. DISSIPATE - DISSIPARE for Doublet words and DISGRACE - DISGRAZIA for control

words). The letters are as follows: letter 1 (L1) = D, letter 2 (L2) = I, letter 3 (L3) = S, letter 4 (L4) = S/G

Analysis of stroke duration revealed a significant difference for letter 1 (L1), t(26.00) = -2.47, p = .010, and letter 4 (L4), t(17.71). = -7.49 , p < .001, but other effects Not statistically significant There was no significant effect of word type on English data (F(1, 19.5) = 1.49, p = .236). Letter position had a significant effect on stimulus time (F(3, 2172.1) = 232.74, p < .001), and the interaction of word type and letter position was also significant (F(3, 2172.1).) =) 47.55, p < .001) Further analysis indicated that the duration of the strokes for the paired words was shorter than the duration of the control words in all positions (letters 1 to 4).

Discussion

This study examines how letter pairs in words affect the writing process. Previous research by Kandel and colleagues (2013) showed in English that two letters affect spelling retrieval and writing style. The aim of this study was to determine whether this effect also holds for Italians. Considering the phonological differences between English and Italian letter pairs, We therefore sought to determine whether the presence of double letters would have a marked effect on writing in these two languages. to test this English-Italian speakers are asked to write words on a digitizer. These words either have double syllables (such as "DISSIPATE" in English and "DISSIPARE" in Italian) or do not have double syllables. But the initial syllable is the same (such as "DISGRACE" in English and "DISGRAZIA" in Italian). We measure several aspects of the writing process. including latency This reflects the time spent pulling spells and preparing moves. When I started writing We record the duration of each letter and the interval between them. The results showed that two-letter words had a noticeable effect on the timing of writing. especially Participants wrote control words more slowly than doublet words, however, this effect was larger in Italian. where the latency of doublet words was shorter compared to control words. This indicates that doubling letters has a greater effect on spelling processing in Italian than in English.

Table 1: Mean Latencies (in milliseconds) for Control and Doublet Words in English and Italian

Language	Doublet (ms)	Control (ms)	All (ms)
English	1153 (354)	1198 (407)	1176 (382)
Italian	1484 (517)	1543 (580)	1514 (549)
All	1317 (472)	1370 (529)	

The following table shows the average delays with standard deviations in parentheses for the English and Italian words Doublet and Control. These results show that the effects of two letters during spelling differ between the two languages. The effect is more pronounced than in Italian. Letter pairs influence the timing of motor processes involved in writing. As specified in the information Specifically, the space between the second and third syllables in pairs was shorter compared to control words. The rhythmic durations of the first and fourth syllables follow a similar pattern. Showing the effect of doubling syllables on the writing

process in Italian, especially before the motor construction process and during the phase... In English, when the latency of doublet words was less than that of control words, This difference was nearly significant (p = .055). The interval between syllables was shorter for pairs, especially between the third and fourth syllables. The stroke duration of the fourth syllable in pairs was also shorter compared to control words. It has been shown that the presence of diphthongs reduces the time required to write in both languages, although the effect is less pronounced than in English. What's interesting is the effect of doubling letters is greater in Italian than in English. Although numerical trends are similar in both languages, but the statistical difference in Italian is more significant. This suggests that the effect of digraphs on delay in Italian is stronger. It changes both the spell calling process and the preparation of movement before starting to write. In terms of producing movement Italian shows clear language-specific differences, with the second interval (just before the doublet, as seen in DISSIPARE vs. DISGRAZIA) being shorter in Doublet words than in Control words. These differences were not observed in English.

The results showed that word formation had a stronger effect on movement times in Italian compared to English. This observation is consistent with the idea of how acoustic differences between syllable pairs in two languages control motor processes. In English, digraphs mostly appear to affect later stages of the writing process, especially before both appear in the word. Moreover, analysis of seizure durations in both languages suggests that tubular pairs play a role in peripheral motor processing. Pair words had a shorter first syllable interval than control words. This is because the first syllable (such as the D in DISSIPATE/DISSIPARE) has the same shape and movement pattern in both word types. The time when participants began to write occurred due to active spelling processing. which will show the interaction between the central (spell extraction) and peripherals (motor formation) writing process The study also contributes to the understanding of how phonology affects written production, as Qu et al (2011) respectively point out that the global spelling retrieval process is not completed before phonology. start up Motor tasks are performed all the time (Roux et al., 2013). This supports the idea of an interactive process in Italian writing. where both characters are encoded not only by the choice of letters and sequence. but also the quantity. which affects the timing of the motor birth... Another pattern found in both languages is the distribution of movement times in the early stages of writing. Stroke duration decreased from 1–2 letters (D to I) and 2–3 (I to S), but in pairs (S to S), was constant between –4 syllables but increased significantly. In the duration of the rhythm between S and G in control words, according to the models of Kandel et al. (2013, 2014) and van Gaalen (1991), no increase in duration was observed in syllable pairs 3–4 because the fourth syllable was It is pre-programmed during the first stage of writing. This shows that the fourth syllable was not premeditated by increasing its duration. in controlling speech These results are consistent with neuropsychological studies of patients with English and Italian language impairments. The orthography appears to divide two letters. It is the different processing units that affect the timing of the motor. The time it takes to create a letter depends more on the size of the letter than on its uniqueness.

The current study extends these findings by showing that syllable segmentation and processing also influences later writing processes. This format is found in both English and Italian. But France tends to be different. Where digraph processing delays movement production (Kandel et al., 2014), the contrasting effects of letter doubling in English/Italian

and French raise interesting questions. One possibility might be that processing of French word pairs overlaps with processing of following letters. It creates an intellectual burden. This leads to a long writing process. Unlike English, there is no competition in processing word-letter pairs (Cutler et al., 1986). It also facilitates faster processing when writing, another explanation for the effect. The frequency of doublets in a language can be determined by how often doublets appear in the graph for each language. Can be doublet encoded. Another explanation for the different effects of doublets across languages could be the frequency with which doublets appear in each language's graph. When double values often appear in written texts Double encoding may be more efficient, for example, a previous study (Kandel et al., 2011) found that the frequency of diagrams influenced the handwriting production of French adults. to check this We examined the frequency of letter pairs in Italian, English, and French using word lists. Although all three languages have many different consonant pairs, but the distribution of consonant pairs is somewhat different, an example is, ZZ, CC, and TT are more Italian than French and English, while NN and SS are more Italian. Despite these differences, the overall percentage of words containing doublets is similar across languages (29.8% for Italian, 21.6% for English, 24.8% for French), as is the frequency of doublets.

Finally, the online system measures Letters and duration... It helps to determine where the double effect will be most evident. The results indicate that double processing begins during movement preparation up to the third syllable, when doubles are actually written, meaning that double letters appear to affect writing more slowly than latency measures used in studies of doubles word processing. These findings enhance our understanding of how writing works from an interactive perspective that combines cognition (spelling) and movement. (writing production). factor This view has been widely discussed in the context of speech production (Kawamoto et al., 1998; Rastle et al., 2000) and more recent research on writing production. It has been successful in combining measures of motor performance with cognitive factors (Afonso et al., 2015a, 2015b; Álvarez et al., 2009; Delattre et al., 2006; Kandel et al., 2006, 2012; Lambert & Quemart, 2015).

Implications

- Educational: Orthographic difficulty should be taken into account when teaching handwriting, especially to English language learners.
- Cognitive neuroscience: Neural correlates of orthography-motor interactions should be investigated in future studies.

Limitations & Future Work:

- The sample size might be increased.
- Cross-linguistic comparisons could be strengthened by the addition of additional languages, such as French or German.

Our knowledge of how language structure influences motor behavior is improved by this research, which also provides new avenues for multidisciplinary linguistics and cognitive science research.

Conclusion

Our results clearly show that the presence of double letters (double letters) affects how long the motor construction takes before the actual letters are written. These findings support the theory that central processes involved in spelling extend to motor writing processes, as suggested by Roux and colleagues (2013). Moreover, our data indicate that phonological information plays a role in modulation. Double change orthographic processing It is proposed that the duration of motor processes during letter formation is not only determined by letter size and activation of motor programs. But it also affects how orthographic representations are encoded during spelling retrieval. Handwriting motor execution is directly influenced by letter encoding, which is formed by orthographic depth. Italian spelling is consistent, which makes execution easier, whereas English spelling is erratic, which increases the demands on motor planning.

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Appendices

Appendix1

Doublet and Control words in Italian and English

Italian words		English words[a]	
Doublet	Control	Doublet	Control
BALLATA	BALCONE	BALLOT	BALCONY
CARRUGIO	CARTIERA	CARRIER	CARING
COLLARE	COLMARE	COLLAR	COLONY
CORRIDOIO	CORPOREO	CORRIDOR	CORPORAL
DISSIPARE	DISGRAZIA	DISSIPATE	DISGRACE
DISSOLUTO	DISTINTO	DISSOLUTE	DISTINCT
FERROSO	FERTILE	FERROUS	FERTILE
MANNAIA	MANDATO	MANNER	MANAGE
MARRONE	MARZIALE	MARROW	MARTIAL
MASSONE	MASTINO	MASSIVE	MASTER
PASSATA	PASTOSO	PASSIVE	PASTING
PASSIVO	PASTORE	PASSION	PASTOR
POLLAIO	POLMONE	POLLUTE	POLEMIC
PRESSIONE	PRESTIGIO	PRESSURE	PRESTIGE

a. From Kandel et al. (2013)

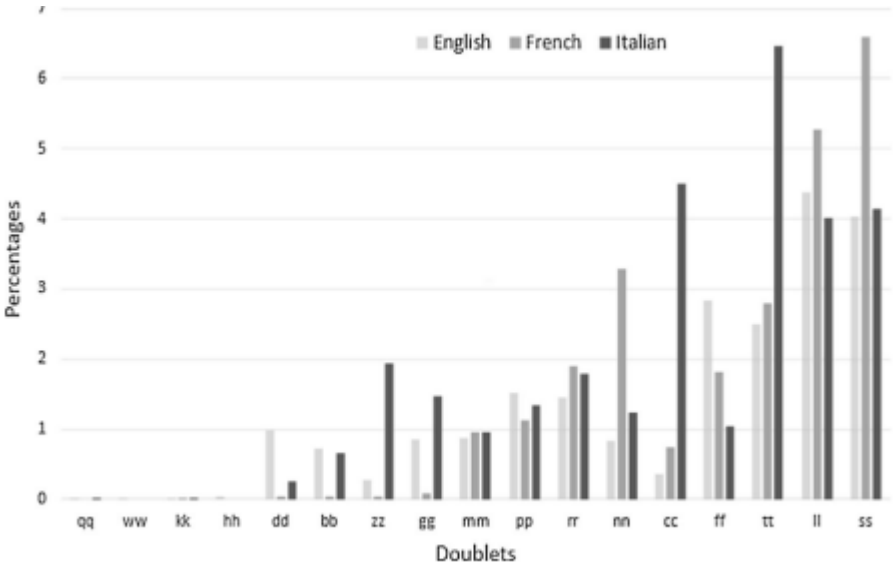
Appendix2

Characteristics of the Italian and English Words

Characteristics	Italian words		English words	
	Doublet	Control	Doublet	Control
Word frequency (pm)[a]	7.53	7.69	26.16	14.18
Number of letters	7.57	7.57	7.14	6.93
Number of syllables	3.21	3.07	2.21	2.29
Number of phonemes	6.50	7.57	5.36	6.14

***Note**: a. Word frequency data for Italian are sourced from CoLFIS (Bertinetto et al., 2008), and for English, from Celex (Baayen et al., 1995).*

Appendix3



Percentages of Words Including Double Consonant Letters in Bi- and Tri-Syllabic Words in Italian, English, and French

This analysis examines the occurrence of double consonant letters in bi- and tri-syllabic words across three languages: Italian, English, and French. The data comes from three word corpora:

- **PhonItalia** for Italian (Goslin et al., 2014)
- **Celex** for English (Baayen et al., 1995)
- **Lexique** for French (New et al., 2001)