Stress affects articulatory planning in reading aloud

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Abstract

Three experiments of pseudoword reading assessed whether stress assignment affects reading aloud at the level of articulation planning. In experiment 1 (immediate reading) both stimulus length (in syllables) and stress type affected reading latency and accuracy. Italian pseudowords were named faster and more accurately when they were assigned stress on the antepenultimate than on the penultimate syllable. In experiment 2 (delayed reading) reading aloud of the same stimuli was not affected by length but was still affected by stress type, with shorter latencies for pseudowords stressed on the antepenultimate syllable. Experiment 3 replicated the results of the first two experiments with new materials and with a tightly controlled procedure. These results indicate that stress assignment exerts an effect in a processing component where articulation is planned as articulation can not start until stress is assigned. Our results also suggest that, in reading aloud, the minimal planning unit for articulation is smaller than the whole stimulus, including the first syllable up to the stressed unit.

A comprehensive understanding of reading processes must include understanding of how stress assignment works and at which levels of computation. Research in polysyllabic languages, such as English or Italian, reported much evidence on how readers retrieve or assign stress based on orthography (e.g., Arciuli & Cupples, 2006; Burani & Arduino, 2004; Burani, Paizi, & Sulpizio, 2014; Colombo, 1992) and how this process develops when learning to read (Arciuli, Monaghan, & Ševa, 2010; Sulpizio & Colombo, 2013; for a review, see Sulpizio, Burani, & Colombo, 2015).

However, stress assignment may impact reading processing not only with regard to the retrieval of phonological information or in terms of orthography-to-phonology mapping. Since articulation of a word cannot start until it has received stress, stress assignment may also affect the process of articulation planning. Reading a stimulus requires computing stress information separately from segmental information, and the active stress pattern has to be associated before articulation to the stimulus' phonemes. Thus, stress may affect reading latency in terms of the time needed to identify the correct metrical structure and to assemble it with the segmental content (Sulpizio, Job, & Burani, 2012).

Stress computation may also affect the reading process further downstream, that is during articulatory planning of the response, when the assembled phonological codes are converted into articulatory programs. This idea has been recently tested in a reading aloud study conducted in Italian (Sulpizio, Arduino, Paizi, & Burani, 2013), a language in which stress position is neither fixed nor governed by rules (note 1). In Experiment 3 (three-syllable items) and 4 (four-syllable items), Sulpizio and colleagues (2013) asked participants to read pseudowords aloud by assigning them either stress on the penultimate (e.g., binTOro, cofePOla; capital letters indicate stress) or the antepenultimate syllable (e.g., BINtoro, coFEpola), which are the two main stress patterns in Italian (note 2). Although antepenultimate stress is not the dominant stress in Italian, participants read pseudowords faster when

assigning stress on the antepenultimate than on the penultimate ones. To explain this finding, Sulpizio and colleagues (2013) proposed that stress computation may affect reading latency during the process of stimulus articulation. When reading polysyllables, participants would buffer a partial articulatory representation of stimuli that proceeds from the first up to the stressed syllable. Thus, assigning stress to the antepenultimate syllable would require the articulatory planning of a shorter unit than assigning stress to the penultimate syllable, with faster pronunciation times for the former than for the latter. This idea is in line with the speech production literature, which suggests that during phonological encoding, segments are associated to a metrical frame through a serial rightward incremental process (e.g., Roelofs, 2004; for a similar assumption in the case of reading, see, e.g., Malouf & Kinoshita, 2007), and as soon as the first syllable has been created, the corresponding articulatory code is accessed and stored in an output buffer (Levelt, Roelofs, & Meyer, 1999). Thus, if we assume with Roelofs (2004) that speech production and reading aloud may share, at least in part, the last components of processing, and that models of speech production and reading aloud might be merged at the level of phonological encoding, then similar processing assumptions can be made for the latest stages of speech production and reading aloud in which readers must determine stress position before starting articulation.

The present study is a follow-up of that by Sulpizio and colleagues (2013), with the aim to focus on the locus of the stress effect reported by Sulpizio and colleagues (2013) – i.e., faster pronunciation times for antepenultimate- than penultimate-stress stimuli. The question we address here is the following: Does such stress effect originate during articulatory planning of the stimulus, or does it rather arise earlier in processing? To answer this question we ran three reading aloud experiments, in which participants read three- and four-syllabic pseudowords aloud by assigning them the antepenultimate or penultimate stress. Experiment 1 and 2 differed from each other only in the procedure we adopted, that is immediate and delayed reading aloud, respectively. The comparison of

the effects following the two procedures may help us to identify the locus of the stress effect. We used delayed reading because this task is assumed to tap into the processing component of articulation planning, with readers being able to pre-process the stimulus up to response execution (e.g., Balota & Chumbley, 1985; Ferrand, 2000; Forster & Chambers, 1973; Ghyselinck, Lewis, & Brysbaert, 2004; McCann & Besner, 1987; Zoccolotti, De Luca, Judica, & Burani, 2006). Experiment 3 served the purpose of validating the results of the first two experiments: To this aim, we used a new set of stimuli and a different design in which we asked participants to perform both the immediate and the delayed tasks.

A further difference between the present study and the (immediate) reading study of Sulpizio and colleagues (2013) is that in the present experiments three- and four- syllable pseudowords were presented in the same experiment. The orthogonal manipulation of stress type and stimulus length (in terms of syllable number) allowed us to outline clear-cut predictions for the immediate and delayed conditions, respectively. Let us consider immediate reading aloud first (Experiment 1 and part of Experiment 3). Based on previous evidence, we expected that both stress type (antepenultimate *vs.* penultimate stress) and stimulus length (three *vs.* four syllables) would affect pronunciation times – with participants being faster when assigning antepenultimate than penultimate stress to pseudowords (Sulpizio et al., 2013), and when reading three-syllable than four-syllable pseudowords (Ferrand, 2000) – because stimulus length affects reading up to the stimulus' phonological encoding (e.g., Ferrand, 2000; Rastle, Havelka, Wydell, Coltheart, & Besner, 2009), whereas stress type would affect the stimulus' articulatory planning, where the assembled phonological word is planned to be executed (Sulpizio et al., 2013).

For the delayed condition (Experiment 2 and part of Experiment 3), a different pattern may be expected. The execution of a delayed response would allow participants computing the stimulus up to

articulatory planning, with the consequence that the stimulus phonological encoding would be concluded at the time of responding and the length effect canceled (Ferrand, 2000; Weekes, 1997). The prediction for the stress type effect might be twofold: If stress assignment affects the stimulus' articulation planning, then the effect should occur also in the delayed procedure; alternatively, if the effect arises somewhere before articulatory planning of the stimulus – e.g., during the computation of phonological codes or in the segment-to-metrical frame association – it should be canceled by the response delay.

Experiment 1 – Immediate reading aloud

Method

Participants. Thirty university students (26 female, mean age: 22.8, sd: 6.14) took part in the experiment. They were all Italian native speakers with normal or corrected-to-normal vision.

Materials & Design

The same materials as in Sulpizio et al. (2013; Experiments 1, 3, and 4) were used. There were two sets of three-syllable and four-syllable pseudowords, respectively. For each set, half pseudowords had an antepenultimate stress neighborhood – that is they ended with a sequence shared by a majority of words bearing antepenultimate stress (e.g., -ola as in *pentola* 'pot'*, bambola* 'doll') – and half had a penultimate stress neighborhood – that is, they ended with a sequence shared by a majority of words bearing penultimate stress (e.g., -oro as in *lavoro* 'work', *tesoro* 'treasure'; Burani & Arduino, 2004). In both sets, pseudowords with penultimate- and antepenultimate-stress neighborhood were matched for two initial phonemes. Each experimental set contained 40 pseudowords. Three-syllable pseudowords had 6-8 letters, whereas all four-syllable pseudowords had 8 letters. All pseudowords had very few or no orthographic neighbors, similar orthographic complexity and bigram frequency (for a summary of the

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stimuli characteristics, see Table 1). Stimuli were presented in four blocks, two of three-syllable and two of four-syllable items. Stimuli are reported in the Appendix.

- Table 1 -

Procedure. Participants were 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 specific practice session (one for each stress pattern) was used to induce pronunciation with the specific stress pattern (either on the penultimate or on the antepenultimate syllable). 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 (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 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 as they had practiced during the practice session. 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 was arranged in such a way that participants always read the first two blocks by assigning the same stress pattern and the last two blocks by assigning the other stress pattern. The two blocks that received the same stress were composed one of three-syllable pseudowords and one of four-syllable pseudowords. 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. The experimenter noted reading errors.

Results

Invalid trials due to technical failures (or responses that exceeded the time limit as well as responses

shorter than 200 ms) accounted for 4.04% of the data points and were discarded from the analyses.

Pronunciation times and errors (13.2% of all data points, including both phonemic and stress errors)

were both analyzed using mixed-effects models (Baayen, Davidson, & Bates, 2008; Jaeger, 2008). The

models were fitted using the *lmer* function (lmerTest package version 1.0; Kuznetsova, Brockhoff, &

Christensen, 2013) in R software (Version 3.1.0). In all analyses, a maximal random structure approach

was used by including all the random effects when possible (i.e., intercepts and slopes of fixed effects

for within factors; see Barr, Levy, Scheepers, & Tily, 2013). Results are reported in Table 2. In Table 2

and in all the following Tables that report the results of the experiments we present raw data means

although analyses of latencies were based on log transformed RTs (see below).

-Table 2-

Reaction times. Only correct responses were analyzed. RTs were log transformed to reduce the

skewness of the data (Baayen, 2008). Since three-syllable and four-syllable pseudowords were not

matched for initial phoneme, a phonetic characteristic that could affect the activation of voice key (e.g.,

Kessler, Treiman, & Mullenix, 2002), in the analysis we also included codings for the initial phoneme

of the pseudowords. The initial phonemes were coded with dummy variables for voicing, manner, and

place of articulation. In this way we were able to estimate the effects of stress type and stimulus length

controlling for the variability due to the onsets of pseudowords. The mixed-effects model was run with

RTs as dependent variable and phonemic features, stress type (antepenultimate vs. penultimate stress) and stimulus length (three vs. four syllables) as fixed factors. Results of the analysis are reported in Table 3. The results for initial phoneme predictors are not commented here because they are not of theoretical interest in the present study. The model showed a main effect of stress type: Participants were faster when reading pseudowords with antepenultimate (665 ms) than penultimate stress (702 ms); the main effect of stimulus length was also significant, with readers being faster with three-syllable (660 ms) than four-syllable pseudowords (707 ms).

-Table 3-

Pronunciation Accuracy. A mixed-effects model was run with response correctness as dependent variable and stress type (antepenultimate vs. penultimate stress) and stimulus length (three vs. four syllables) as fixed factors. The model showed a main effect of stress type ($\beta = 1.10$, st. err. $= 0.34$, z $=$ 3.19, p $= .001$), with participants being more accurate when reading antepenultimate than penultimate stress pseudowords. No further effect reached significance (stimulus length: z <1, p $>.9$; stress type by stimulus length interaction z $= -2.44$, p $> .1$).

Results of Experiment 1 show a stimulus length effect, with participants being faster when reading three-syllable than four-syllable pseudowords. Moreover, the study finely replicates the findings by Sulpizio et al.'s (2013), showing that pseudoword pronunciation was faster and more accurate when participants assigned antepenultimate than penultimate stress.

Experiment 2 – Delayed reading aloud

In Experiment 2 we assessed whether stress assignment affects the planning of stimulus articulation. To

this aim, we ran a second version of the previous experiment, by implementing a delayed reading procedure. Following the articulation planning hypothesis, we expected that stress type, but not stimulus length, would affect pronunciation times in the delayed condition, with participants being faster when assigning antepenultimate than penultimate stress to stimuli.

Method

Participants. Thirty university students (19 female, mean age: 22.2, sd: 2.82), all Italian native speakers with normal or corrected-to-normal vision, took part in the experiment. None had participated in the previous experiment.

Materials. The same stimuli were used as in Experiment 1.

Procedure. Participants were instructed to read the stimuli 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. The same practice procedure as in Experiment 1 was adopted, except that participants were instructed to wait for a response cue before starting to produce the response. Each trial started with a fixation cross centered on the screen (500 ms). Then, the stimulus was presented for 1,500 ms, followed by the response cue (******) after an interval of 1000 or 1,200 ms. The response cue was displayed until the participant started to read or for a maximum of 1,500 ms. The interstimulus interval was 1,500 ms. Using E-Prime software, a voice key connected to the computer measured RTs at the onset of pronunciation.

Results

Invalid trials due to technical failures (or responses that exceeded the time limit as well as responses shorter than 200 ms) accounted for 4.3% of the data points and were discarded from the analyses.

Pronunciation times and errors (7.3% of all data points, including both phonemic and stress errors) were both analyzed using mixed-effects models (Baayen et al., 2008; Jaeger, 2008). For random factors, a maximal random structure approach was adopted (Barr et al., 2013). Results are reported in Table 4.

-Table 4-

Pronunciation times. Only correct responses were analyzed. As in the previous experiment, the analysis also included information about the initial phoneme of pseudowords to account for variability due to phonemic differences among stimuli. The mixed-effects model was run with log transformed RTs as dependent variable (Baayen, 2008) and phonemic features (coded as dummy variables), stress type (antepenultimate vs. penultimate stress), and stimulus length (three vs. four syllables) as fixed factors. Only results for stress type and stimulus length are commented as relevant in the present research. Results of the analysis are reported in Table 5. The model showed a main effect of stress type, with participants being faster in reading pseudowords with antepenultimate (462 ms) than with penultimate stress (485 ms). No further effect reached significance.

-Table 5-

Pronunciation Accuracy. A mixed-effects model run with response correctness as dependent variable and stress type (antepenultimate vs. penultimate stress) and stimulus length (three vs. four syllables) as fixed factors revealed a significant effect of stress type (β = -0.63, st. err. = 0.28, z = -2.18, p = .02): Participants made fewer errors when they assigned antepenultimate than penultimate stress to pseudowords. No further effect reached significance (stimulus length: z = -1.79, p > .05; stimulus length x stress type: z = 1.38, p > .16).

Joint Analyses of RTs. A further analysis was run to compare results of the two experiments and assess

whether the effect of stress type was modulated by the experimental procedure. A mixed-effects model was run with log-transformed RTs as dependent variable and phonemic features of the pseudoword onsets, stress type (antepenultimate vs. penultimate stress), stimulus length (three vs. four syllables), and experimental procedure (immediate vs. delayed reading) as fixed factors. The introduction of phonemic features allowed us to control for their effect on pronunciation times. The results for initial phoneme predictors are not presented here. The model showed a main effect of experimental procedure ($\beta = 0.34$, st. err. $= 0.05$, t $= 6.03$, p $< .001$), with participants being slower in the immediate than in the delayed reading experiment. The main effect of stress type was significant ($\beta = -0.05$, st. err. $= 0.02$, t $= -2.23$, p $= .03$), with participants faster when reading pseudowords with antepenultimate than with penultimate stress. Finally, stimulus length interacted with the experimental procedure ($\beta = 0.07$, st. err. $= 0.03$, t $= 2.54$, p $= .01$), with participants being faster when reading three-syllable than four-syllable pseudowords, but only when they performed an immediate reading task. No further effect reached significance (stimulus length: t $= -1.10$, p $> .2$; experimental procedure x stress type: t <1, p $> .6$; stimulus length x stress type: t $= 1.32$, p $> .1$; experimental procedure x stimulus length x stress type: t < 1).

Joint Analyses of Response correctness. The same joint analyses run on RTs were also run on response correctness as dependent variable, to compare reading accuracy across experiments. The mixed-effects logistic model was run with stress type, stimulus length, and experimental procedure as fixed factors. The model showed a main effect of experimental procedure ($\beta = -0.69$, st. err. $= 0.26$, z $= -2.58$, p $= .009$), with participants being less accurate in the immediate than in the delayed reading experiment; the main effect of stress type was also significant ($\beta = 0.72$, st. err. $= 0.28$, z $= 2.56$, p $= .01$), with participants being more accurate when antepenultimate than penultimate stress to pseudowords was

assigned. No further effect reached significance (stimulus length: $z = 1.60$, $p > .1$; stimulus length x stress type: $z = -1.34$, $p > .1$; experimental procedure x stimulus length: $z < 1$; experimental procedure x stress type: $z < 1$; experimental procedure x stimulus length x stress type: $z < 1$).

Results of Experiment 2 show that the delayed response cancels the effect of stimulus length but not the stress type effect, which is still there when participants are asked to delay the articulation of their response. The absence of any interaction between stress type and experimental procedure in the joint analyses of the two experiments indicates that the stress effect is comparable in the two experiments.

In order to ascertain the solidity and generalizability of the stress type effect we ran a further experiment, that differed from previous experiments in two characteristics: a) A new set of stimuli was adopted; b) In order to better account for individual differences related to the different experimental procedures we adopted, all participants were presented with both the immediate and delayed procedure. We also introduced a variation in the delayed procedure, by reducing the delay time from 1200 to 500 ms. This modification in the delay was made in order to assess whether the stress effect could still hold when participants had less time to wait before pronouncing the stimulus, therefore had less chance to refresh the stimulus trace before articulation

Experiment 3 – Within-participants design

Participants. Thirty-two university students (23 female, mean age: 24.7, sd: 2.40), all Italian native speakers with normal or corrected-to-normal vision, took part in the experiment. None had participated in the previous experiments.

Materials. Two sets of three-syllable and four-syllable pseudowords, respectively, were constructed. For each set, half pseudowords had an antepenultimate stress neighborhood – that is they ended with a sequence shared by a majority of words bearing antepenultimate stress – and half had a penultimate stress neighborhood – that is, they ended with a sequence shared by a majority of words bearing penultimate stress. Pseudowords in the two sets, as well as pseudowords with penultimate- and antepenultimate-stress neighborhood within each set, were matched for two initial phonemes. Each experimental set contained 80 pseudowords. Three-syllable pseudowords had 6 letters, whereas all four-syllable pseudowords had 8 letters. All pseudowords had the same CV structure, very few or no orthographic neighbors, similar orthographic complexity and bigram frequency (for a summary of the stimuli characteristics, see Table 1). Stimuli were presented in eight blocks, four of three-syllable and four of four-syllable items. Stimuli are reported in the Appendix.

Procedure. Participants completed both an immediate and a delayed reading task. They were 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. Moreover, in the immediate task, they were instructed to read aloud the stimuli as soon as possible, whereas in the delayed task they were instructed to wait until the cue signal. A specific practice session (one for each stress pattern) was used to induce pronunciation with the specific stress pattern (either on the penultimate or on the antepenultimate syllable (see procedure of Experiment 1 for full description).

During the experiment, each participant read one half of both experimental sets (three- and four syllable stimuli) applying penultimate stress and one half of both sets applying antepenultimate stress. Thus, each participant read one fourth of the experimental list applying penultimate stress and one fourth of the list applying antepenultimate stress in the immediate condition, and one fourth of the list applying penultimate stress and one fourth of the list applying antepenultimate stress in the delayed

condition.

Block order was arranged in such a way that participants always read the first two blocks by assigning the same stress pattern and the last two blocks by assigning the other stress pattern. The two blocks that received the same stress were composed one of three-syllable pseudowords and one of four-syllable pseudowords. Block order as well as the order in which participants were asked to assign each stress type (first penultimate or antepenultimate) and task order (first immediate or delayed task) were counterbalanced across participants. Stimulus order was randomized within each block.   The trial sequence of the immediate task was identical to that of Experiment 1; in the delayed task, the only difference between Experiment 2 and the present experiment was that in the latter the delay between the offset of the stimulus and cue indicating to respond was either 300 or 500 ms (instead of either 1000 or 1200 ms). The Experiment was run using DMDX software (Forster & Forster, 2003).

Results

Invalid trials due to technical failures (or responses that exceeded the time limit as well as responses shorter than 200 ms) accounted for 3.3% of the data points and were discarded from the analyses. Pronunciation times and errors (2.6% of all data points, including both phonemic and stress errors) were both analyzed using mixed-effects models. For random effects, a maximal random structure approach was adopted (Barr et al., 2013). Results are reported in Table 6.

- Table 6 -

Pronunciation times. The mixed-effects model was run on log transformed RTs as dependent variable (Baayen, 2008) and stress type (antepenultimate vs. penultimate stress), stimulus length (three vs. four syllables), and experimental procedure (immediate vs. delayed) as fixed factors. The model showed a main effect of stress type (β = -0.052, st. err. = 0.022, t = -2.14, p = .03), with participants being faster

in reading pseudowords with antepenultimate (592 ms) than with penultimate stress (622 ms). The main effect of experimental procedure was also significant ($\beta = 0.271$, st. err. $= 0.044$, t $= 5.82$, p $< .001$): Participants were slower in the immediate than in the delayed procedure. Finally, the interaction between stimulus length and experimental procedure was significant ($\beta = 0.223$, st. err. $= 0.028$, t $= 7.53$, p $< .001$). The inspection of the interaction shows that stimulus length affects reading in the immediate procedure ($\beta = 0.166$, st. err. $= 0.021$, t $= 7.91$, p $< .001$), but not in the delayed one ($\beta = -0.032$, st. err. $= 0.019$, t $= -1.69$, p $> .05$).

Pronunciation accuracy. The model did not show any significant effect (stress type: z $= 1.24$, p $>. 2$; stress type x stimulus length: z $= -1.35$, p $> .1$; experimental procedure x stress type x stimulus length: z $= 1.16$, p $> .2$; all other effects: zs < 1, ps $> .3$).

The results of Experiment 3 nicely replicate those of the first two experiments: Stress assignment affects pseudoword reading irrespective of the experimental procedure, whereas the effect of stimulus length is restricted to the immediate reading task.

General Discussion

In the present study we investigated whether and how stress assignment affects polysyllabic pseudoword reading aloud in Italian. When an immediate reading procedure was adopted (Exp. 1), both stimulus length and stress type affected reading latency, with participants being faster when assigning antepenultimate than penultimate stress, and when reading shorter than longer stimuli. With a delayed reading procedure (Exp. 2) the stimulus length effect disappeared while only stress type still affected reading latency, with participants being faster in reading pseudowords with antepenultimate than penultimate stress. The effect of stress type was comparable in the immediate and delayed experiment.

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The results on pronunciation times were paralleled by those on pronunciation accuracy, with no evidence of any speed/accuracy trade-off. An identical pattern of results emerged in Experiment 3, in which a new set of stimuli was used in a within-participants design. Again, irrespective of the procedure involved, either immediate or delayed, stimuli receiving antepenultimate stress were read faster than those receiving penultimate stress.

These results are consistent with the idea that stress assignment affects articulatory planning of the stimulus to be read. If the difference in pronunciation latency between antepenultimate and penultimate stress pseudowords had arisen at any other preceding level of computation, it would have disappeared in the delayed reading aloud experiment as did the stimulus length effect. As this was not the case, the effect of stress type has to be located in a different component than the length effect. While stimulus length may affect reading during orthographic encoding of the stimulus (e.g., Zoccolotti et al., 2006) and up to the assembling of the stimulus phonological code (Ferrand, 2000; Stenneken, Conrad, & Jacobs, 2007), the effect of stress type may arise during the planning of stimulus articulation.

The findings we reported, especially the persistence of the stress type effect in delayed pronunciation, shed new light on the operations involved in the planning and execution of articulation during reading aloud, and support the proposal advanced by Sulpizio and colleagues (2013). According to these authors, stress location would affect the size of the units involved in the planning of articulation: such units would include the stimulus beginning up to the stressed syllable and readers would buffer a partial articulatory representation of the stimulus to be produced. This idea is based on the consideration that stress assignment is fundamental for starting articulation (Perry, Ziegler, & Zorzi, 2010), mainly to determine the coarticulation properties of phonemes for rhythmic organization of syllables. In such a view, assigning stress to the antepenultimate syllable involves the articulatory

planning of a smaller portion (i.e., either one or two syllables in three- and four-syllable pseudowords, respectively) than assigning stress to the penultimate syllable – which involves the planning of a two- or three-syllable unit (in three- and four-syllable pseudowords, respectively). As a consequence, the time needed to retrieve the articulatory programs for antepenultimate stress stimuli would be shorter than that needed for stimuli with penultimate stress, since the two stress patterns require a different number of items to be buffered as a lower limit for articulation (Levelt, 1989).

Even assuming that the type of stress readers assign to a pseudoword may affect the planning of articulation, one might still ask why such effect seems not to be modulated by our procedure manipulation, being comparable in the immediate and delayed reading tasks. To answer this question, we may consider the theory of motor control and execution proposed by Sternberg and colleagues (Sternberg, Knoll, Monsell, & Wright, 1988; Sternberg, Monsell, Knoll, & Wrigth, 1978). According to this theory, response execution takes place through a series of operations (i.e., retrieval, unpacking, and execution of the motor program) that can be completed only by the moment at which production starts, that is immediately in the immediate reading aloud condition, or after the start signal in the delayed reading aloud condition. The reasons why response execution would have to wait for the signal to be computed may be twofold: First, the building up and activation of a motor program would be tightly linked to its execution and the latter directly follows from the former. Second, the information in the motor buffer would be subject to a rapid decay and, for this reason, when a program is set up it has to be immediately used. The theory of motor control and execution might thus account for our pattern of results: Stress type affects pseudoword reading at the level of articulatory planning, that is when the motor programs for stimulus articulation are retrieved, unpacked, and executed; moreover, since response execution is assumed to be tightly linked to the cue signaling the start of production, and the effect of stress type is assumed to occur at this moment, the immediate and delayed conditions are

assumed to show a similar stress type effect. Note that assuming that the stress effect arises during planning of articulation does not necessarily imply assuming discrete stages of computation; rather, phonological encoding and planning of articulation may operate as cascaded processes (cf. Perret, Schneider, Dayer, & Laganaro, 2014).

One might ask whether our account of the stress effect on pseudoword reading would also hold in the case of word reading. Some evidence for a stress type effect with real words comes from the study of Burani and Arduino (2004; Experiment 2), who reported faster pronunciation times for antepenultimate- than penultimate-stress low-frequency words. However, no other study reported such effect. A possible explanation for the difficulty to detect the stress type effect with real words may refer to how readers activate the phonetic representation of the stimulus: When reading a known word, participants may activate the phonetic representation of the stimulus as a whole unit, since it has already been assembled several times; in contrast, when reading a pseudoword participants must convert the newly assembled phonological word in a phonetic representation that they have never articulated before and the phonetic encoding must occur on-line.

The difference in reading latency between antepenultimate- and penultimate-stress pseudowords allows us for further considerations on the functioning of the phonological output buffer in reading. The reported stress type effect indicates that, at least for reading new stimuli, the articulatory planning unit is flexible and is linked to the number of elements the reading system must encode from the stimulus beginning up to the stressed unit (Sternberg et al., 1978; 1988; Sulpizio et al., 2013; Sulpizio & Burani, 2014). Planning of articulation may proceed rightward incrementally and, as soon as the stressed unit is encoded, articulation may start being executed. Such perspective seems to be functionally reasonable as, on the one hand, articulation cannot start until stress has been assigned and, on the other hand, there is no *a priori* reason to fully encode a long polysyllabic stimulus before

starting its motor execution. Our proposal seems to be consistent with the prevalent view in the reading literature, which posits that the size of the articulatory unit is the full word (e.g., Rastle, Harrington, Coltheart, & Palethorpe, 2000). In fact, most research in reading used monosyllabic stimuli: In this case, the stressed syllable unit overlaps with the full word. As a consequence, in the case of a monosyllable, the reader may start articulation after having encoded the full word. However, the assumption that word reading starts only after the full word has been encoded may be a by-product of the use of monosyllables as stimuli.

If the interpretation we propose is correct, the minimal planning unit for reading a polysyllabic stimulus can be smaller than the full stimulus and correspond to a unit of flexible size spanning the stressed syllable. A similar proposal has been recently advanced for speech production, suggesting that, with polysyllabic words, the articulatory encoding may start before a full phonological encoding is accomplished and the speaker may thus begin to speak before she/he has encoded the whole stimulus (Meyer, Belke, Hacker, & Mortesen, 2007).

The stress type effect we have reported does not easily fit within any current computational model of reading polysyllables (e.g., Arciuli et al., 2010; Perry, Ziegler, & Zorzi, 2014). No extant model of reading considers how information in the phonological output buffer is planned for articulation and none has developed a phonology-to-phonetics interface. As a consequence there is no current computational model of reading aloud that accounts for the operations involved in the planning of articulation – i.e., how phonological codes are converted into phonetic representations and motor gestures. This stands as an important goal for future models that aim to provide a full account of the reading aloud process.

The results of our study suggest two main conclusions: First, the computation of stress may affect reading also beyond phonological retrieval and up to its final phases, by modulating the time

required for articulation planning; second, in reading polysyllabic new stimuli, the smaller unit for

articulatory planning has a flexible size going from the stimulus beginning up to the stressed syllable.

Appendix

Stimuli used in Experiment 1 and 2.

Three-syllable pseudowords. Bimpiro, bippile, bintoro, birnolo, dassoro, dazzolo, esmiro, espile, fempile, fempiro, fubbile, fubbiro, liddera, lispano, meffola, meppora, miloro, mirdolo, naprita, nastica, plamita, plarica, pragera, prallano, pumbola, punnora, stemica, stermita, tagnora, tammola, tidoro, timpolo, trudano, truggera, vordano, vosola, vosora, vostera, vuccita, vullica.

Four-syllable pseudowords. Beranica, beritica, besavora, betolora, bidulero, biretero, bisediro, bitaniro, coberola, cofepola, colebita, conamita, dabisoro, dabonoro, dacatero, daconiro, dagomile, dalotero, damosiro, davemile, fimarolo, fipamita, firelita, fiterolo, fobalora, fobitola, fomedola, fosagora, gobamile, gofelata, gosadile, gosibata, nabogata, nadibata, napegolo, naratolo, zicavoro, zidebica, zilonica, zipavoro.

Stimuli used in Experiment 3.

Three-syllable pseudowords. Baniro, besita, betoro, bezolo, bicica, bidola, bifano, budolo, buloro, busora, cefera, cesica, cidolo, ciforo, cobita, cumora, cusolo, dabora, dafica, dapica, dasile, debera, detera, difiro, difola, fenoro, fevora, fezano, fomile, gabolo, gafita, gomera, laniro, lefile, liniro, lopano, losile, lunera, lutora, matola, mubera, nebolo, nefile, nepiro, nicoro, nipita, niviro, nizano, nobica, patoro, pavile, pidile, pidita, pigora, pobiro, pofita, povica, pudola, pulano, refica, sefora, sipano, tebolo, tediro, tefica, tidera, tifile, tilita, tozano, tucora, turola, vofica, vudola, vusoro, vutola, zabolo, zaporo, zebano, zenita, zicora.

Four-syllable pseudowords. Basavora, batovola, becanolo, besadita, betiliro, bilitica, binelita, boracata, bosatora, bufetero, cafirica, cedopola, cefelata, cifibata, cobediro, coradile, cuvipile, dabonola,

dalevoro, danibata, danifita, davemica, desifile, dozelata, dufeloro, fanolora, fevisile, fibanoro, foditero, ganetoro, garipita, gorapola, labutora, laditero, lemifile, lerovica, lifetiro, lipenero, livecata, mapeviro, mirevolo, nabidiro, narodola, nebitero, necofata, nelivoro, nepitica, nicavile, nobitora, padetolo, padinita, padoniro, patonora, petilica, pevidiro, pidevola, poranolo, pumebita, putidero, refadolo, selitero, sibanita, tepicoro, tevebile, tifacoro, tisobolo, tivinero, tonacola, tunopora, tusebiro, tuvetile, vitelora, vonebica, vosibolo, vulepola, zavenita, zibidero, zidebata, zitefolo, zulanica.

References

Arciuli, J., & Cupples, L. (2006). The processing of lexical stress during visual word recognition: Typicality effects and orthographic correlates. *The Quarterly Journal of Experimental Psychology*, *59*, 920-948.

Arciuli, J., Monaghan, P., & Ševa, N. (2010). Learning to assign lexical stress during reading aloud: Corpus, behavioral, and computational investigations. *Journal of Memory and Language, 63,* 180-196.

Baayen, R. H. (2008). *Analyzing linguistic data. A Practical Introduction to Statistics Using R.* Cambridge University Press.

Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language, 59*, 390-412.

Balota, D., & Chumbley, J. I. (1985). The locus of word-frequency effects in the pronunciation task: Lexical access and/or production? *Journal of Memory and Language, 24*, 89-106.

Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language*, *68*, 255-278.

Burani, C., & Arduino, L. S. (2004). Stress regularity or consistency? Reading aloud Italian polysyllables with different stress patterns. *Brain and Language, 90,* 318-325.

Burani, C., Barca, L., & Ellis, A. W. (2006). Orthographic complexity and word naming in Italian: Some words are more transparent than others. *Psychonomic Bulletin & Review, 13,* 346–352.

Burani, C., Paizi, D., & Sulpizio, S. (2014). Stress assignment in reading Italian: Friendship outweighs dominance. *Memory & Cognition, 42,* 662-675.

Colombo, L. (1992). Lexical stress effect and its interaction with frequency in word pronunciation.

Journal of Experimental Psychology: Human Perception and Performance, *18*, 987-1003.

Ferrand, L. (2000). Reading aloud polysyllabic words and nonwords: The syllabic length effect reexamined. *Psychonomic Bulletin & Review, 7*, 142-148.

Forster, K. I., & Chambers, S. M. (1973). Lexical access and naming time. *Journal of Verbal Learning and Verbal Behavior, 12*, 627-635.

Forster, K. I., & Forster, J. C. (2003). DMDX: A Windows display program with millisecond accuracy. *Behavior Research Methods, Instruments, & Computers*, *35*, 116-124.

Ghyselinck, M., Lewis, M. B., & Brysbaert, M. (2004). Age of acquisition and the cumulative-frequency hypothesis: A review of the literature and a new multi-task investigation. *Acta Psychologica, 115,* 43-67.

Jaeger, T. F. (2008). Categorical data analysis: Away from ANOVAs (transformation or not) and towards logit mixed models. *Journal of Memory and Language, 59*, 434-446.

Kessler, B., Treiman, R., & Mullennix, J. (2002). Phonetic biases in voice key response time measurements. *Journal of Memory and Language, 47,* 145-171.

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2013). lmerTest: Tests for random and fixed effects for linear mixed effect models (lmer objects of lme4 package). *R package version*, 2-0.

Levelt, W. J. M. (1989). *Speaking: From intention to articulation*. Cambridge, MA: MIT Press.

Levelt, W. J. M., Roelofs, A., & Meyer, A. S. (1999). A theory of lexical access in speech production. *Behavioral and Brain Sciences, 22,* 1-38

Malouf, T., & Kinoshita, S. (2007). Masked onset priming effect for high-frequency words: Further support for the speech-planning account. *The Quarterly Journal of Experimental Psychology*, *60*, 1155-1167.

McCann, R. S., & Besner, D. (1987). Reading pseudohomophones: Implications for models of

pronunciation assembly and the locus of word-frequency effects in naming. *Journal of Experimental Psychology: Human, Perception, and Performance, 13*, 14-24.

Meyer, A. S., Belke, E., Hacker, C., & Mortesen, L. (2007). Use of word length information in utterance planning. *Journal of Memory and Language, 57,* 210-231.

Perret, C., Schneider, L., Dayer, G., & Laganaro, M. (2014). Convergences and divergences between neurolinguistic and psycholinguistic data in the study of phonological and phonetic encoding: A parallel investigation of syllable frequency effects in brain-damaged and healthy speaker. *Language, Cognition and Neuroscience, 29, 714-727.*

Perry, C., Ziegler, J. C., & Zorzi, M. (2010). Beyond single syllables: Large-scale modeling of reading aloud with the Connectionist Dual Process (CDP++) model. Cognitiv*e Psychology, 61,* 106-151.

Perry, C., Ziegler, J. C., & Zorzi, M. (2014). CDP++.Italian: Modelling sublexical and supralexical inconsistency in a shallow orthography. *PlosOne, 9, e94291.*

Rastle, K., Harrington, J., Coltheart, M., & Palethorpe, S. (2000). Reading aloud begins when the computation of phonology is complete. *Journal of Experimental Psychology: Human Perception and Performance, 26,* 1178-1191.

Rastle, K., Havelka, J., Wydell, T. N., Coltheart, M., & Besner, D. (2009). The cross-script length effect: Further evidence challenging PDP models of reading aloud. *Journal of Experimental Psychology: Learning, Memory and Cognition, 35*, 238-246.

Roelofs, A. (2004). Seriality of phonological encoding in naming objects and reading their names. *Memory & Cognition*, *32*, 212-222

Stenneken, P., Conrad, M., & Jacobs, A. M. (2007). Processing of syllables in production and recognition tasks. *Journal of Psycholinguistics Research, 36*, 65-78.

Sternberg, S., Knoll, R. L., Monsell, S., & Wright, C. E. (1988). Motor programs and hierarchical

organization in the control of rapid speech. *Phonetica, 45*, 175–197.

Sternberg, S., Monsell, S., Knoll, R., & Wright, C. E. (1978). The latency and duration of rapid

movement sequences: Comparisons of speech and typewriting. In G. Stelmach (Ed.), *Information*

processing in motor control and learning (pp. 117–152). New York: Academic Press.

Sulpizio, S., Arduino, L. S., Paizi, D., & Burani, C. (2013). Stress assignment in reading Italian

polysyllabic pseudowords. *Journal of Experimental Psychology: Learning, Memory & Cognition,*

39, 51-68.

Sulpizio, S., & Burani, C. (2014). Reading segments is not reading words: Comment on Kawamoto et

al. (2014). *The Quarterly Journal of Experimental Psychology,* DOI:

10.1080/17470218.2014.975255

Sulpizio, S., Burani, C., & Colombo, S. (2015). The Process of Stress Assignment in Reading Aloud:

Critical Issues From Studies on Italian. *Scientific Studies of Reading, 19,* 1-16. DOI:

10.1080/10888438.2014.976340

Sulpizio, S., & Colombo, L. (2013). Lexical stress, frequency, and stress neighborhood effects in the

early stages of Italian reading development. *The Quarterly Journal of Experimental Psychology*, ,

3, 731-738.

Sulpizio, S., Job, R., & Burani, C. (2012). Priming lexical stress in reading Italian aloud. *Language*

and Cognitive Processes, 27, 808-820.

Wagenmakers, E. J. M., & Raaijmakers, J. G. W. (2006). Long-term priming of neighbors biases the

word recognition process: Evidence from a lexical decision task. *Canadian Journal of Experimental*

Psy- chology/Revue canadienne de psychologie expe´rimentale, *60,* 275–284

Weekes, B. S. (1997). Differential effects of number of letters on word and nonword naming latency.

The Quarterly Journal of Experimental Psychology Section A: Human Experimental Psychology,

50, 439-456.

Zoccolotti, P., De Luca, M., Judica, A., & Burani, C. (2006). Delayed naming cancels the word length

effect in developmental dyslexia. *Brain and Language, 99*, 36-37.

Table 1. Mean characteristics of Stimuli used in the Experiments.

	Length	N Size	N Frequency	Bigram Frequency	Orthographic complexity
Experiments 1-2	7.46	0.08	0.03	11.18	0.37
Experiment 3	7	0.05	0.02	11.51	0.3

Note. Length is in number of letters; 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); Bigram frequency is log transformed on the basis of the natural logarithm. 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, Barca, & Ellis, 2006).

Table 2. Mean latencies for correct responses and percentage of errors by condition (with standard deviations in parenthesis). Experiment 1.

Stimulus length	Antepenultimate stress		Penultimate stress	
	Mean RTs	% E	Mean RTs	% E
Three-syllables	634 (170)	9 (11.7)	686 (195)	12.4 (15.9)
Four-syllables	696 (180)	17.2 (14.6)	718 (201)	14.2 (8.9)

Table 3. Fixed effects in the RT model. Experiment 1 - Immediate reading aloud.

Effects	Estimate	Standard error	t-value	pMCMC
Intercept	6.3924	0.0632	101.02	<.001
Voiced	-0.0190	0.0165	-1.20	.34
Stop	0.1049	0.0510	2.05	.044
Affricate	-0.0437	0.0575	< 1	.450
Fricative	-0.0108	0.0618	< 1	.861
Nasal	0.1263	0.0540	2.33	.02
Bilabial	0.0170	0.0273	< 1	.535
Labiodental	0.1481	0.0748	1.98	.05
Dental	-0.0311	0.0265	-1.17	.246
Alveolar	0.1707	0.0593	2.87	.005
Stress type (antep.)	-0.0680	0.0276	-2.45	.02
Stimulus length (4 syll.)	0.0528	0.0219	2.41	.01
Stress type (antep.) * Stimulus length (4 syll.)	0.0316	0.030	1.02	.3

Table 4. Mean latencies for correct responses and percentage of errors by condition (with standard deviations in parenthesis). Experiment 2.

Stimulus length	Antepenultimate stress		Penultimate stress	
	Mean RTs	% E	Mean RTs	% E
Three-syllables	461 (94)	5.8 (8.1)	491 (108)	10.1 (11.9)
Four-syllables	463 (103)	6.1 (6.6)	479 (104)	7.3 (6.7)

Table 5. Fixed effects in the RT model; the final column reports the parameters that were estimated in the model applied to the untransformed RTs. Experiment 2 - Delayed reading aloud.

Effects	Estimate	Standard error	t-value	pMCMC
Intercept	6.0847	0.0600	101.40	<.001
Voiced	-0.0173	0.01716	-1.01	.316
Stop	0.0320	0.0533	< 1	.550
Affricate	-0.0104	0.0610	< 1	.864
Fricative	-0.0461	0.0659	< 1	.486
Nasal	0.0404	0.0564	< 1	.475
Bilabial	0.0436	0.0281	1.55	.125
Labiodental	0.1494	0.0794	1.88	.06
Dental	-0.0022	0.0274	< 1	.935
Alveolar	0.1467	0.0633	2.31	.02
Stress type (antep.)	-0.0581	0.0237	-2.45	.02
Stimulus legth (4 syll.)	-0.0257	0.0284	< 1	.370
Stress type (antep.) * Stimulus length (4 syll.)	0.0370	0.0249	1.48	.142

Table 6. Mean latencies for correct responses and percentage of errors by condition (with standard deviations in parenthesis) Experiment 3.

| Stimulus length | Immediate reading | | | | Delayed reading | | | |
| | Antepenultimate stress | | Penultimate stress | | Antepenultimate stress | | Penultimate stress | |
	Mean RTs	% E	Mean RTs	% E	Mean RTs	% E	Mean RTs	% E
Three-syllables	636 (151)	0.9 (1.9)	660 (147)	2.5 (3.1)	498 (124)	0.9 (2.9)	523 (128)	1.6 (3.0)
Four-syllables	745 (215)	4.5 (8.9)	815 (257)	5.7 (7.1)	488 (126)	2.6 (4.0)	496 (121)	2.6 (3.1)

Footnotes

1. There is one rule to assign stress to three-syllable words that applies most of the times and refers to the weight of the penultimate syllable: If it is heavy – that is, if it ends with a consonant (e.g., bi.SON.te, bison) – then the syllable attracts stress. However, there are exceptions to the rule as, for example, MAN.dor.la (almond) or LE.pan.to (Lepanto).

2. A very small number of Italian words bears stress on the final syllable, but in this case stress is graphically marked (*coliBRÌ*, hummingbird).