William Harrison (wharris2@andrew.cmu.edu)
Department of Psychology, Carnegie Mellon University,
5000 Forbes Avenue, Pittsburgh, PA 15232 USA

Christopher R. Hepner (chepner@andrew.cmu.edu)
Department of Psychology, Carnegie Mellon University,
5000 Forbes Avenue, Pittsburgh, PA 15232 USA

Nazbanou Nozari (bnozari@andrew.cmu.edu)
Department of Psychology, Carnegie Mellon University,
5000 Forbes Avenue, Pittsburgh, PA 15232 USA

Abstract

The paper investigates the existence of position-independent segments in written and typed word production. In two experiments, we employed the segmental interference effect to first replicate past findings that naming a picture is more difficult in the context of another picture with which it shares segments in the same position (e.g., glow-flow) compared to an unrelated word (e.g., glow-cave). We then tested a new condition, in which the same target word is paired with an anagram of the original competitor (glow-wolf). Critically, the anagram shared the same number of segments with the target word, but never in the same position. Both experiments found robust interference for targets produced in the context of anagrams, with a magnitude comparable to the interference induced by the position-overlapping word. The results suggest that not only are position-independent segments represented in the production system, but they also play a critical role in activating segmentally related words and creating competition during word production.

Keywords: word production; segmental encoding; positional frame; segmental interference

Introduction

One of the most important questions in models of language production is the nature of the representations involved in the process of mapping meaning to sound. Major advances in the field resulted from the discovery of separate lexical and segmental layers, with distinct stages of processing (e.g., Garrett, 1975), and a very large body of literature, both on spoken and written production, has since focused on determining the nature of additional representations in the production system (e.g., Levelt et al., 1999). A special challenge in this regard is the nature of segments (phonemes in spoken and graphemes in written production) which mediate the mapping between lexical items and motor commands to articulate the word or write it down. The challenge stems from the fact that segments, unlike higher-level representations such as lemmas, lexemes, and semantic features, must be ordered and produced in the correct sequence even at the level of single-word production. This problem can be readily seen in words such as "pot" vs. "top", which have the same segments but differ in where those segments appear. This problem has led to the proposal of position-dependent segments in production (e.g., onset /p/ vs. coda /p/ as opposed to the generic /p/). The question of whether position-independent segments are still represented in the production system or not remains. This paper addresses this question.

Representation of segments in models of language production

The nature of segments in language first came under scrutiny after Lashley's seminal article criticizing chaining as a viable account of serial order in language (Lashley, 1951). The first instance of an alternative, *context-sensitive coding*, was proposed by Wickelgran (1969), who proposed that segments are further specified by the environment in which appear. For example, /p/ in "pot" is $/_{-}p_{ɒ}/$, while /p/ in "top" is $/_{ɒ}P_{-}/$. The two are thus distinct representations, distinguished by the attachments which represent their context within the word. Apart from requiring a large number of segments, this account was unable to explain findings like the strong tendency for segmental migration errors to maintain their positions within syllables: onsets are much more likely to replace other onsets than codas, and vice versa. This finding gave rise to the proposal of segmenta]ʹO я gm ”C Ï its predecessors). This implementation is, of course, to some extent a matter of computational simplification. But if position-independent representations are essential for explaining fundamental aspects of word production, such as the dynamics of facilitation and interference due to the activation of competitors, then this simplification has non-negligible consequences. We approach this question of position-independent segmental representations in writing and typing by comparing interference between words that share segments in either the same or different positions.

Segmental interference in word production

For years, overlap in segments was thought to facilitate production. In addition to priming paradigms, blocked cyclic naming paradigms, in which a small set of pictures were to be repeatedly named, have been used to show that the same target was named faster if it shared its onset with other words in the cycle (e.g., pig, pen, pot) compared to when it did not (e.g., pig, bed, sun; e.g., O'Séaghdha & Frazer, 2014). This effect, however, turned out to be strategic, and turned into interference when overlap was moved to non-onset segments (e.g., mat/hat; Nozari et al., 2016), or when onset-overlapping words were interleaved with words that overlapped in non-onset positions (Breining et al., 2019). The interference was referred to as "competitors") in three conditions (Overlap, Anagram, and Baseline). In the Overlap condition, the competitor shared all but the initial segment with the target (e.g., *flow*). In the Anagram condition, the segments of the word used in the overlap condition were rearranged to create an anagram (e.g., *wolf)*[1]. In the Baseline condition, target words were paired with words that did not share segments or CV structure with either the target or anagram (e.g., *cave*). Stimuli were balanced for frequency across condition using frequency data from the SUBTLEX-US corpus. Color images corresponding to the 48 words in the experiment were selected from Google images and sized to 320x320 pixels.

The 12 targets, each appearing with a competitor in three conditions, created 36 blocks. The order was counterbalanced such that the first, second, and third appearances of the targets were equally distributed across the three experimental conditions. With this constraint, six lists with pseudo-randomized block orders were created, with the same target never appearing in two adjacent blocks.

Procedure The experiment was developed in jsPsych (de Leeuw, 2015) and administered in an internet browser running on a PC and displayed on a Huion Kamvas Pro 12 tablet, on which participants also wrote their responses. Prior to beginning the experiment, participants saw and labeled four practice images, presented one at a time, to get comfortable using the tablet.

Participants were then assigned to one of the six lists and completed 36 blocks of word pairs as described above. At the start of each block, participants were shown a pair of images and their corresponding labels (e.g. *glow-flow*), and practiced the labels until comfortable, to reduce imageability effects. From this point on, only one image at a time was presented, and participants were instructed to write down the label as quickly and accurately as possible on the tablet. In each trial, a fixation cross was presented in the middle of the screen for 700 ms. The image was then presented in the center of the screen along with a 1×2.5-inch response box underneath. The image remained on the screen for 2000 ms, or until a response was initiated. Participants then had 2000 ms to complete their response. After that, the fixation cross for the next trial would immediately appear on the screen. At the beginning of each block, participants completed 4 practice trials with the pictures of that particular block. They then completed 16 experimental trials (8 presentations of each image). Trials in a block were pseudo-randomized such that an image did not appear more than twice in a row. Across all blocks, a total of 576 responses were collected in the experimental trials. The experiment took approximately 50 minutes to complete, including two short breaks.

Analyses Analyses were conducted in R (version 3.6.1; R Core Team, 2019). Trials with incorrect or null responses, RTs of less than 200 ms, or RTs more than 3 standard deviations away from each participant's mean were excluded

[1] Because of the limited number of 4-letter words with anagrams, imageability could not be matched at the trial level, but was balanced in the experiment.

ɑsts 792 9.96 Tf1 0 0 1 140.3 41.99f1 0 0 1 498.1 7 0 1 1g0.09.96 Tf1 0 03 1031084 664.66 TmGen analysif1 0 0 1 178.82 101.06 Tm0 g0 G[( )] TJET7

the Baseline, which, despite its small effect size, was highly robust in both methods of analyses. Moreover, both methods showed significantly longer RTs in Anagram compared to Baseline conditions. Together, these results point to a clear interference effect induced by words that share segments with the target, even when there is no positional overlap between any of the segments.

Figure 2: Mean (a) RTs and (b) durations for responses to target items in Baseline, Anagram, and Overlap conditions across participants in Experiment 1. Error bars represent 95% CIs, not corrected for between-subject variance.

Several findings, however, called for a replication and further investigation of the effect. First, the effect of interference on RTs was absent in the Overlap condition (cf. Nozari et al., 2016). The reason could be that handwriting is not ideal for exploring RTs, because participants could put the pen on the pad (and register an RT) before having decided exactly what letter to write. Typing, on the other hand, does not have this problem, since the identity of the letter must be determined before durations. Unlike RTs and durations, we did not have clear a priori predictions regarding effects on specific IKIs. All IKI analyses were thus corrected for multiple comparisons.

Results & Discussion

Because we were interested in analyzing the timing of individual keystrokes, the exclusion of all trials that contained an incorrect letter was unavoidable, even if participants had efficiently corrected that letter. Together with uncorrected errors, these trials comprised 9.9%, 9.1%, and 10.7% of trials in Baseline, Overlap, and Anagram conditions, respectively, and did not differ between conditions. With an additional 1.5% of trials excluded based on the criteria defined under Analysis, 5,547 target trials were included in the analyses.

Figure 3 shows the RTs, durations, and IKIs for the target words in the three conditions in Exp 2. As in Exp 1, durations were significantly longer for both Overlap and Anagram conditions compared to the baseline (M = 6.57 ms, p = .042, and M = 13.54 ms, p < .001, respectively). This time, the direct comparison between

General Discussion

In two experiments, we employed the segmental interference effect to test whether segments cross-activate similar segments in different syllabic positions or not. The results