

Stress Assignment in Reading Italian Polysyllabic Pseudowords

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In 4 naming experiments we investigated how Italian readers assign stress to pseudowords. We assessed whether participants assign stress following distributional information such as stress neighborhood (the proportion and number of existent words sharing orthographic ending and stress pattern) and whether such distributional information affects naming speed. Experiments 1 and 2 tested how readers assign stress to pseudowords. The results showed that participants assign stress on the basis of the pseudowords' stress neighborhood, but only when this orthographic/phonological information is widely represented in the lexicon. Experiments 3 and 4 tested the naming speed of pseudowords with different stress patterns. Participants were faster in reading pseudowords with antepenultimate than with penultimate stress. The effect was not driven by distributional information, but it was related to the stage of articulation planning. Overall, the experiments showed that, under certain conditions, readers assign stress using orthographic/phonological distributional information. However, the distributional information does not speed up pseudoword naming, which is affected by stress computation at the level of the articulation planning of the stimulus. It is claimed that models of reading aloud and speech production should be merged at the level of phonological encoding, when segmental and metrical information are assembled and articulation is planned.

Keywords: stress assignment, pseudoword reading, reading aloud, stress neighborhood, articulation planning

There has been growing interest in how readers assign stress to polysyllabic words and which orthographic and phonological components are involved in this process. If we consider languages such as Italian, Spanish, or Dutch, in which polysyllables are a large part of the lexicon and stress position is not fixed, then understanding how word stress is computed and assigned becomes a fundamental component of understanding the reading process itself. If we do not know where the position of stress is, we are not able to read out a word correctly. Stress assignment may affect not only reading accuracy but also reading speed, because the articulation of a word cannot start until the word has received stress.

Thus, the assignment of word stress is a central issue in reading research.

The first studies on word stress assignment addressed two main issues. First, in line with the dual-route view of reading, some studies investigated whether and how stress is computed through a lexical and/or a sublexical mechanism (Rastle & Coltheart, 2000). Second, in line with a connectionist approach, the relationship between stress and some orthographic/phonological units that may be able to affect the reading process was studied (Kelly, Morris, & Verrekia, 1998). Research conducted in English and Italian has shown that readers, in assigning stress, are affected by the presence of some specific orthographic units (cues) in the stimulus. Both word beginning and word ending units may work as cues to stress assignment (for word beginning, see Arciuli & Cupples, 2007; Arciuli, Monaghan, & Ševa, 2010; Kelly, 2004; for word ending, see Arciuli & Cupples, 2006; Arciuli et al., 2010; Burani & Arduino, 2004; Colombo, 1992; Kelly et al., 1998). However, the two cues do not have the same role, and word ending seems to be the strongest predictor of stress position (Arciuli et al., 2010). Research in Italian has shown that stress neighborhood may affect placement of stress: When readers process a word whose final sequence is shared by a majority of stress friends (words with the same final sequence and the same stress pattern), stress assignment is facilitated by this orthographic/phonological cue (Burani & Arduino, 2004; Colombo, 1992).

The relationship between orthographic information and stress assignment has also been investigated in pseudoword (PW) read-

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ing. A first group of studies focused on mechanisms such as rule application or analogy with real words. Research in English and Greek showed that properties such as the similarity of a pseudoword to a real word (Guion, Clark, Harada, & Wayland, 2003; Protopapas, Gerakaki, & Alexandri, 2007) or the presence of morphemic constituents in the pseudoword (Rastle & Coltheart, 2000) are among the factors that influence stress assignment.

Other studies focused on the role of distributional information in stress assignment to PWs. In Italian, the first study was conducted by Colombo (1992, Experiment 5). She investigated how the distributional knowledge concerning stress and its orthographic/phonological cues may affect the reading of three-syllabic pseudowords. Colombo claimed that the probability that a pseudoword receives a certain stress may depend on two factors: first, the reader's knowledge concerning the asymmetrical distribution of stress patterns in Italian (where 80% of words bear penultimate stress, while 18% bear antepenultimate stress; Thornton, Iacobini, & Burani, 1997),¹ so that penultimate stress would work as a default; second, the composition of the stress neighborhood, which would interact with the default to drive stress assignment to pseudowords.

In Italian, each of the two main stress patterns is usually associated with certain word endings. For example, the final sequence *-oro* is associated with the most frequent stress in the language (on the second syllable)—that is, it occurs predominantly in three-syllabic words with penultimate stress (e.g., *caSTOro*, beaver). In contrast, the final sequence *-ola* is associated with the least frequent stress (on the first syllable), that is, it occurs predominantly in three-syllabic words with an antepenultimate stress pattern (e.g., *PENtola*, pot). Accordingly, the stress neighborhood of the final sequence *-oro* is mainly composed of penultimate stress words, while the final sequence *-ola* has a stress neighborhood mainly composed of antepenultimate stress words.

Colombo (1992) found that readers followed the default bias and pronounced pseudowords mostly with penultimate stress. She also found that readers assigned the antepenultimate (nondominant) stress pattern mainly when the pseudoword targets had a stress neighborhood composed of many words associated with nondominant stress. According to Colombo, pseudoword reading is only partially affected by stress neighborhood, which would play a role only when it is predominantly associated with the antepenultimate (nondominant) stress pattern. This result is in line with the finding of the same study on low-frequency words (Experiment 4), where stress neighborhood facilitated only the antepenultimate stress words, with no effect on the words bearing penultimate (dominant) stress.

In a more recent study on Italian word and pseudoword reading, Colombo and Zevin (2009) reported somewhat different results. They investigated stress computation within a lexical (word primes) or a sublexical (pseudoword primes) context. The authors found that the default mechanism (which assigns penultimate stress) only applies when stimuli are processed through the sublexical route, and stress neighborhood can drive not only antepenultimate stress but also penultimate stress assignment (see also Burani & Arduino, 2004). These results on Italian find further support in a recent study investigating how English-speaking children assign stress to bisyllabic pseudowords (Arciuli et al., 2010, Study 2). The authors tested whether both the orthographic cues and the distributional bias (in English, the initial stress is the most

common) affect children's stress assignment. The results showed that younger (5- to 6-year-old) children assigned stress more frequently to the first syllable, following the general distribution of English stress and paying little attention to the initial and the final part of the pseudowords. In older (7- to 8-year-old) children, the bias toward the initial stress became weaker; they started assigning stress following the orthographic cues, with the final sequence playing a main role.

The findings on pseudoword reading so far (Arciuli et al., 2010; Colombo, 1992; Colombo & Zevin, 2009) suggest that readers can assign stress on the basis of their distributional knowledge. All studies agree that word ending, and thus stress neighborhood, is a strong orthographic cue for stress assignment. However, the contrasting results on the role of the default bias are an open issue. While some studies show that readers may use the default bias when they assign stress to a pseudoword (Colombo, 1992; Colombo & Zevin, 2009), other studies (e.g., Arciuli et al., 2010) suggest that the bias toward the most common stress in the language rapidly decreases its effect with age, and its role becomes less influential than the role of stress neighborhood.

It has been assumed that stress assignment may affect word naming time at the level of the phonological output buffer (Perry, Ziegler, & Zorzi, 2010).² However, none of the previous studies has investigated the timing of stress computation in PW reading. Whether readers have knowledge concerning the distribution of stress patterns in their language and how such knowledge may affect PW reading in terms of both accuracy and naming speed is a matter of ongoing debate.

In the present study we aimed at investigating stress computation in reading aloud Italian pseudowords. We investigated not only whether stress neighborhood affects stress assignment but also how it may affect naming speed. When reading a stimulus, we execute at least two operations related to stress: We select one stress pattern, and we associate such metrical structure with the stimulus's phonemes separately retrieved (Roelofs & Meyer, 1998; Sulpizio, Job, & Burani, in press). The two operations may affect both pronunciation accuracy (in terms of which stress pattern readers assign to a PW) and naming speed (in terms of the time necessary to assemble the stimulus's metrical and segmental structure and to execute it) of PWs. Understanding stress computation requires that both issues—assignment of correct stress and its influence on naming speed—are addressed.

Let us first consider stress assignment to PWs. In line with previous studies in Italian (Colombo, 1992; Colombo & Zevin, 2009), we may expect that participants assign stress following the main distributional bias according to which the penultimate stress is dominant in Italian, with stress neighborhood playing a minor role limited to antepenultimate stress assignment. On the other hand, stress neighborhood might be considered as the main distributional information used by readers when assigning stress to a

¹ The remaining 2% of three-syllable words bear stress on the final syllable, and in this case stress is graphically marked (e.g., *colibrì*, hummingbird).

² The architecture of the CDP++ implies that stress assignment may affect reading aloud. Although the authors do not simulate stress effect on naming speed, they theoretically assume that such an effect would be allowed by the CDP++.

pseudoword. According to the pseudoword study in English by Arciuli et al. (2010) and the study by Burani and Arduino (2004) on low-frequency word reading, participants did not use the bias toward the most common stress pattern when reading pseudowords aloud. In such a view, participants would assign stress on the basis of stress neighborhood: If a pseudoword has a majority of antepenultimate stress friends—words with the same final sequence and the same stress pattern—it will receive antepenultimate stress; conversely, if the pseudoword has a majority of penultimate stress neighbors, it will receive penultimate stress.

The second issue that we investigate here is the naming speed of antepenultimate-stress and penultimate-stress pseudowords. Previous studies on low-frequency word reading reported ambiguous results. Colombo (1992) found both an effect of the default bias—penultimate-stress words were read faster than antepenultimate-stress words—and an effect of stress neighborhood, but only for antepenultimate-stress pseudowords: they were read faster when they had a majority of stress neighbors. Burani and Arduino (2004) found a facilitatory effect on naming latencies of stress neighborhood only (a large stress neighborhood equally affected antepenultimate- and penultimate-stress stimuli) and no evidence for the default bias. With respect to pseudowords, three different predictions can be made. First, if readers mainly use the default bias when assigning stress to pseudowords, penultimate-stress stimuli should be read faster than antepenultimate-stress stimuli. Second, if readers mainly use stress neighborhood as a cue for stress assignment and the default bias plays a minor role, then no difference in naming times is expected between pseudowords read with penultimate and antepenultimate stress when they are matched for stress neighborhood. Third, if naming speed does not depend on distributional information, but on articulatory planning factors—such as the size of the unit that has to be planned before articulation can start (Levelt, 1989)—then antepenultimate-stress words might be read faster than penultimate-stress words, since in the latter case assigning stress would involve the articulatory planning of a larger unit (two syllables) than assigning stress to the antepenultimate syllable (only one syllable).

To summarize, in the present study we investigated two main issues related to stress assignment in PW reading: what kind of information is used in assigning stress to a pseudoword and how the different stress patterns affect naming speed. Experiments 1 and 2 address the issue of whether readers rely on stress neighborhood—instead of the default bias—in assigning stress to a pseudoword. Experiments 3 and 4 assess whether antepenultimate and penultimate stress differently affect the speed of pseudoword naming and whether such difference is driven by any distributional knowledge or is due to factors related to the unit of articulatory planning.

Experiment 1

In this experiment we presented pseudowords created to be read with stress on the penultimate or the antepenultimate syllable on the basis of their final sequence. According to previous findings on Italian words (Burani & Arduino, 2004), certain final sequences are able to drive stress assignment. Thus, if the effect of stress neighborhood is based on the presence in the language of many words with a shared word ending and the same stress pattern, then word ending sequences will potentially drive stress assignment to novel stimuli. In this case, pseudowords should be assigned the

stress pattern (either penultimate or antepenultimate) with which their ending is predominantly associated (e.g., since *-ola* has a stress neighborhood mainly composed of antepenultimate stress words, a PW ending in *-ola* should receive antepenultimate stress). If, however, stress is driven by stress dominance (or a default bias), then most pseudoword stimuli will be read with penultimate syllable stress (Colombo, 1992).

Similar predictions can be made for naming speed. If stress neighborhood is the main source of stress assignment in pseudoword reading, there is no reason to expect that one of the two PW sets (created to be read with stress on the penultimate or the antepenultimate syllable, respectively) will yield shorter latencies than the other. In contrast, if a default stress pattern is at work during pseudoword reading, then participants may be faster in reading a pseudoword when penultimate stress is assigned compared to when antepenultimate stress is assigned. Finally, if stress assignment affects naming speed at the level of articulation planning, then participants may read a PW bearing antepenultimate stress faster than a PW bearing penultimate stress, because the latter requires a two syllable planning unit before articulation can start (for further discussion on this issue, see Experiments 3–4 and the General Discussion).

Method

Participants. Twenty-three (15 male) volunteers at the Institute of Cognitive Sciences and Technologies in Rome participated in the experiment. They were all native Italian speakers, aged 18–35 (mean age: 26), with normal or corrected-to-normal vision.

Materials. Two sets of three-syllable³ pseudowords were created to be assigned a certain stress pattern—either penultimate (dominant pattern) or antepenultimate (nondominant pattern)—on the basis of their ending (i.e., on the basis of the composition of their stress neighborhood; Burani & Arduino, 2004). Stress neighborhood was calculated on a frequency count of written Italian (CoLFIS; Bertinetto et al., 2005) both on word types (i.e., the amount of different words that have the same ending) and tokens (i.e., the summed frequency of all the words with the same ending). The calculations were made both as a proportion (the percentage of words sharing the stress pattern out of the total words ending with a given sequence) and as an absolute number (the number of words sharing the final sequence and the stress pattern). Ten final sequences were selected to create the pseudowords. Five endings (*-era*, *-iro*, *-ita*, *-ora*, *-oro*) occurred predominantly in penultimate stress words—that is, in words that have mainly friends with penultimate stress; the other five endings (*-ano*, *-ica*, *-ile*, *-ola*, *-olo*) occurred predominantly in antepenultimate stress words—that is, in words that mainly had friends with antepenultimate stress (see Table 1).

Each experimental set contained 20 pseudowords (four for each final sequence), for a total of 40 stimuli. The two pseudoword sets were matched on length in letters, orthographic complexity (Burani, Barca, & Ellis, 2006), mean bigram frequency, two initial phonemes (Kessler, Treiman, & Mullenix, 2002), orthographic neighborhood size (*N*-size), and summed neighbors' frequency (Wagenmakers & Raaijmakers, 2006; all *t* comparisons with *p*

³ One pair of items accidentally had four syllables.

Table 1
Mean Characteristics of the Orthographic Endings Used in Experiments 1–4

Word ending	% of types for PS	% of types for AS	No. of types for PS	No. of types for AS	% of tokens for PS	% of tokens for AS	No. of tokens for PS	No. of tokens for AS
Experiments 1 & 3								
Penultimate stress								
ERA	64.1	35.9	134	75	53.8	46.2	2,612	2,240
IRO	84.6	15.4	22	4	96.7	3.3	295	10
ITA	72.8	27.2	233	87	59.7	40.3	3,327	2,245
ORA	63.8	36.2	51	29	97.4	2.6	7,312	195
ORO	74.5	25.5	35	12	97.8	2.2	2,512	57
<i>M</i>	72.0	28.0	95.0	41.4	81.1	18.9	3,211.6	949.4
Antepenultimate stress								
ANO	25.3	74.7	402	1,118	19	81	2,211	9,441
ICA	4.7	95.3	22	450	7.5	92.5	890	11,009
ILE	29.3	70.7	49	118	29.9	71.1	1,986	4,896
OLA	23	77	55	184	29.4	70.6	1,125	2,704
OLO	23.4	76.6	56	183	18.4	81.6	401	1,775
<i>M</i>	21.1	78.9	116.8	410.6	20.6	79.4	1,322.6	7,287.6
Experiments 2 & 4								
Penultimate stress								
ATA	99.6	0.4	1,211	5	99.7	0.3	9,752	26
IRO	84.6	15.4	22	4	96.7	3.3	295	10
ITA	72.8	27.2	233	87	59.7	40.3	3,327	2,245
ORA	63.8	36.2	51	29	97.4	2.6	7,312	195
ORO	74.5	25.5	35	12	97.8	2.2	2,512	57
<i>M</i>	79.1	20.9	310.4	27.4	90.3	9.7	4,639.6	506.5
Antepenultimate stress								
ERO	27.7	72.3	84	219	37.6	62.4	2,892	4,808
ICA	4.7	95.3	22	450	7.5	92.5	890	11,009
ILE	29.3	70.7	49	118	29.9	71.1	1,986	4,896
OLA	23	77	55	184	29.4	70.6	1,125	2,704
OLO	23.4	76.6	56	183	18.4	81.6	401	1,775
<i>M</i>	21.6	78.4	53.2	230.8	24.5	75.5	1,458.8	5,038.4

Note. PS = penultimate stress; AS = antepenultimate stress. Percentage and number of word types including a given orthographic ending are calculated out of 3,191,137 occurrences (Bertinetto et al., 2005).

values > .1). All the pseudowords had very few or no orthographic neighbors. We also ascertained that no relationship existed between each stimulus's initial letter/phoneme and certain stress patterns. (All stimuli can be found in the Appendix.) Pseudowords in the two sets had similar syllable structures. The matching characteristics of the stimuli (in Experiments 1 and 3 as well as the

stimuli used in the subsequent Experiments 2 and 4) are reported in Table 2.

Procedure. The 40 items were presented in two blocks of 20 trials each. Each block included an equal number of pseudowords that were expected to be assigned penultimate or antepenultimate stress according to their ending. Effort was made to equally dis-

Table 2
Matching Characteristics of Stimuli in Experiments 1–4

Variable	Experiments 1 & 3		Experiment 2		Experiment 4	
	PSN	ASN	PSN	ASN	PSN	ASN
Length	7.00	7.05	6.34	6.31	8.00	8.00
Bigram frequency	10.69	10.66	10.71	10.74	11.20	11.27
Orthographic complexity	0.30	0.30	0.26	0.34	0.40	0.55
<i>N</i> size	0.10	0.10	0.29	0.40	0.00	0.00
<i>N</i> frequency	0.10	0.55	0.63	1.03	0.00	0.00

Note. PSN = penultimate stress neighborhood; ASN = antepenultimate stress neighborhood. All the reported values are mean values. Length is in number of letters; bigram frequency is log transformed on the basis of the natural logarithm; *N* size is calculated as the number of words that are obtained by changing the target's letters one at a time; *N* frequency is calculated as the summed neighbors' frequency (Wagenmakers & Raaijmakers, 2006). The measure of orthographic complexity is based on the number of *c*, *g*, *sc*, and *gl* letters that are present in a given word. These letters and letter clusters require the following letter context (contextual rules) to be assigned the correct pronunciation (see Burani et al., 2006).

tribute pseudowords with the same endings across blocks to control for the number of repetitions of the same ending within the same block. The stimuli order was pseudorandomized, to avoid presenting two PWs with the same ending one after the other. The presentation order of the two blocks was counterbalanced across participants. There was a short pause between the blocks. Preceding the first experimental block, a practice of 30 trials was administered to each participant. The items included in the practice session were all words: 15 with penultimate and 15 with antepenultimate stress. The words in the practice block had different endings from those used for the experimental items.

The participants were informed that they would be presented with nonsense words (PWs), which they had to read aloud as fast and accurately as possible. Stimuli appeared in the center of the computer screen. Before the presentation of each stimulus, a fixation cross was displayed in the center of the screen for 500 ms. A voice key connected to the computer measured reaction times (RTs) in ms at the onset of pronunciation that were collected using E-Prime software (Psychology Software Tools, Pittsburgh, PA; <http://www.psnet.com>). Each stimulus disappeared at pronunciation or after 1,500 ms. There was an interstimulus interval of 1,500 ms.

Results

Invalid trials due to technical failures (or responses that exceeded the time limit as well as responses shorter than 250 ms) accounted for 1.4% of the data points and were discarded from the analyses. Naming responses consisting of pronunciation errors (i.e., phoneme substitutions, omissions, insertions or transpositions, hesitations, stuttering, or false starts) were 5.4% (5.2% for dominant stress and 5.6% for nondominant stress targets) of all the data points and were also discarded from the analyses.

Responses were classified as being consistent or inconsistent. A pseudoword was judged to be read consistently with its stress neighborhood when it was assigned the stress pattern predicted by its ending (e.g., when the antepenultimate stress was assigned to a pseudoword that included the final sequence *-ola*, which is associated with antepenultimate stress). In contrast, the stress response was judged to be inconsistent when it was different from the stress predicted on the basis of the stimulus's final sequence (e.g., when the penultimate stress was assigned to a pseudoword that included the final sequence *-ola*, associated with the antepenultimate stress).⁴

The capability of stress neighborhood to drive stress assignment was investigated using a logistic regression. This type of analysis was adopted because on the one hand, it allowed us to treat the final sequences as mainly associated with a stress pattern and not totally associated with a stress pattern (e.g., *-ola*, which appears in many words with antepenultimate stress but also in some words with penultimate stress); on the other hand, it allowed us to build a statistical model to explain the events (in terms of probability). The naming times of pseudowords that were stressed either consistently or inconsistently with their stress neighborhood—either mostly penultimate or antepenultimate stressed—were also analyzed using mixed-effects models.

Percentages of consistent and inconsistent stress responses for penultimate and antepenultimate stress endings are reported in Figure 1. Mean naming times (in milliseconds) for pseudowords read with penultimate and antepenultimate stress in each group,

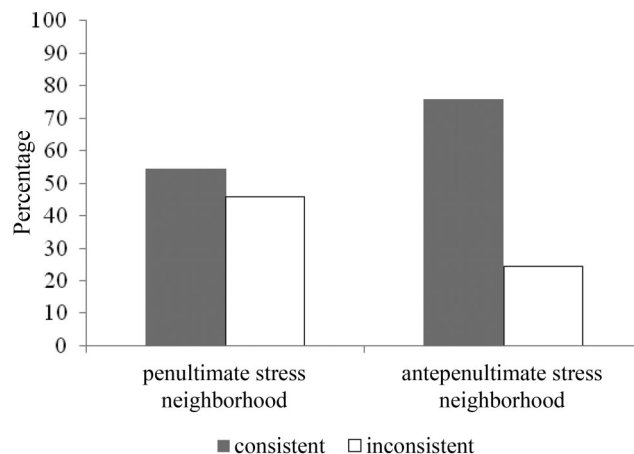


Figure 1. Experiment 1: Percentages of consistent and inconsistent stress responses on the pseudowords having orthographic endings with mostly penultimate or mostly antepenultimate stress neighborhood.

with either predominantly penultimate stress neighborhood or predominantly antepenultimate stress neighborhood, are illustrated in Table 3.

Stress responses: Logistic regression analysis. A logistic regression model was performed to investigate the role of stress neighborhood in driving stress assignment. The logistic regression was conducted with stress neighborhood (neighbors mostly associated with penultimate stress words, or neighbors mostly associated with antepenultimate stress words; stress neighborhood was coded as a binary variable) as predictor and the consistency of responses (stress consistent with the neighborhood, e.g., when a pseudoword ending in *-ola* received antepenultimate stress; or stress not consistent with the neighborhood, e.g., when a pseudoword ending in *-ola* received penultimate stress), for both penultimate and antepenultimate stress pseudowords as dependent variables. In this way, we investigated whether stress neighborhood guided stress assignment and if there was a difference between penultimate and antepenultimate stress pattern in inducing stress assignment.

The logistic regression model was fitted using the `lrm` function (Design package; Baayen, 2008) in R software (Version 2.11). The analysis showed a significant effect of stress neighborhood ($\beta = 0.96$, $SE = 0.14$, Wald $Z = 6.48$, $p < .01$). The odds ratio⁵ showed that the proportion of consistent readings—that is, when stress is assigned in accordance with the final sequence's stress neighborhood—was 2.62 ($\exp[0.96]$) higher when a sequence had predom-

⁴ Two experimenters completed the scoring of this experiment by keeping record of all of the responses.

⁵ The *odds* are a way to show a probability using a ratio. The odds are a ratio between the probability (p) of an event and the probability ($1 - p$) of its complementary event. The odds ratio is the ratio of the odds of an event occurring in one group to the odds of that event occurring in another group. That is, the odds ratio is a way to compare whether the probability for an event is the same for two groups. If the odds ratio is equal to 1, the event is equally likely in both groups. If the odds ratio is greater than 1, the event is more likely in the first group. If the odds ratio is less than 1, the event is less likely in the first group.

Table 3

Experiment 1: Mean (Standard Deviation) by Participants' Naming Times (in ms) for Pseudowords Having Orthographic Endings With Mostly Penultimate or Mostly Antepenultimate Stress Neighborhood and Assigned Either Penultimate or Antepenultimate Stress

Stress assigned	Penultimate stress neighborhood	Antepenultimate stress neighborhood
Penultimate stress assigned	628 (163)	647 (171)
Antepenultimate stress assigned	604 (148)	605 (142)

inantly antepenultimate stress neighbors (e.g., antepenultimate stress for pseudowords ending in *-ola*), than when the sequence had predominantly penultimate stress neighbors (e.g., penultimate stress for pseudowords ending in *-ora*). This means that the possibility that participants assign antepenultimate stress to a pseudoword consistently with many antepenultimate stress neighbors is more than two times higher than the possibility that participants assign penultimate stress to a pseudoword consistently with many penultimate stress neighbors.

After the overall comparison between the effects of penultimate and antepenultimate stress neighborhood on stress assignment, we performed an analysis to evaluate the contribution of each final sequence in driving stress assignment. The percentages of consistent and inconsistent responses for each final sequence associated with a given stress type are reported in Figure 2.

We ran a logistic regression model with the consistency of responses as dependent variable and the type of final sequence as a factor (see Table 4). The final sequence *-iro* (associated to a majority of penultimate stress neighbors) was used as baseline (i.e., the default value of the independent variable). The default sequence was selected because the number of pseudowords that were read according to its stress neighborhood (penultimate stress) was almost equal to the number of pseudowords that were read using antepenultimate stress.

Table 4

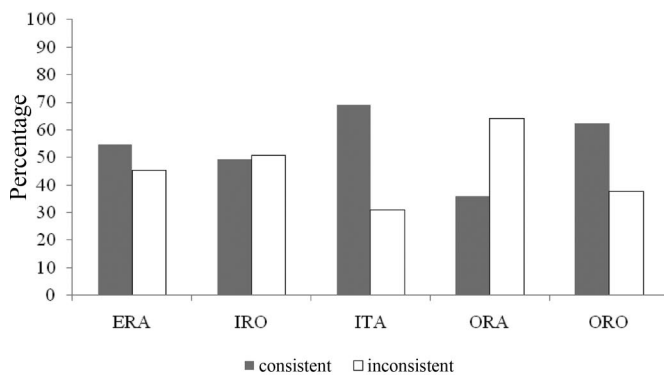
Coefficient Probability Estimations for Each Final Sequence in Experiment 1

	β coefficient	SE	Wald Z	p
Intercept	-0.02	0.22	-0.11	0.91
Penultimate final sequences				
ORA	-0.55	0.31	-1.75	0.08
ORO	0.53	0.31	1.70	0.08
ERA	0.21	0.31	0.68	0.49
ITA	0.82	0.32	2.55	0.01
Antepenultimate final sequences				
ILE	0.88	0.32	2.69	0.00
OLA	2.65	0.47	5.54	0.00
OLO	1.28	0.34	3.74	0.00
ANO	-0.19	0.31	-0.6	0.54
ICA	2.309	0.43	5.30	0.00

Note. β coefficient is the coefficient estimated by the logistic regression for each final sequence. All the coefficients are estimated in comparison with the intercept value (the default ending *-IRO*). A negative coefficient indicates a decrease in the probability, whereas a positive coefficient indicates an increasing probability. SE = the estimated standard error for each estimated coefficient.

Results showed that some final sequences were able to drive stress assignment consistently with their stress neighborhood better than others. The probability that a pseudoword ending in *-ica* ($\beta = 2.3$; Wald Z = 5.3, $p < .01$), *-ile* ($\beta = 0.88$; Wald Z = 2.69, $p < .01$), *-ita* ($\beta = 0.82$; Wald Z = 2.55, $p < .05$), *-ola* ($\beta = 2.65$; Wald Z = 5.54, $p < .01$), and *-olo* ($\beta = 1.28$; Wald Z = 3.74, $p < .01$) had been read consistently the stress neighborhood of its final sequence is significantly higher than the probability for the baseline. Four of the latter sequences (*-ica*, *-ile*, *-ola*, *-olo*) were associated with antepenultimate stress and one (*-ita*) with penultimate stress. The other four final sequences did not differ significantly from the baseline (one of them, *-ano*, was associated with antepenultimate stress; three of them, *-era*, *-ora*, *-oro*, were associated with penultimate stress).

(a) Penultimate stress neighborhood



(b) Antepenultimate stress neighborhood

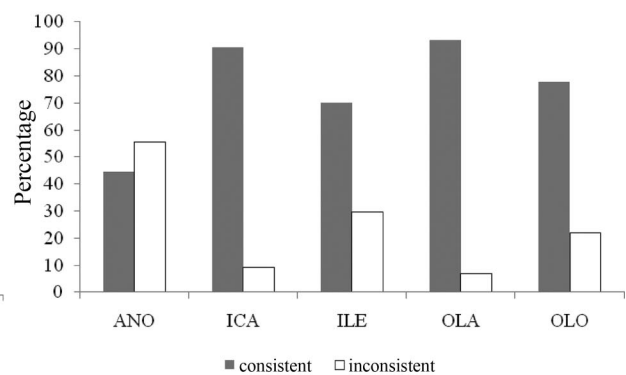


Figure 2. Experiment 1: Percentages of consistent and inconsistent responses for each final sequence associated to each stress type for (a) penultimate and (b) antepenultimate stress neighborhood, respectively.

Overall, the results show higher percentages of consistent stress responses in the case of pseudowords that include final sequences with an antepenultimate stress neighborhood—that is, present in a majority of words with antepenultimate stress. In reading pseudoword stimuli, readers are more influenced by stress neighborhood when it is mainly composed of words bearing the antepenultimate (nondominant) stress pattern than when it is mainly composed of words bearing the penultimate stress pattern.

Reaction times: Mixed-effects model analysis. RTs were log transformed to reduce the skewness of the data. We ran mixed-effects models to analyze log RTs (Baayen, 2008) to the pseudowords that were pronounced correctly at the phonemic level and were assigned a stress pattern that was either consistent or inconsistent with the stress neighborhood of their endings. The models were fitted using the `lmer` function (languageR package; Baayen, Davidson, & Bates, 2008) in R software (Version 2.11). Participants and items were treated as random factors.

A mixed-effects model was run considering naming times as the dependent variable. The type of stress that had been assigned to pseudowords (penultimate vs. antepenultimate) and stress neighborhood (penultimate-stress neighborhood vs. antepenultimate-stress neighborhood) were fixed factors. The model showed a main effect of stress type ($t = -2.00$, $\beta = -0.03$, $p < .05$): Pseudowords that received antepenultimate stress were read faster than pseudowords that received penultimate stress. No other effect reached significance (stress neighborhood: $t = 1.02$, $\beta = 0.02$; Stress Type \times Stress Neighborhood: $t = -1.2$, $\beta = -0.02$).

Overall, the results on RTs show that participants were faster when reading pseudowords that are assigned antepenultimate stress—either consistently or inconsistently with stress neighborhood—than for pseudowords that are assigned penultimate (the most common) stress.

Discussion

Pseudowords that had been created with endings that are predominantly associated with penultimate stress were expected to be (consistently) pronounced with penultimate stress; conversely, pseudowords that included endings that predominantly occur in antepenultimate stressed words were expected to be (consistently) pronounced with antepenultimate stress. The results partly confirmed our predictions: Stress neighborhood exerted an effect on stress assignment when pseudowords included final sequences that are predominantly associated with antepenultimate stress (e.g., *-ola*). In contrast, final sequences predominantly associated with penultimate stress (e.g., *-ora*) weakly induced penultimate stress assignment. Overall, readers assigned the antepenultimate more often than the penultimate stress pattern to pseudowords.

No evidence in favor of a default mechanism was found: If readers had applied penultimate stress as a default, then most pseudowords would have been pronounced with this stress pattern. At the same time, the results showed that polysyllabic pseudoword reading is not always affected by the orthographic/phonological characteristics of the ending: Final sequences associated with antepenultimate stress drove stress more strongly than final sequences associated with penultimate stress, with some endings being more effective than others.

Naming times to pseudowords that were assigned antepenultimate stress were shorter than naming times to pseudowords that

were assigned penultimate stress, irrespective of consistency with the stress neighborhood. Shorter naming times for PWs that were assigned antepenultimate stress were in the opposite direction from what was predicted by the default mechanism (Colombo, 1992), which should work when sublexical processing is favored (Colombo & Zevin, 2009), as in the case of the present list which was composed of pseudowords only. The antepenultimate stress pattern may have speeded up reading latencies due to the articulatory planning factors that are involved in the final stages of word reading. Such a hypothesis deserves specific investigation (see below, Experiments 3 and 4). However, before investigating how stress characteristics may affect pseudoword naming latencies, we further investigated the effect of stress neighborhood on both stress assignment and naming times to pseudowords.

Experiment 2

In Experiment 1, the consonant–vowel (CV) structure of the stimuli had been matched across the experimental sets. However, we selected the CV structure of each pseudoword without controlling how representative it was of the possible CV structures associated to a specific orthographic ending in three-syllable words. Thus, it could have been the case that the pseudoword CV structure had interacted with stress neighborhood, biasing readers toward a certain stress pattern.

If CV structure is computed during reading as an interface level between syllabic and segmental representations (see, e.g., Berent & Marom, 2005; Dell, 1988; for a different approach, see Cholin & Levelt, 2009; Levelt, Roelofs, & Meyer, 1999) and certain CV structures are distributionally associated with a given stress pattern, they may provide additional orthographic/phonological constraints that would contribute to the assignment of stress. Consequently, if pseudowords are created to include not only a given final sequence (associated with either penultimate or antepenultimate stress) but also the CV structures that occur more frequently in stress neighbors sharing the same ending, these pseudowords should be more likely to be read consistently with stress neighborhood. The possible contribution of CV structure to the stress neighborhood effect was controlled across experimental sets in Experiment 2.

Method

Participants. Thirty-two volunteer students (nine men) at the Sapienza University of Rome participated in the experiment. They were all native Italian speakers, aged 18–35 (mean age: 22.8), with normal or corrected-to-normal vision. None of them had participated in the previous experiment.

Materials. A list of 70 new pseudowords, seven for each final sequence, was created. Ten final sequences were used: Five were predominantly associated with penultimate stress and five were predominantly associated with antepenultimate stress. We created two lists of 35 pseudowords each. Each list consisted of pseudowords to be read with either penultimate or antepenultimate stress on the basis of their ending. We adopted the same final sequences used in Experiment 1 with the exception of two cases: *-era* was substituted for *-ata* (in the penultimate stress list) and *-ero* was used instead of *-ano* (in the antepenultimate stress list). The substitutions were made to

better match the two sets of endings for both the numerosity of word types and the proportion of stress neighbor word types and tokens, that is, for the percentages of word types and tokens that are consistent with each stress pattern (penultimate/antepenultimate; see Table 1).⁶

In the construction of the pseudowords we used the most frequent CV structures occurring in the words that included a given orthographic ending. For each orthographic final sequence, lexical statistics were performed on the entire CoLFIS database (Bertinetto et al., 2005) to obtain the distribution of three-syllable words' CV structures with respect to each stress pattern. For each final sequence, the two CV structures most frequently associated to its main stress pattern were identified. To create the pseudowords, each final sequence was combined with its most frequent CV structure(s). For instance, a pseudoword such as *damboro* was created by combining the final sequence *-oro*, predominantly associated with penultimate stress words, with the most frequent CV structure as found in the CoLFIS database for words ending in *-oro* and bearing the penultimate stress (in this case: CVCCVCV). The stimuli in the two experimental sets, all three-syllabic, were matched on the same variables as in Experiment 1 (see Experiment 1, Materials). All stimuli are reported in the Appendix.

Procedure. The experimental session consisted of two blocks, each with an equal number of pseudowords to be assigned a penultimate or antepenultimate stress according to their ending. The block orders and the order of stimuli within each block were pseudo-randomized, as in Experiment 1, controlling for the number of repetitions of final sequences. There was a short pause at the end of each block. Each experimental session started with a practice block consisting of 30 words, half with penultimate stress and half with antepenultimate stress. The final sequences used in the practice block were different from the experimental ones.

The rest of the experimental procedure was the same as in Experiment 1.

Results

Invalid trials due to technical failures (or responses that exceeded the time limit), as well as responses shorter than 250 ms, accounted for 5.6% of the data points and were discarded from the analyses. The percentage of pronunciation errors was 6.3% (7.9% for dominant stress and 4.6% for nondominant stress targets) of all the data points. Pronunciation errors were also discarded from the analyses.

Answers were categorized as stress consistent or inconsistent following the same procedures as in Experiment 1. The data were submitted to the same analyses as in Experiment 1: A logistic regression was run to test whether stress neighborhood was able to drive stress assignment. As in Experiment 1, the naming times of pseudowords were analyzed using mixed-effects models.

Percentages of consistent and inconsistent stress responses for each stress type are reported in Figure 3. Mean naming times (in milliseconds) for consistently and inconsistently stressed pseudowords in each stress group—with either a predominantly penultimate or antepenultimate stress neighborhood—are illustrated in Table 5.

Stress responses: Logistic regression analysis. The logistic regression was conducted with stress neighborhood (neighbors mostly associated with penultimate stress words, neighbors mostly

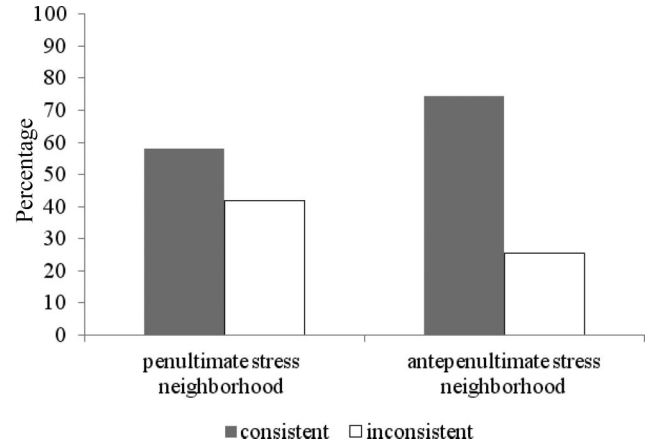


Figure 3. Experiment 2: Percentages of consistent and inconsistent stress responses on the pseudowords having orthographic endings with mostly penultimate or mostly antepenultimate stress neighborhood.

associated with antepenultimate stress words) as predictor and the consistency of responses for both penultimate and antepenultimate stress pseudowords responses as dependent variable.

The analysis showed a significant effect of stress neighborhood ($\beta = 0.74$, $SE = 0.09$, Wald $Z = 7.76$, $p < .01$). As in Experiment 1, the odds ratio showed that the proportion of consistent readings—when stress is assigned according to stress neighborhood—was 2.09 ($\exp[0.74]$), higher when a sequence had mainly antepenultimate stress neighbors than when a sequence had mainly penultimate stress neighbors. Once more, the possibility of assigning antepenultimate stress to a pseudoword, consistently with its stress neighbors, is more than two times higher than the possibility of assigning penultimate stress to a pseudoword, consistently with many penultimate stress neighbors.

As in Experiment 1, we ran a further analysis to evaluate the contribution of each final sequence in driving stress assignment. The percentages of consistent and inconsistent responses for each final sequence associated with a given stress type are reported in Figure 4.

A logistic regression model was run using the consistency of responses as dependent variable and the type of final sequence as factor (see Table 6). As a baseline, we adopted the same final sequence used in Experiment 1, that is, *-iro* (predominantly associated with penultimate stress neighbors).

Similar to Experiment 1, results showed that some sequences were able to drive stress assignment—based on stress neighborhood—better than others. The probability that a pseudoword end-

⁶ The final sequence *-ano* was substituted for an independent theoretical reason. We realized that it was the only final sequence for which there is a full association between grammatical class and stress type: *-ano* occurs almost exclusively in inflected verbal forms when associated to the antepenultimate stress, whereas it occurs only in noun and adjectival forms when associated to the penultimate stress. Moreover, *-ano* was the only final sequence for which the count of antepenultimate stress words included a high proportion of four-syllable words, in which main stress falls on the pre-antepenultimate syllable, with the possible presence of a secondary stress on the penultimate syllable.

Table 5

Experiment 2: Mean (Standard Deviation) by Participants' Naming Times (in ms) for Pseudowords Having Orthographic Endings With Mostly Penultimate or Mostly Antepenultimate Stress Neighborhood and Assigned Either Penultimate or Antepenultimate Stress

Stress assigned	Penultimate stress neighborhood	Antepenultimate stress neighborhood
Penultimate stress assigned	580 (126)	587 (112)
Antepenultimate stress assigned	571 (134)	575 (114)

ing with *-ata* ($\beta = 1.19$; Wald $Z = 5.18$, $p < .0001$), *-ero* ($\beta = 0.49$; Wald $Z = 2.43$, $p < .05$), *-ica* ($\beta = 1.79$; Wald $Z = 6.79$, $p < .0001$), *-ola* ($\beta = 1.71$; Wald $Z = 6.69$, $p < .0001$), and *-olo* ($\beta = 0.99$; Wald $Z = 4.55$, $p < .0001$) had been read consistently with the stress neighborhood of its final sequence is significantly higher than the probability for the baseline. The last four sequences (*-ero*, *-ica*, *-ola*, *-olo*) were associated with antepenultimate stress, and one sequence (*-ata*) was associated with penultimate stress. Furthermore, some final sequences were less successful than others in driving stress assignment. The probability that a pseudoword ending with *-ora* ($\beta = -0.45$, Wald $Z = -2.26$, $p < .05$) and *-oro* ($\beta = -0.39$, Wald $Z = -1.96$, $p < .05$) had been read consistently with its stress neighborhood is significantly lower than the probability for the baseline. The last two sequences were associated with penultimate stress.

Once more, the results show higher percentages of consistent stress responses in the case of pseudowords that have a final sequence predominantly associated with antepenultimate stress. Readers are more influenced by stress neighborhood when it is mainly composed of words bearing antepenultimate stress than when it is composed of a majority of words with penultimate stress.

Reaction times: Mixed-effects model analysis. The log transformed RTs of the pseudowords that were correctly pro-

Table 6

Experiment 2: Coefficient Probability Estimations for Each Final Sequence

	β coefficient	SE	Wald Z	p
Intercept	0.24	0.14	1.70	0.08
Penultimate final sequences				
ORA	-0.45	0.20	-2.26	0.02
ORO	-0.39	0.20	-1.96	0.04
ATA	1.19	0.23	5.18	0.00
ITA	0.28	0.20	1.39	0.16
Antepenultimate final sequences				
ILE	-0.12	0.19	-0.61	0.54
OLA	1.71	0.25	6.69	0.00
OLO	0.99	0.21	4.55	0.00
ERO	0.49	0.20	2.43	0.01
ICA	1.79	0.26	6.79	0.00

Note. β coefficient is the coefficient estimated by the logistic regression for each final sequence. All the coefficients are estimated in comparison with the intercept value (the default ending *-IRO*). A negative coefficient indicates a decrease in the probability, whereas a positive coefficient indicates an increasing probability. *SE* = the estimated standard error for each estimated coefficient.

nounced were analyzed using mixed-effects models (Baayen et al., 2008). The model was run with the naming times as dependent variable and stress type that was assigned to pseudowords (penultimate vs. antepenultimate) and stress neighborhood (penultimate-stress neighborhood vs. antepenultimate-stress neighborhood) as fixed factors. Participants and items were treated as random factors. Neither stress type effect ($t < 1$) nor stress neighborhood effect ($t < 1$) were found.

However, their interaction was significant ($t = -2.41$, $\beta = -0.04$, $p < .05$): Antepenultimate stress pseudowords were read faster than penultimate stress pseudowords, but only when they had a consistent (antepenultimate) stress neighborhood. Although the Stress Type \times Stress Neighborhood interaction is present, the

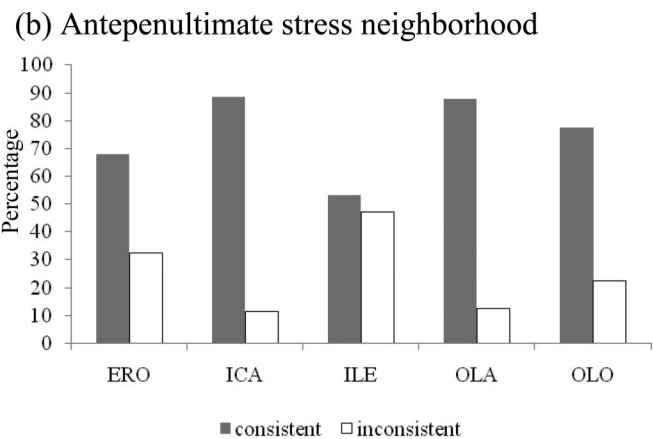
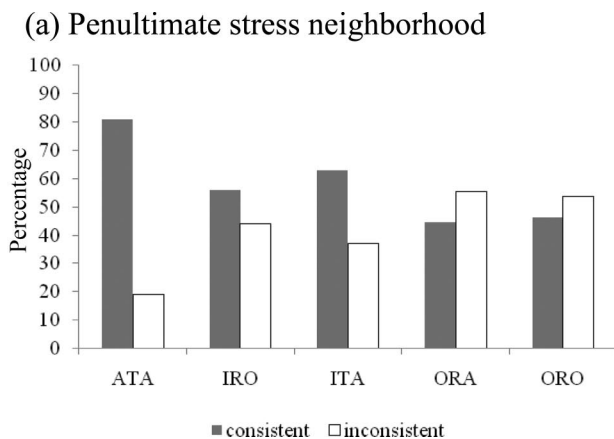


Figure 4. Experiment 2: Percentages of consistent and inconsistent responses for each final sequence associated to each stress type for sequences associated with (a) penultimate and (b) antepenultimate stress neighborhoods, respectively.

results are in line with those of Experiment 1, indicating facilitation for the computation of antepenultimate stress.

Discussion

The results of Experiment 2 were obtained with a large set of new stimuli that had been created paying great attention to the pseudoword CV structure and carefully controlled for the quantitative/distributional characteristics of final sequences. The results of Experiment 1 were confirmed: When pseudowords have the CV structure(s) that occur more frequently in those three-syllable words that end in a given orthographic segment, stress neighborhood mainly affects the computation of pseudowords with an ending associated with antepenultimate stress. Similar to Experiment 1, antepenultimate stress neighborhood significantly affected the assignment of stress to a pseudoword, whereas the penultimate stress neighborhood did not. Again, we did not find any evidence in favor of a mechanism that assigns penultimate stress as a default. Overall, our results show that pseudoword reading is not always affected by the orthographic/phonological characteristics of the stress neighborhood. Similar to what we found in Experiment 1, antepenultimate final sequences (e.g., *-ola*) drive stress assignment better than penultimate final sequences (e.g., *-ora*), and there is no evidence for a default mechanism.

With regard to naming times, as observed in Experiment 1, participants were faster in naming pseudowords bearing antepenultimate than penultimate stress. However, in the present experiment, although all stimuli that received antepenultimate stress tended to be read faster than stimuli that received penultimate stress (see Table 5), the difference in naming speed was only significant for those stimuli that had an antepenultimate stress neighborhood. The partial overlap of the results of the first two experiments in terms of stress effect on naming speed leaves this issue still open. To further investigate the readers' tendency to be faster in reading pseudowords bearing antepenultimate than penultimate stress, we designed two new experiments to assess whether readers are always faster in planning and articulating pseudowords with antepenultimate stress than with penultimate stress.

Experiments 1 and 2: Additional Analyses

The reasons why readers assigned antepenultimate stress more frequently than penultimate stress, and why antepenultimate stress speeded up the reading process, are still unclear. To understand this finding, we can consider how stress neighborhood is defined. Stress neighborhood can be calculated in two ways—as a proportion (the percentage of words sharing the stress pattern out of the total words ending with a given orthographic sequence) or as an absolute number (the number of words sharing the final orthographic sequence and the stress pattern)—and the two measures do not totally overlap. Consider, for example, the final sequences *-oro* and *-olo*: While they have a similar stress neighborhood in terms of proportion (percentage of stress friends: 74.5 and 76.6, respectively), they differ from each other in terms of absolute number of words associated with the penultimate stress (number of stress friends: 35 for the former and 183 for the latter sequence). Thus, one possible reason for the results of Experiments 1 and 2 is that the final sequences associated with antepenultimate stress, al-

though matched with the sequences associated to penultimate stress for the proportion of stress friends, nevertheless exerted a facilitatory effect on naming times because they occurred in a higher number of different word types per final sequence than the final sequences associated with penultimate stress. This distributional asymmetry of the numerosity of word types in the stress neighborhoods of segments associated to antepenultimate versus penultimate stress was present in Experiment 1 (see Table 1), and it could have made final sequences associated with antepenultimate stress easier to identify and to segment than final sequences that are associated with penultimate dominant stress. In Experiment 2, the mean number of word types associated with each of the two (penultimate and antepenultimate stress) neighborhood sets was matched. However, three out of five sequences included in the penultimate set (*-iro*, *-ora*, *-oro*) had very low values of word-type numerosity, whereas one sequence (*-ata*) occurred in an outstandingly high number of word types. Interestingly, the last sequence was the only one for which there was a significant probability that a pseudoword ending with it would be read consistently with penultimate stress (see Table 6).

To assess the possible contribution of the absolute number of word types constituting a neighborhood to stress assignment (and naming latencies), we ran another series of analyses on the results of Experiments 1 and 2. The additional analyses tested the role of stress neighborhood not only defined as the proportion of words bearing a given stress on the total of words having a given ending (i.e., stress neighbors' percentage) but also in terms of the absolute number of word types bearing a given stress (i.e., neighbors' numerosity). A new logistic regression with both neighbors' percentage and neighbors' numerosity (both coded as continuous variables) as predictors allowed us to estimate the respective roles of two different measures of stress neighborhood on stress assignment consistency. A mixed-effects model to estimate the role of the same two measures of stress neighborhood on naming speed was also run. Separate analyses were run for Experiments 1 and 2. Before running the analyses, we tested how far the two measures of neighborhood—neighbors' percentage and (log transformed) neighbors' numerosity—were correlated. To reduce the risk of collinearity in case of a high correlation between the variables—that is, when the Pearson correlation index r is higher than .50—we de-correlated them by fitting a regression model in which we used one variable as predicted by the other variable (Baayen, 2008).

Experiment 1

First, we checked whether neighbors' numerosity and neighbors' percentage were correlated. The correlation analysis did not show a high correlation ($r = .21$), and we did not de-correlate the two variables. A logistic regression model was run to investigate the respective roles of neighbors' numerosity and neighbors' percentage in driving stress assignment. We used the consistency of responses (stress consistent with the neighborhood, e.g., when a pseudoword ending in *-ola* received antepenultimate stress; stress not consistent with the neighborhood, e.g., when a pseudoword ending in *-ola* received penultimate stress) for both penultimate and antepenultimate stress pseudowords as dependent variable, while the number of stress neighbors, the percentage of stress neighbors out of the total number of words ending with a given

sequence, and the neighborhood stress type (the stress pattern associated with the final sequence; e.g., antepenultimate stress for *-ola*) were used as predictors.⁷ We aimed at verifying the relative contribution to stress assignment of the two measures of stress neighborhood for both antepenultimate and penultimate stress pseudowords. The logistic regression showed a significant effect not only of neighbors' percentage ($\beta = 0.04$, $SE = 0.01$, Wald $Z = 2.91$, $p < .01$) but also of neighbors' numerosity ($\beta = 0.46$, $SE = 0.13$, Wald $Z = 3.39$, $p < .001$). Neither neighborhood stress type (Wald $Z < 1$) nor any interaction reached significance (Neighbors' Percentage \times Stress Type: Wald $Z = -1.17$; Neighbors' Numerosity \times Stress Type: Wald $Z = 1.10$). Therefore, both numerosity and percentage of stress neighbors independently contributed to predict stress assignment similarly for penultimate and antepenultimate stress neighborhoods.

We also ran a mixed-effects model to investigate the role of neighbors' numerosity and neighbors' percentage on naming speed for both penultimate and antepenultimate stressed stimuli. Log transformed RTs were used as dependent variables, and neighbors' number, neighbors' percentage, and neighborhood stress type (the stress pattern associated with the final sequence; e.g., antepenultimate stress for *-ola*) as predictors. Neither numerosity nor percentage of stress neighbors significantly predicted naming latencies ($ts < 1$). Again, there were no effects of stress type ($t = 1.14$) or interaction (Neighbors' Numerosity \times Stress Type: $t = -1.06$; Neighbors' Percentage \times Stress Type: $t < 1$).

Experiment 2

Since the correlation between neighbors' numerosity and neighbors' percentage was high ($r = .55$, $p < .01$), we de-correlated the two variables by fitting a regression model with neighbors' percentage as predicted by neighbors' numerosity. Thus, in the following analyses we used the residuals of neighbors' percentage together with neighbors' numerosity as predictors.

The logistic regression model assessed the relative contribution of neighbors' numerosity and neighbors' percentage in driving participants' stress assignment. Again, we used the consistency of responses (stress consistent/inconsistent with the neighborhood) for both penultimate and antepenultimate stress pseudowords as dependent variable, while neighbors' number, residuals of neighbors' percentage, and neighborhood stress type were used as predictors. The logistic regression showed that both neighbors' numerosity ($\beta = 0.38$, $SE = 0.05$, Wald $Z = 7.43$, $p < .00001$) and neighbors' percentage ($\beta = 0.02$, $SE = 0.006$, Wald $Z = 3.87$, $p < .0001$) were significant. Therefore, both numerosity and percentage of stress neighborhood contributed to predicting the assigned stress pattern. Neither neighborhood stress type (Wald $Z = -1.16$) nor any interaction reached significance (Neighbors' Numerosity \times Stress Type: Wald $Z = 1.65$; Neighbors' Percentage \times Stress Type: Wald $Z = 1.17$).

Next we ran a mixed-effects model to investigate whether naming speed was affected by neighbors' numerosity and neighbors' percentage. Log transformed naming times for both penultimate and antepenultimate stress stimuli were used as dependent variables, and neighbors' number, neighbors' percentage, and neighborhood stress type as predictors. Neither main effects (neighbors' numerosity: $t = -1.01$; neighbors' percentage: $t < 1$; neighborhood stress type: $t < 1$) nor the interactions ($ts < 1$)

reached significance. Naming times were not affected by numerosity or percentage of stress neighbors.⁸

Overall, the results of the additional analyses show that not only the proportion of stress neighbors but also the absolute numerosity of stress neighbors contribute to the assignment of stress to pseudowords. Some differences exist in the absolute number of word types that characterize the stress neighborhood of penultimate and antepenultimate final sequences. The neighborhoods of those final sequences associated with penultimate stress almost always had a small numerosity; that is, they were composed of few word types. In contrast, the neighborhoods of the final sequences associated with antepenultimate stress had a larger numerosity; that is, they were composed of many different word types. One reason why antepenultimate stress neighborhood is able to drive stress assignment better than penultimate stress neighborhood can be found in the larger number of neighbors constituting antepenultimate stress neighborhoods. To drive stress assignment, a sequence not only has to be associated with a given stress in a relatively high proportion of cases but also has to appear in a large number of stress neighbors.

The differences in either numerosity or percentage of stress neighbors did not affect naming latencies to pseudowords in any of the experiments. Readers were faster in naming a pseudoword bearing antepenultimate stress, but this did not depend on the larger number of stress neighbors for pseudowords with antepenultimate stress than pseudowords with penultimate stress. A different explanation for the latter finding must be conceived. It could be thought that different articulatory planning factors are responsible for the differences in naming latencies of stimuli that have different stress patterns. We designed two further experiments to test whether, in reading pseudowords aloud, the difference in naming speed between antepenultimate and penultimate stress is due to differences in the planning and release of articulation for stimuli with the two stress patterns. In Experiments 3 and 4, the naming latencies to the same pseudowords, read once with stress on the penultimate and once on the antepenultimate syllable, were compared.

⁷ The final sequence *-ano* was not included in the analyses.

⁸ The same analyses were run with neighbors' percentage, residuals of neighbors' number, and neighborhood stress type as predictors. In this way we made sure that both neighbors' number and neighbors' percentage contributed to pseudowords' stress assignment after residualization of either one or the other measure. The logistic regression on the consistency of responses for penultimate and antepenultimate stress pseudowords showed that both neighbors' numerosity ($\beta = 0.24$, $SE = 0.05$, Wald $Z = 4.37$, $p < .001$) and neighbors' percentage ($\beta = 0.04$, $SE = 0.06$, Wald $Z = 6.72$, $p < .001$) were significant. Moreover, neighborhood stress type ($\beta = 0.56$, $SE = 0.16$, Wald $Z = 3.36$, $p < .001$) and its interaction with neighbors' percentage ($\beta = 0.04$, $SE = 0.01$, Wald $Z = 3.14$, $p < .01$) were also significant, suggesting that the neighbors' percentage would affect mostly antepenultimate stress stimuli rather than penultimate stress stimuli. Then, a mixed-effects model was run to investigate the effect of neighbors' percentage, residuals of neighbors' number, and neighborhood stress type on the RTs. The analyses replicated previous results, with no effect reaching significance (Neighborhood Stress Type \times Neighbors' Percentage Interaction: $t = 1.68$, $p > .09$; all other $ts < 1$).

Experiment 3

In Experiments 1 and 2, pseudowords bearing stress on the antepenultimate syllable were named consistently faster than pseudowords bearing stress on the penultimate syllable. In the present experiment we investigated whether factors related to the planning of articulation for the two types of Italian stress could be responsible for the differences in pronunciation speed for pseudowords that were assigned different stress patterns.

In reading polysyllabic stimuli, the planning of articulation may start before the whole printed stimulus has been processed. The size of the unit that serves as the basis for starting articulation (whether the first phoneme, syllable, morpheme, or the whole word) has been a matter of debate in the last two decades of research on reading processing (see, e.g., Kawamoto, Kello, Jones, & Bame, 1998; Rastle, Harrington, Coltheart, & Palethorpe, 2000). However, most studies on reading have employed monosyllabic stimuli and languages other than Italian.

Studies on spoken word production suggest that a metrical structure encoding number of syllables and stress pattern is involved in preparing for an utterance (Levelt et al., 1999; Roelofs & Meyer, 1998). It could be assumed that in reading aloud Italian polysyllabic stimuli, the units for articulation planning are the syllables, with a main role for the syllable that bears stress (since stress assignment determines the coarticulation properties of phonemes). Before starting articulation, participants must know the stress place (Perry et al., 2010). In such a view, for a three-syllable stimulus, assigning stress to the antepenultimate syllable would involve the articulatory planning of a smaller portion (i.e., the first syllable) than assigning stress to the penultimate syllable. In the latter case, the assignment of stress would involve a larger planning unit, extending up to the second syllable. This idea follows the assumption that a partial articulatory representation can be buffered and the time needed to retrieve an articulatory program is a linear function of the number of items in the articulatory buffer (Levelt, 1989). The time needed to retrieve the articulatory program for Italian stimuli bearing antepenultimate stress would thus be shorter than the time needed to plan articulation of stimuli with penultimate stress, because in the former case one item (the first syllable) would be placed in the articulatory buffer, whereas in the latter case two items (the first two syllables) need to be present in the articulatory buffer to plan coarticulation of phonemes and to set parameters for loudness, pitch, and duration. It has also been shown that the duration of the stressed vowel in Italian stimuli with antepenultimate stress is shorter than the duration of the stressed vowel on the penultimate syllable (see, e.g., D'Imperio & Rosenthal, 1999; Krämer, 2009, pp. 163–165). If the metrical representation captured (among other things) syllable-internal positions, the shorter duration of the stressed vowel in antepenultimate stress words might contribute to shorten the planning time in the articulatory buffer. Therefore, if articulation planning of Italian three-syllable stimuli involves the syllable that bears stress, it could be expected that stress on the antepenultimate (first) syllable might speed up release of articulation, resulting in faster naming times for polysyllabic pseudowords that are assigned stress on the antepenultimate syllable (see Experiments 1 and 2).

In the present experiment we tested whether factors involved in the planning of articulation affect naming latencies to polysyllabic pseudowords. The question of interest here is whether a given

stimulus, irrespective of stress neighborhood, is read faster when it is pronounced with stress on the antepenultimate syllable compared to when it is pronounced with penultimate syllable stress. If the time needed for articulation planning plays a role in reading polysyllables, then a pseudoword should be read faster when it is assigned antepenultimate syllable stress than when it is assigned penultimate syllable stress, irrespective of its stress neighborhood. Conversely, if no syllabic and stress information are involved in starting articulation, there should not be significant differences in RTs when a given pseudoword, identical for orthographic/segmental form, is read with stress on the penultimate or the antepenultimate syllable. If a default penultimate stress driven by the statistical bias toward assigning penultimate stress is at work, it is expected that pseudowords will be read faster when assigned penultimate syllable stress than when assigned stress on the antepenultimate syllable.

Method

Participants. Forty students (11 men) at the Sapienza University in Rome participated in the experiment. They were aged 18–35 (mean age: 26); all were native Italian speakers and had normal or corrected-to-normal vision. None of them had participated in the previous experiments.

Materials. The same stimuli were used as in Experiment 1, with the exception of the two four-syllable items, for a total set of 38 pseudowords.

Procedure. Participants were explicitly instructed to read the stimuli that appeared on the computer screen by assigning a certain stress pattern (either on the penultimate or on the antepenultimate syllable), the same for all the trials of each block. A practice session (one for each stress pattern) preceded each block to induce pronunciation with the specific stress pattern. Each practice session consisted of two parts: The first part included 15 words (with either penultimate or antepenultimate stress, depending on the experimental block) and the second part included 18 pseudowords. In this second part of the practice (pseudoword reading), for the first five trials the letter that had to receive stress was presented in a different color (red) from the rest of the letters, to make sure that the participants would assign stress to that position. The participants were then asked to pronounce all the stimuli of the following block with the same stress type as they had practiced during the practice session. After a short pause, there was another practice session to induce the other stress pattern, which was followed by the second experimental block. Thus, each participant read half of the experimental list applying penultimate stress and the other half of the list applying antepenultimate stress. The other half of the participants read the two halves of the lists applying the opposite stress patterns. Block order as well as the order in which participants were asked to assign each stress type (first penultimate or antepenultimate) were counterbalanced across participants. Stimulus order was automatically randomized within each block.

Each trial started with a fixation cross centered on the screen (500 ms). Then, the stimulus was displayed and remained on the screen until participants began to read it aloud or for a maximum of 1,500 ms. The interstimulus interval was 1,500 ms. A voice key connected to the computer measured reaction times (RTs) in

milliseconds at the onset of pronunciation, which were collected using E-Prime software.

Results

Invalid trials due to technical failures (or responses that exceeded the time limit, as well as responses shorter than 250 ms) accounted for 8.5% of the data points and were discarded from the analyses. Naming times and errors (12.6% of all data points, including both pronunciation errors at the phonemic level and a few cases in which the pseudowords did not receive the induced stress)⁹ were both analyzed using mixed-effects models (Baayen et al., 2008). The analyses of naming errors can be informative about the possible presence of trade-off effects in performance between speed and accuracy.

Results are presented in Table 7 (mean RTs and error percentages to pseudowords when assigned dominant or nondominant stress, respectively).

Reaction times. A mixed-effects model was performed with log RTs as dependent variable and stress type (penultimate vs. antepenultimate stress) as fixed factor. The model showed a significant effect of stress type ($t = -4.38$, $\beta = -0.03$, $p < .001$). Pseudowords were read faster when assigned the antepenultimate stress (588 ms) than when they were assigned the penultimate stress (609 ms).

Naming errors. A mixed-effects model was performed with the response's correctness as dependent variable and stress type as fixed factor. A significant effect of stress type was found ($z = 4.11$, $\beta = 0.71$, $p < .001$). Pseudowords were read more accurately when assigned the antepenultimate stress than when they were assigned the penultimate stress. Thus, no speed/accuracy trade-off was found.

Discussion

The results of Experiment 3 indicate that speed of articulation planning plays a role in reading aloud polysyllabic pseudowords. The results are in line with theories that postulate the involvement of metrical information in the advance planning of articulation (see Levelt et al., 1999). However, the possibility that a number of articulatory factors may have exerted an effect on the functioning of the voice key device cannot be excluded. In fact, RT recording by means of the voice key is affected by the initial part of the stimulus, in particular by the first and second phonemes (Kessler et al., 2002; Rastle & Davis, 2002). It is well known that stress modifies the tonic vowel, which in turn affects the quality of the preceding consonant. The shortening of the first consonant (of

unvoiced stop consonants specifically) which is caused by stress falling on the antepenultimate (first) syllable (Vaggel, Ferrero, Magno-Caldognetto, & Lavagnoli, 1978) may thus result in faster triggering of the voice key. To exclude that the faster RTs in naming three-syllable pseudowords stressed on the first syllable might be due to the articulatory/acoustic characteristics of the stimuli's initial phoneme(s), we ran Experiment 4, in which four-syllable pseudowords stressed either on the second (antepenultimate stress) or the third syllable (penultimate stress) were used.

Experiment 4

In the present experiment we controlled for possible artifacts due to the voice key device, using four-syllable pseudowords. In this way, we aimed at excluding the "first syllable doubt." In Italian four-syllable stimuli stressed either on the penultimate or the antepenultimate syllable, the first vowel is unstressed, and so it is equal in both cases. If the results of Experiment 3 were an artifact due to the effects of articulatory characteristics of the first syllable on the recording device, in reading four-syllable pseudowords aloud, there should be no difference between the two stress conditions. In contrast, if the differences in naming times between pseudowords stressed on the antepenultimate and pseudowords stressed on the penultimate syllable are due to differences in the planning of articulation of the stimuli, then once again pseudowords should be read faster when assigned antepenultimate syllable stress than when assigned penultimate syllable stress.

Method

Participants. Thirty-eight students (19 male) at the University of Trento participated in the experiment. They were aged 18–35 (mean age: 26), native Italian speakers with normal or corrected-to-normal vision. None of them had participated in the previous experiments.

Materials. Forty four-syllable pseudowords were created using the same 10 final sequences used in Experiment 2. The stimuli were matched on length of letters (they were all eight letters long), bigram frequency, orthographic complexity, and two initial phonemes. The stimuli had no orthographic neighbors. Only the CVCVCVCV structure, which has similar distributions in penultimate and antepenultimate stress four-syllable words in CoLFIS (Bertinetto et al., 2005), was used to create all the stimuli. All stimuli can be found in the Appendix.

Procedure. The stimuli were divided in two blocks of 20 trials each. Each block contained an equal number of pseudowords with mostly penultimate stress neighbors and with mostly antepenultimate stress neighbors on the basis of their endings. Participants were explicitly instructed to read all the stimuli in each block, assigning a certain stress type, the same for the whole block (as in Experiment 3), as fast and accurately as possible. There were two practice sessions, one for each stress pattern (either penultimate or antepenultimate). Each practice session was composed of 15 four-syllable words and 15 four-syllable pseudowords, respec-

Table 7
Experiment 3: Mean (Standard Deviation) by Participants' Naming Times (in ms) and Error Percentages for the Sets of Three-Syllable Pseudowords Read With Penultimate or Antepenultimate Stress, Respectively

Variable	Penultimate stress	Antepenultimate stress
RT	609 (139)	588 (130)
% E	15.8 (13)	9.4 (9.4)

Note. RT = reaction time.

⁹ In both Experiments 3 and 4, for the first participants, stress assignment was judged by two of the authors. Then, since the interrater agreement between the two raters was very high (above 95%), only one author continued to rate stress assignment.

tively. The procedures for the practice session and the experimental session were identical to those adopted in Experiment 3.

Results

Invalid trials due to technical failures (or responses that exceeded the time limit, as well as responses shorter than 250 ms) accounted for 3.7% of the data points and were discarded from the analyses. Naming times and errors (16.6% of all data points, which included both pronunciation errors at the phonemic level and a few cases in which the pseudowords had not been assigned the induced stress) were both analyzed using mixed-effects models (Baayen et al., 2008). Participants and items were treated as random factors.

Main results are presented in Table 8 (mean RTs and error percentages to pseudowords when assigned penultimate or antepenultimate stress, respectively).

Reaction times. The mixed-effects model was performed with log RTs as dependent variable and stress type (penultimate vs. antepenultimate stress) as fixed factor. A significant effect of stress type was found ($t = -6.07$, $\beta = -0.06$, $p < .001$). Pseudowords were read faster when assigned antepenultimate stress (673 ms) than when they were assigned penultimate stress (727 ms).

Naming errors. The mixed-effects model was performed with response correctness as dependent variable and stress type as fixed factor. A significant effect of stress type was found ($z = 3.30$, $\beta = 0.47$, $p < .001$). Pseudowords were read more accurately when they were assigned antepenultimate stress than when penultimate stress was assigned. Again, there was no speed/accuracy trade-off.

Discussion

Results of Experiment 4 confirm the results obtained in Experiment 3, thus allowing us to exclude the voice-key artifact explanation. If the difference in naming times between penultimate and antepenultimate stress pseudowords had been due to a voice-key artifact, then such difference would have disappeared using four-syllable stimuli. The difference in naming times between four-syllable stimuli stressed either on the penultimate or the antepenultimate syllable can thus be interpreted as due to the amount of articulatory representation that needs to be buffered before starting articulation (Levelt, 1989): In the case of stimuli stressed on the antepenultimate syllable, readers would plan two syllables, whereas three syllables would be needed for planning articulation of pseudowords with penultimate stress, with consequently longer naming times.

Table 8
Experiment 4: Mean (Standard Deviation) by Participants' Naming Times (in ms) and Error Percentages for the Sets of Four-Syllable Pseudowords Read With Penultimate or Antepenultimate Stress, Respectively

Variable	Penultimate stress	Antepenultimate stress
RT	727 (249)	673 (218)
% E	19.8 (15.7)	13.3 (9.6)

Note. RT = reaction time.

Altogether, the results of Experiments 3 and 4 suggest that metrical information is involved in the advance preparation of reading a pseudoword aloud. The assignment of a stress pattern to the pseudoword is required to plan fast and correct articulation.

General Discussion

In the present study we investigated polysyllabic pseudoword reading in Italian, focusing on two issues: how readers assign stress to pseudowords and whether penultimate and antepenultimate stress pseudowords differ in naming speed. In Experiments 1 and 2 we tested whether readers assign stress to three-syllable pseudowords on the basis of distributional information such as stress neighborhood rather than on a default bias—possibly due to the fact that about 80% of Italian three-syllable words bear penultimate stress. Our results showed no evidence for a default mechanism and indicated that stress neighborhood can drive stress assignment. However, the results also showed that the probability that stress is assigned consistently with stress neighborhood is constrained by both the proportion and the absolute number of word types that have the same ending and the same stress pattern. Stress neighborhood effects were found in the case of neighborhoods that had not only a large proportion of stress friends but also were composed of a large number of word types. In Experiments 3 and 4 we assessed the naming speed of penultimate and antepenultimate stress in three- and four-syllable stimuli, respectively, showing that antepenultimate stress speeds up the articulation of stimuli.

Our results shed a new light on different aspects of polysyllabic pseudoword reading. First, we considered how distributional information provided by orthography may affect stress assignment. Previous studies on the role of word ending in word and pseudoword reading have shown that such orthographic information is able to drive stress assignment (Arciuli & Cupples, 2006; Arciuli et al., 2010; Burani & Arduino, 2004; Colombo, 1992; Colombo & Zevin, 2009; Kelly et al., 1998). To assign stress to a target pseudoword, participants can rely on the orthographic/phonological information which is provided by the pseudoword's final sequence. Because readers know several words that have the same ending and the same stress pattern, they benefit from this information when assigning stress to a target pseudoword. Our data only partially confirmed such a view, indicating that the probability that a pseudoword will receive a certain stress pattern also depends on the amount of words that compose its stress neighborhood: A large stress neighborhood would be able to affect stress assignment more than a small stress neighborhood, because in the latter case readers may have a weak representation of the distribution of stress.

Consistently, we found that only those final sequences that are widely represented in the lexicon were able to affect placement of stress. In Experiments 1 and 2 this was mostly true for the sequences associated with antepenultimate stress. Our results challenge the view of a default mechanism for assigning stress. Contrary to a previous study on stress assignment in Italian pseudoword reading (Colombo, 1992; Experiment 5), we did not find any support for the hypothesis that the most common stress in a language is assigned by default, not even when reading is performed mainly through a sublexical route (Colombo & Zevin, 2009). If a default bias had been present, the majority of pseudo-

words would have received penultimate stress, contrary to what we found. However, the absence of a default mechanism does not mean that participants are not sensitive to the distribution of the two stress patterns in Italian. Readers may know that most three-syllable words bear penultimate stress and that this pattern is the most common in the language. However, they seem to resort to word endings as finer predictors for assigning stress to a pseudoword. As argued by Arciuli et al. (2010), word endings and thus stress neighborhood (Burani & Arduino, 2004) provide the greatest contribution to pseudowords' stress assignment: The orthographic input, when largely represented, becomes the main cue for stress.

The effect of stress neighborhood on pseudoword stress assignment can be accounted for by a single way connectionist model as well as a dual route connectionist model of reading aloud. Recently, Ševa, Monaghan, and Arciuli (2009; see also Arciuli et al., 2010) have proposed a single way connectionist model able to map the orthography of words into the corresponding stress position. The authors showed that such a connectionist network was able to discover the distributional information concerning stress driven by the orthographic input: The model was able to assign stress to bisyllabic English pseudowords in a comparable way with human data. During training, the longer the model is exposed to a certain orthography-to-stress association, the stronger this association becomes. If the orthography-to-stress relationship is shared by a large number of words, then the model will easily activate the stress pattern that is associated with the orthographic input. Otherwise, the selection of the correct stress pattern will be uncertain. Although this model can account for the stress neighborhood effect, it does not provide any implementation of how orthography is mapped onto phonology, and it is not able to offer any explanation for the difference in naming speed between antepenultimate and penultimate stress.

A better account for the present results may be offered by the CDP++ model of reading aloud (Perry et al., 2010). This connectionist dual process model assumes that the sublexical route is a network that maps not only graphemes into phonemes but also the orthographic input into a stress pattern. Stress information is sent to the stress output nodes that are placed at the level of the phonological output buffer and receive information also from the lexical route. The probability that a pseudoword is assigned a certain stress pattern depends on the strength of the connections established in the sublexical network. This means that if the orthographic cue is mainly associated with a given stress pattern and if the association is highly frequent in the language, then such orthographic information will establish a strong connection with the stress pattern that will thus receive strong activation at the level of the stress output nodes. In the same way, if a final sequence is mainly associated with a certain stress pattern, but there are only few words in the language that share these characteristics, then the sublexical network will establish a weak pattern of activation between the orthographic cue and its related stress. In this case, the final sequence will be a weaker cue for stress assignment, and the sublexical computation will send weaker activation to the stress output node.

In assigning stress to a pseudoword, Italian readers make use of their distributional knowledge concerning stress neighborhood and do not show a default bias. These data can be easily accounted for by the CDP++ model, assuming that a sublexical network is able to discover the distributional association between orthographic

input and stress pattern. However, our study shows another result related to stress processing in pseudoword reading: Pseudowords are read faster when they receive antepenultimate stress than when they receive penultimate stress. The latter effect is not influenced by stress neighborhood: Across all four experiments, antepenultimate stress stimuli were always read faster than penultimate stress stimuli, and this effect did not depend either on the proportion or on the absolute number of stress neighbors. We propose that the effect of stress type on naming latencies is located at the level of articulatory planning, where the phonological word undergoes planning and successive execution of articulatory programs to be produced as a spoken form. Unfortunately, while the CDP++ model can explain the stress neighborhood effect on stress assignment, it cannot deal with the stress type effect on naming latencies. The model does not predict any difference in naming latencies when readers compute different stress patterns,¹⁰ and it does not provide any account of how information in the phonological output buffer is planned for articulation. In line with the reading literature, the CDP++ model, as well as other computational models of polysyllabic word reading (Arciuli et al., 2010; Pagliuca & Monaghan, 2010; Rastle & Coltheart, 2000), has not developed a phonological-to-phonetic interface. There is no computational modeling of how the word's phonological representation is assembled and then converted into its phonetic representation—that is, the level at which the effect of stress type on naming times may occur.

To explain the effect of stress type on naming speed we may turn to studies on speech production, where the phonological-to-phonetic interface has been investigated in detail. Roelofs (2004) showed that speech production and reading aloud may share the last stages of processing. He suggested that models of speech production and reading aloud might be merged at the level of phonological encoding, where the segment-to-frame association takes place, and the phonological word is encoded by associating the segmental information with the retrieved metrical information. This stage is then followed by the word phonetic encoding, where the phonological representation is translated into articulatory programs (Levelt et al., 1999).

Similar processing assumptions can be made for the latest stages of reading aloud, in which readers must determine stress position before starting articulation (Perry et al., 2010). Our data suggest that the unit for articulation planning must include the stressed syllable. Thus, assigning stress to the antepenultimate syllable would require the articulatory planning of a smaller unit than in the case in which stress is assigned to the penultimate syllable. Readers can buffer a partial articulatory representation, namely, the planned unit up to the stressed syllable, and the time required to retrieve the articulatory program is a function of the number of items in the articulatory buffer (Levelt, 1989). It has been shown

¹⁰ The CDP++ model simulates the stress regularity effect found by Rastle and Coltheart (2000): Low-frequency bisyllabic words were read faster when they received the regular stress (on the first syllable) than when they received the irregular stress (on the second syllable). However, the simulation of such an effect required an increase of the stress node naming criterion, which is the parameter that has to be activated for starting the articulation. The authors of the CDP++ have argued that the parameter manipulation worked as a strategic manipulation similar to those strategic behaviors assumed by readers in particular list contexts.

that the encoding of metrical stress, similar to segmental encoding, is rightward incremental (Schiller, 2006; Schiller, Jansma, Peters, & Levelt, 2006). Thus, the encoding of later occurring metrical information takes longer when compared with earlier occurring metrical information. This means that the planning of articulation not only involves units of different sizes, depending on the number of syllables that have to be buffered, but may also require more or less time for phonological encoding that proceeds in a left-to-right manner. As a consequence, starting the articulation would require less time when only one syllable has been buffered than in the case of a two-syllable unit (for a similar assumption, see Laudanna, Burani, Cermele, & Parisi, 1989). This idea finds further support when the naming latencies of Experiments 3 and 4 are compared. If we inspect the naming times in Experiment 4, where four-syllable pseudowords were used, we note that RTs are longer than RTs obtained in Experiment 3 (the difference is approximately 100 ms); this happens both when we consider antepenultimate and penultimate stress stimuli. Such a difference may support the view that the articulatory unit in reading polysyllabic stimuli proceeds from the first syllable up to the stressed syllable. The more syllables are included in the articulatory unit, the longer it takes to start articulation. We do not exclude that other factors may have contributed to the difference in naming times between three- and four-syllable pseudowords—for example, the effect of stimulus length on the stimulus's decoding at the perceptual level—but we retain such difference as a good clue for the view that the articulatory unit in reading may vary according to the position of the stressed syllable.

Evidence that antepenultimate and penultimate stress stimuli may show a difference in naming times comes also from the study by Burani and Arduino (2004). In Experiment 2, the authors found that low-frequency words were read faster when they received antepenultimate stress than when they received penultimate stress. The authors assumed that the effect was due to a difference in the numerosity of stress neighborhood: The antepenultimate stress neighborhood was larger in numerosity than the penultimate one. However, such an interpretation is not supported by the present results: Naming speed is not affected by the composition of stress neighborhood, but it seems to be a function of the size of the unit that must be buffered. The study of Burani and Arduino (2004; Experiment 2) provides the only evidence for a difference in naming speed between antepenultimate and penultimate stress words. It might be argued that such a difference in naming speed is apparent in naming a word rarely encountered before—thus subject to being read with a contribution of the sublexical route—and it is even more visible with pseudowords. As suggested by Laudanna et al. (1989), it may be the case that when participants read a known word aloud, they are able to address the phonetic representation directly from the phonological representation of the word; thus, readers may retrieve a phonetic representation that they have assembled several times and that is represented as a whole unit. In contrast, when participants read aloud a pseudoword, they must convert the newly assembled phonological word in a phonetic representation that they have never articulated before. Thus, in the case of word reading, phonetic encoding might work more as a mechanism that activates a whole phonetic representation of the stimulus; whereas in the case of pseudoword reading, the phonetic representation cannot be retrieved thus it must be encoded on line.

Within a more general perspective, the effect of stress type on naming speed may be taken as a further piece of evidence in favor of the involvement of metrical information in the advance preparation of reading a stimulus aloud (Colombo & Zevin, 2009; Levelt et al., 1999; Sulpizio et al., in press). All our experiments show that pseudowords are read faster when they receive antepenultimate stress than when they receive penultimate stress. To read a polysyllabic stimulus aloud, participants need to combine segmental and metrical information. Thus, stress computation may affect not only the phonological word encoding but also the successive stage of articulation planning: The timing of metrical encoding may affect the timing of phonological encoding and the following stage of articulation, required for the phonological word to be executed.

Overall, the findings of the present study shed new light on how stress is assigned during reading aloud and how it affects the speed of pseudoword naming. A stimulus's spelling, especially its ending, works as a stress cue: Readers may assign stress according to the distributional information concerning stress neighborhood. However, the strength of a final orthographic sequence as a cue for a certain stress pattern may depend on the composition of stress neighborhood: The larger the number of word types sharing final sequence and stress pattern, the stronger the orthographic cue that drives stress assignment. While stress neighborhood influences stress assignment to pseudowords, it does not affect naming speed. Readers were always faster in reading aloud pseudowords with antepenultimate stress than with penultimate stress. The difference in naming time may have its origin in the latest stages of the reading process, when the phonological representation has to be articulated. When readers start to articulate a (pseudo)word is a matter of ongoing debate in the reading literature. We assume that the minimal unit to start executing the articulatory programs may vary according to stress position; that is, the unit for articulation planning must include the stressed syllable.

To conclude, the results of our study suggest that the processing of stress may involve different stages of the reading process, affecting not only the level of orthography-to-phonology mapping but also the level at which the phonological representation has to be articulated.

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(Appendix follows)

Appendix

Pseudoword Stimuli

Pseudoword Stimuli Used in Experiments 1 and 3

Pseudowords with penultimate stress neighbors. Bimpiro, bintoro, dassoro, esmiro, fempiro, fubbiro, liddera, meppora, miloro, naprita, plamita, pragera, punnora, stermita, tagnora, tidoro, truggera, vosora, vospimera, vuccita.

Pseudowords with antepenultimate stress neighbors. Bip-pile, birmolo, dazzolo, espile, fempile, fubbile, lispano, meffola, mirdolo, nastica, plarica, prallano, pumbola, stemica, tammola, timpolo, trudano, voccibano, vosola, vullica.

Pseudoword Stimuli Used in Experiment 2

Pseudowords with penultimate stress neighbors. Bildoro, bitora, bivata, bompiro, cendiro, cesita, dalpiro, damboro, dumbata, fobita, fupita, gediro, gesora, gunoro, lenora, lonviro, lutita, misporo, nampora, nediro, nipata, potora, puvata, revoro, rugnoro, segoro, selgoro, suntora, tabata, tadiro, tufita, vorita, vupita, zabata, zicata.

Pseudowords with antepenultimate stress neighbors. Bimpola, bintolo, bisile, botile, cebica, cesile, dabica, dapola, dulica,

fontolo, furgolo, gerile, gertolo, gumica, lemero, losile, lufero, mitrolo, nardolo, nebola, nilero, povica, pudero, rembolo, rulica, sembola, sepica, subrola, tamile, tampola, turile, vobero, vurola, zadero, zimero.

Pseudoword Stimuli Used in Experiment 4

Pseudowords with dominant stress neighbors. Besavora, betolora, bisediro, bitaniro, colebita, conamita, dabisoro, dabonoro, daconiro, damosiro, fipamita, firelita, fobalora, fosagora, gofelata, gosibata, nabogata, nadibata, zicavoro, zipavoro.

Pseudowords with nondominant stress neighbors. Beranica, beritica, bidulero, biretero, coberola, cofepola, dacatero, dagomile, dalotero, davemile, fimarolo, fiterolo, fobitola, fomedola, gobamile, gosadile, napegolo, naratolo, zidebica, zilonica.

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