Syllable Frequency and Stress Priming Interact in Reading Italian Aloud

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Abstract

In current theories of word reading the structure and operations of the phonological buffer are quite underspecified. We investigated this issue by running a reading aloud experiment in Italian. We adopted a priming paradigm, with three-syllabic words as primes and targets and we jointly manipulated two effects ascribed to the stage of phonological and phonetic encoding, that is stress priming and syllable frequency. Target words varying for the frequency of their initial syllable were preceded by words congruent or incongruent for the stress pattern. The results showed an interaction between syllable frequency and stress prime, with the stress congruency effect larger for the targets with low-frequency first syllable. This result suggests that, in reading aloud, stress assignment and syllable computation have a tight time dynamics in the phonological output buffer, and that the process at the level of phonology-to-phonetic interface operates interactively.

Keywords: Lexical stress; syllable frequency; phonological-to-phonetic interface; phonological buffer; reading aloud.

Introduction

Reading aloud requires the execution of multiple operations, e.g., perceiving the stimulus, converting the printed information in a speech signal, and articulating the word's sounds, taking into account both segmental (e.g., sounds) and suprasegmental (e.g., stress) information. While many reading studies have investigated the operations involved in word recognition, the phonological encoding of a word and its phonetic realization have received less attention. The same happens with computational models of reading aloud: They usually implement in a detailed way the procedures readers use to recognize words, but they are less specific about those phenomena related to the production stages (see, e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), and the very few that have attempted to implement procedures for stress assignment differ in the solutions they propose (see, e.g., Arciuli, Monaghan, & Seva, 2010; Perry, Ziegler, & Zorzi, 2010; Rastle & Coltheart, 2000; Sibley, Kello, & Seidenberg, 2010).

The investigation of the production stage of reading aloud can benefit from the speech production literature, as it has been argued that speech production and reading aloud may share the last stages of processing, specifically the phonological and phonetic encoding of the word (Roelofs, 2004). In the model developed by Levelt and colleagues (Levelt, Roelofs, & Meyer, 1999) it is assumed that during phonological encoding speakers retrieve in parallel the segmental material and the metrical structure – number of syllables and word's stress pattern – and combine them into the phonological word (see also Roelofs & Meyer, 1998). At this point, the phonological word is phonetically encoded and it is then translated into its phonetic realization.

A detailed architecture of the phonological and phonetic encoding, however, has never been proposed by any model of word reading and how the reading system converts abstract phonological information into phonetic representations is still an open issue. An effort in this direction has been done by Perry and colleagues (2010): In their CDP++ model of reading, at the level of phonological output buffer, the authors implement a double process analogous to the one proposed for word production, with two different loci for stress and phonemes activation. In particular, the model presents stress-output nodes, i.e. nodes specifying the position of the stress within the lexical string. Such nodes are activated autonomously from the segmental information, although full processing of the latter is conditional upon the former: Articulation of the word phonemes cannot be initiated until the word stress has been fully determined. However, despite the improvement of the phonological output buffer, nothing is said about how segmental and suprasegmental information are assembled together, and how the selected phonological information is converted into a phonetic representation.

Recent empirical data that can help to better understand how the phonological and phonetic encoding work within the reading system. Some studies run in Italian (Colombo & Zevin, 2009; Sulpizio, Boureux, Burani, Deguchi, & Colombo, 2012a; Sulpizio, Job, & Burani, 2012b), support the view that metrical and segmental information are autonomously involved in planning and assembling an utterance, both when stress is sub-lexically computed (Colombo & Zevin, 2009; Sulpizio et al., 2012a) or lexically retrieved (Sulpizio et al., 2012b). In particular, the latter study showed an effect of stress position priming for segmentally different prime-target pairs. Specifically, readers are faster in reading a word when it is preceded by a word with the same stress, e.g., TESsera (card) – BUfala (hoax), than when in is preceded by a word with a different stress, *e.g,.* cuGIno (cousin) – BUfala (hoax)[1]. The pattern was interpreted as showing that stress priming affects the

[1] Capital letters indicate stressed syllable.

stage of phonological word encoding in the phonological buffer.

An effect that has also been ascribed to the later stages of reading aloud is that of syllable frequency. Researches in different languages have shown that participants are faster in producing a word that starts with a high-frequency syllable than one with a low-frequency syllable (see, *e.g.,* for Dutch: Cholin, Levelt, & Schiller, 2006; English: Cholin, Dell, & Levelt, 2011; French: Laganaro & Alario, 2006; Italian: Sulpizio & Job, 2010; Spanish: Carreiras & Perea, 2004) and there is consensus on the claim that such effect is attributed to the phonetic encoding, when readers convert the abstract phonological word into abstract motor programs.

Jointly considering the effects of stress assignment and of syllable frequency in reading aloud may allow us to better articulate the operations involved in the phonological-to-phonetics interface, the rather neglected and oversimplified component of reading models. Both stress priming and syllable frequency are assumed to affect the latest stages of reading process, when readers (a) spell out segmental and metrical information and (b) plan the articulation of the word, with syllable frequency affecting the word's phonetic encoding (Carreiras, Mechelli, & Price, 2006; Laganaro & Alario, 2006). Thus, an additive pattern of syllable frequency and stress priming would be consistent with the proposal of two separate consecutive stages for the two effects, or with the assumption of a threshold of activation for one component before the other may start its computations (Perry et al., 2010): In such a view, word phonetic encoding can start only after the processing of stress assignment ends, with the consequence that a delay in the computation of stress would affect the phonetic encoder independently from how fast its content might be computed. Differently, an interaction between syllable frequency and stress priming would suggest that both the effects may concurrently affect the same stage of processing, i.e. the phonological-to-phonetic interface. If this is the case, it would suggest that: a) there is no reason to postulate a threshold setting the timing of either segmental or suprasegmental activation; b) the mapping of the phonological word into phonetic codes may occur through an interactive process.

Experiment

Three-syllabic Italian words were used as stimuli as stress position for these words is not always predictable. Indeed, Italian three-syllabic words have two main stress patterns (Thornton, Iacobini, & Burani, 1997): Antepenultimate stress (i.e., the first syllable bears stress, e.g., TAvolo 'table'), and penultimate stress (i.e., the second syllable bears stress, e.g., coLOre 'color'). Although their distribution differs – 80% of three-syllable words bear penultimate stress and 18% bear antepenultimate stress[2] – the two patterns are lexically stored within the phonological lexicon and the asymmetry does not affect lexical reading (Paizi, Zoccolotti, & Burani, 2011).

By jointly manipulating stress priming and syllable frequency we aimed at investigating the operations involved in the phonological-to-phonetic interface that take place during the later stages of word reading. Specifically, if stress priming and syllable frequency originate at two separate stages of processing or the former is governed by a threshold mechanism, then the stress priming effect should be of similar size for both words starting with a high- and words staring with a low-frequency syllable. Differently, if stress priming and syllable frequency may concurrently affect the phonological-to-phonetic interface, an interaction between the two effects should be expected.

Method

Participants

Twenty-four students (14 male, mean age: 24, sd: 3.8) of the University of Trento. They were all Italian native speakers and they had normal or corrected-to-normal vision. They received credit course for their participation.

Materials and Design

Four sets of three-syllabic words were used as targets. The sets were selected by combining two variables: Frequency of the first syllable (high or low) and stress pattern (penultimate or antepenultimate). Each set was composed of 22 low-frequency words selected from the CoLFIS database (Bertinetto et al., 2005). Stimuli were matched on length in letters, orthographic neighborhood size, orthographic neighbors' summed frequency, frequency of the second and third syllable, mean bigram frequency, orthographic complexity, initial phoneme (Table 1), and had a stress neighborhood composed mainly of stress friends (Burani & Arduino, 2004).

Table 1. *Summary statistics: means (and standard deviations) for the three-syllabic target words.*

	First Syllable Frequency			
	High		Low	
	Pen. stress	Antep. stress	Pen. Stress	Antep. Stress
First Syllable Frequency	690 (561)	720 (505)	28 (25)	41 (30)
Second+third Syllable Frequency	1588 (847)	1711 (809)	2088 (919)	2228 (769)
Word frequency	4.5 (4.9)	6.5 (11.2)	7.1 (12)	6.05 (7.3)
Length in letters	7 (0.6)	6.8 (0.4)	7.1 (0.3)	7 (0.2)
Mean Bigram frequency	11.6 (0.2)	11.5 (0.2)	11.4 (0.2)	11.5 (0.4)
N of orthographic neighbors	1 (1.2)	1 (1.1)	1.1 (0.9)	1 (1)

[2] The remaining 2% of three-syllabic words bears stress on the final syllable, and in this case stress it is graphically marked (e.g., *coliBRÌ*, hummingbird).

Neighbors' summed frequency	4.7 (9.9)	8.1 (22.9)	2.1 (2.8)	6 (14.9)

Note: Pen. = penultimate stress; Antep. = antepenultimate stress; syllable frequency measures are calculated out of 1 milion occurrences (Stella & Job, 2001); word frequency measures are calculated out of 1 million occurrences (Bertinetto et al., 2005); mean bigram frequency is log transformed on the basis of the natural logarithm.

Targets were pre-tested to ensure that none of the initial syllables was a probabilistic orthographic cue for stress (Arciuli, Monaghan, & Ševa, 2010). Thus, syllable frequency was not expected to interact with word's stress pattern. To further rule out such possibility, we ran a pilot experiment asking 18 university students to read aloud all targets. Stimuli appeared in capital letters in the center of the screen, after a fixation cross displayed for 400 ms. Each stimulus remained on the screen until the participant began to read or for a maximum of 1500 ms. The presentation order was randomized between participants. Mean RTs for correct responses were submitted to a 2 (high- vs. low-frequency syllable) x 2 (penultimate vs. antepenultimate stress) ANOVA. The analysis showed an effect of syllable frequency (F_1 (1,17) = 22.19, *MSE* = 1246, $p < .01$; F_2 (1,84) = 17.29, *MSE* = 2033, $p < .01$), with faster reaction time for words with a high-frequency syllable. Neither stress type (F_1 (1,17) = 1.60, *MSE* = 246; $F_2 < 1$) nor the interaction were significant (F_1 (1,17) = 3.60, *MSE* = 217; $F_2 < 1$). No effect was significant in the analysis of errors (4.8%). Results of the pilot experiment suggest that targets' first syllables are not preferentially associated with a certain stress pattern, as suggested by the absence of a syllable frequency by stress type interaction.

Two sets of 44 high frequency three-syllabic words were used as primes. One set included penultimate stress words and the other antepenultimate stress words, all selected from CoLFIS (Bertinetto et al., 2005). The two sets were matched on: Length in letters, orthographic neighborhood size, orthographic neighbors' summed frequency, mean bigram frequency, and initial phoneme (Table 2). Primes were paired with target words in such a way that neither semantic relation nor orthographic overlapping existed between prime and target. Targets were divided between the two prime stress conditions (congruent and incongruent) and each prime word was paired with both a congruent (e.g., niPOte 'nephew' – laSAgna 'lasagna') and an incongruent stress target (e.g., niPOte 'nephew' – MUscolo 'muscle').

Table 2. *Summary statistics: means (and standard deviations) for the three-syllabic prime words.*

	Stress Type	
	Pen.	Antep.
Word frequency	216 (118)	228 (127)
Length in letters	6.9 (0.7)	6.7 (0.7)
Mean Bigram frequency	11.5 (0.4)	11.4 (0.3)
N of orthographic neighbours	1.9 (1.7)	1.8 (1.4)
Neighbors' summed frequency	51.5 (68.7)	52.6 (65.1)

Note: Pen. = penultimate stress; Antep. = antepenultimate stress; syllable Word frequency measures are calculated out of 1 million occurrences (Bertinetto et al., 2005); mean bigram frequency is log transformed on the basis of the natural logarithm.

The Experiment had a 2 (congruent *vs*. incongruent stress pattern) x 2 (high- *vs*. low-syllable frequency) design. Following the procedure adopted by Sulpizio and colleagues (2012b), prime-target pairs were divided in 4 pure blocks (prime and target sharing the stress pattern & target with a high-frequency initial syllable; prime and target sharing the stress pattern & target with a low-frequency initial syllable; prime and target with different stress patterns & target with a high-frequency initial syllable; prime and target with different stress patterns & target with a low-frequency initial syllable). Furthermore, in each block, half of the targets had penultimate stress and half had antepenultimate stress, and in no case prime and target shared the initial phoneme. The order of stimuli was randomized within blocks and block order was counterbalanced across participants. Primes and targets were paired in such a way that for half of the participants a target was in a congruent stress condition (prime and target having same stress), and for the other half the same target was presented in the incongruent stress position (prime and target having different stress).

Apparatus and procedure

Participants were tested individually. They were instructed to read the targets as quickly and accurately as possible. Each trial started with a fixation cross, centered on the screen, for 400 ms. The prime was then presented in lower-case letters just above the center of the screen for 86 ms and it was followed by a 86 ms blank; then, the target stimulus was displayed in upper-case letters just below the center of the screen. The target remained on the screen until the participant began to read it or for a maximum of 1500 ms. The inter-stimulus interval was 1500 ms. A practice session with 8 trials preceded the experiment. Naming times were recorded by means of E-Prime software. The experimenter noted the naming errors.

Results

Responses shorter than 250 ms or longer than 1500 ms (2.4% of all data points) were excluded from the analyses. Naming errors, including both phonemic and stress errors, summed to 2.7% of all data points and were not analyzed. Results are reported in Figure 1.

A 2x2 analysis of variance with syllable frequency (high- vs. low-frequency syllable) and condition (congruent vs. incongruent stress) was conducted on the reaction times (RTs) of correct responses. The factors were within participants (F_1) and between items (F_2). The main effect of condition was significant, with congruent target words read faster than incongruent target words (F_1 (1,23) = 10.49, *MSE* = 3771, $p < .01$, $\eta^2 = .27$; F_2 (1,176) = 51.49, *MSE* = 1558, $p < .001$, $\eta^2 = .23$). The main effect of syllable frequency was also significant, showing that targets with an initial high-frequency syllable were read faster than targets with a low-frequency syllable (F_1 (1,23) = 8.73, *MSE* = 995, $p < .01$, $\eta^2 = .31$; F_2 (1,176) = 10.24, *MSE* = 1558, $p < .01$, $\eta^2 = .15$). Finally, there was a significant interaction between congruency condition and syllable frequency, (F_1 (1,23) = 4.39, *MSE* = 675, $p < .05$, $\eta^2 = .16$; F_2 (1,176) = 4.26, *MSE* = 1558, $p < .05$, $\eta^2 = .12$): LSD post-hoc comparisons showed that the 55 ms stress priming effect (p < .005, $\eta^2 = .31$) for targets with a low-frequency initial syllable was significantly different from the 31 ms effect (p < .05, $\eta^2 = .23$) for the targets with a high-frequency initial syllable.

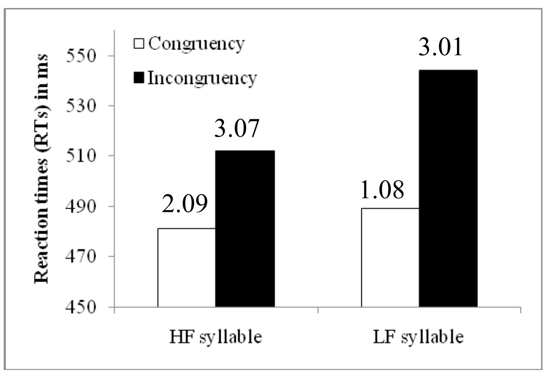

Figure 1. *Reaction times and percentage of errors by condition*

The results of the present experiment are clear. Word targets preceded by stress-congruent primes were read faster than targets preceded by stress-incongruent primes. Moreover, words with a high-frequency first syllable were read faster than words with a low-frequency first syllable. Finally, the priming effect was larger for targets with a low-frequency first syllable than for those with a high-frequency first syllable.

Discussion

The main finding of our study is that syllable frequency and stress priming interact: Reading times are longer to incongruent prime-target stress pairs for both high- and low-frequency syllable targets, but for the latter the difference is larger than for the former. Thus, syllable frequency modulates the impact of stress priming. The findings allow us to better understand some aspects of the mechanics of phonological and phonetic encoding during reading. They also provide hints on the relative timing of the operations underlying stress retrieval and word articulation in reading aloud.

The effect of syllable frequency has been generally ascribed to the phonetic encoding level by assuming that speakers are facilitated in articulating those syllables they produce frequently. Specifically, Levelt et al. (1999) argue that high-frequency syllables can be retrieved from a mental syllabary, while low-frequency syllables are assembled using the phonological word as input. The assumption of a mental syllabary has been accepted by most of the reading literature which reported effects of syllable frequency in word and pseuwdoword reading tasks (Carreiras & Perea, 2004; Carreiras et al., 2006; Laganaro & Alario, 2006; Perea & Carreiras, 1998; Sulpizio & Job, 2010). Thus, also in word reading, the effect of syllable frequency can be located at the stage of phonetic encoding, that is in the phonological output buffer.

The effect of stress priming has been ascribed to mechanisms operating at the level of the phonological buffer (Sulpizio et al. 2012b; see also Colombo & Zevin, 2009; Sulpizio et al., 2012a). In such a view, the preactivation of metrical information by a prime word would affect the component of the phonological buffer responsible for metrical encoding by affecting the timing of the operations the system performs to retrieve and assign the correct stress pattern to the target word.

The interaction we report suggests that syllable frequency and stress assignment may affect a common locus, and that such locus is the phonological output buffer, where the phonological word is phonetically encoded and thus realized. One might argue – contra Levelt *at al.* (1999) – that syllable frequency may affect reading during the orthography-to-phonology conversion. If that were the case, the syllable frequency effect would have emerged only in the congruent stress condition; in the incongruent stress condition, in fact, the time needed to account for the stress mismatch would have delayed the assembling of segmental and metrical information, with the result of allowing enough time for fully computing low-frequency syllables. This being the case, the syllable frequency effect would have been greatly reduced or even annulled. This is not the case, and our results support the proposal that syllable frequency effect arises at the phonetic encoding (Levelt et al., 1999).

The difference in speed of processing between high- and low-frequency first syllables for congruent and incongruent stress targets seems to be the critical factor in the pattern we obtained and the interaction suggests that, at the level of phonology-to-phonetic interface, words with a high-frequency initial syllable are less prone to interference from the stress mismatch. Although the present data do not allow us to finely specify the nature of such interaction – that is, it is hard to establish whether the nature of the stress priming effect is facilitatory or an inhibitory – a possible interpretation of our finding can still be sketched by referring to the different procedures for syllabification of high- and low-frequency syllables. According to the mental syllabary theory (Levelt et al.'s, 1999), the former are retrieved from the repertoire of syllables while for the latter a composition from their constituent phonemes is postulated. The syllable stored in the repertoire are used to drive the motor programs, that is they allow the speakers to map the abstract phonological syllabic representations into phonetic packages, which are still partially abstract representations of the to-be-performed articulatory gestures, and each syllable can thus be still prone to be articulated in different ways (e.g., with longer or shorter duration, with more or less force, or with different kinds of pitch modulation; Levelt, 1989). Therefore, in case of a stimulus with a high-frequency first syllable, the reading system may start the phonological-to-phonetic mapping by processing the segmental information up to the syllable repertoire and independently of how fast the computation of the suprasegmental information occurs; then, as soon as the stress system determines the correct stress pattern the activated phonetic syllable is specified in terms of stress. In such a view, the phonetic code retrieval of a high-frequency syllable is weakly affected by the prime computation as the former can proceed independently from the latter. Thus, for words starting with a high-frequency syllable, the difference between targets in the congruent- and incongruent-stress prime condition would be only due to the different timing required for the specification of the correct stress pattern of the target in the two conditions.

A different process, however, can be postulated for words starting with low-frequency syllables as they do not have a stored representation in the syllabary and are thus assembled on-line. As a consequence, to map the abstract phonological constituents of a syllabic unit into a corresponding phonetic-detailed representation, the reading system needs all the relevant information – the phonemes and the specification of stress (i.e., if the syllable is either stressed or unstressed) – to be both in the phonological output buffer, as a partial or incomplete activation of either segmental or suprasegmental information would make the buffer unable to assemble a well-formed phonetic unit. In such a view, the large priming effect reported for low-frequency syllables may emerge because, for such stimuli, the operations of stress assignment and phonetic syllable computation are sequential. The implication of such assumption is that the time required to assemble a low-frequency syllable is a function of the time required to correctly assign the stress pattern to the word, as the latter can speed up or delay the initiation of phonetic encoding of the former.

The CDP++ model of reading (Perry et al., 2010), which was recently implemented for English bisyllables, explicitly assumes that the start of articulation is conditional to stress retrieval, and thus may be used to frame our interpretation of the pattern of results. In the Perry et al.'s (2010) model, the phonological output buffer includes two distinct mechanisms for segmental and suprasegmental computation, i.e., phonological output nodes and stress output nodes, with the latter nodes being responsible for stress assignment. This is consistent with our claim that the locus of the interaction is the phonological output buffer. However, the functional architecture of the model seems to be still underspecified to be able to fully account for our results since in the model the timing of the operations in the phonological output buffer is such that only after the relevant stress pattern has been activated the word constituent phonemes, structured in their syllabic constituents, can be overtly articulated. Such architecture would predict an additive effect of stress assignment and syllabification, with the consequence that a delay in the processing of stress assignment should equally affect both word with a high-frequency first syllable and words with a low-frequency first syllable. Although our data support the view that stress assignment is essential for articulation to take place, they also suggest different procedures for high- and low-frequency syllables, i.e. an interactive process at the level of phonology-to-phonetic interface (for a similar proposal, see Perret, Schneider, Dayer, & Laganaro, 2012).

To conclude, our findings show that words with an initial low-frequency syllable are more strongly affected by manipulation of incongruent stress priming than words with a high-frequency initial syllable. This is the first evidence showing that, in word reading, the processes of stress assignment and syllable computation may interact within the phonological output buffer. The finding is consistent with the view that the phonological buffer acts as the locus of phonological-to-phonetics interface, where the abstract phonological word is converted into its phonetic representation, and where stress and syllable information may interact.

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