A resource model of phonological working memory in language production and perception

A pivotal concept in classic (buffer) models of working memory (WM) is the notion of fixed capacity, a parameter that determines how many items can be retained in working memory at any given time. Explicitly held in theories of WM in the visual domain (Cowan, 2001), the assumption has also been implicitly held in theories of WM in language, because of the discrete nature of measurement for linguistic units. For example, responses are categorized as correct or incorrect, and errors are defined by nominal categories. Notions of categorical perception (Liberman, Harris, Hoffman, & Griffith, 1957) seem to validate this choice, suggesting that the mechanisms underlying WM in language might indeed be non-continuous.

Recently, the "resource model" of WM has challenged the notion of discrete fixed-capacity WM in the visual domain (Ma, Husain, & Bays, 2014). The resource model views WM as a resource divided between representations to be held in memory regardless of their number. As number of representations increases, each item receives fewer resources and is thus encoded with less "precision", i.e., with more variability around the mean. Fixed-capacity models would predict perfect precision up to the capacity limit (at least 3 items according to any capacity-limited theory), with a sharp drop past the limit. The resource model, on the other hand, predicts a monotonic decrease in precision with any increase in set size (even from 1 to 2). This project tests these predictions in the language domain by devising continuous measures of phonological WM.

To test phonological WM in perception, 48 neurotypical participants rated syllables on a continuum (1-100) between phoneme pairs that differed in a single feature, e.g., from most /kA/-like to most /gA/-like. The stimuli appeared in set sizes of 1, 2 and 4 (4 different pairs, 672 trials). To test phonological WM in production, an individual with aphasia (CK) with intact comprehension and a predominantly phonological error profile named 444 pictures on two separate occasions. CK's responses were aligned with their targets and consonant segments (2,201 total, 675 substitution errors) were scored for dissimilarity using the ALINE distance (Kondrak, 2002), which is the sum of the phonological feature differences weighted by salience. The resource model predicts increasing rating variability with increasing set size and larger ALINE distances with increasing word length.

In keeping with the predictions of the resource model, variability increased monotonically (almost linearly) as a function of number of items to be held in WM in both perception (Fig. 1, $t = 2.025, p < 0.05$) and production (Fig. 2, $t = 6.312, p < 0.001$), even after other variables such as position were accounted for in the model. Moreover, the increase was reliable even between set sizes 1 and 2 ($t = 4.427, p < 0.001$) in perception, which is below the capacity limit in any fixed-capacity model of WM.

In summary, our results demonstrate the utility of continuous measures, i.e., measures of precision instead of accuracy, for probing cognitive operations underlying phonological processing, and specifically support a resource model of phonological WM that functions according to the same principles in perception and production.

Figure 1

Variability (SD) ± 95% CI of ratings in phonological perception as a function of set size.

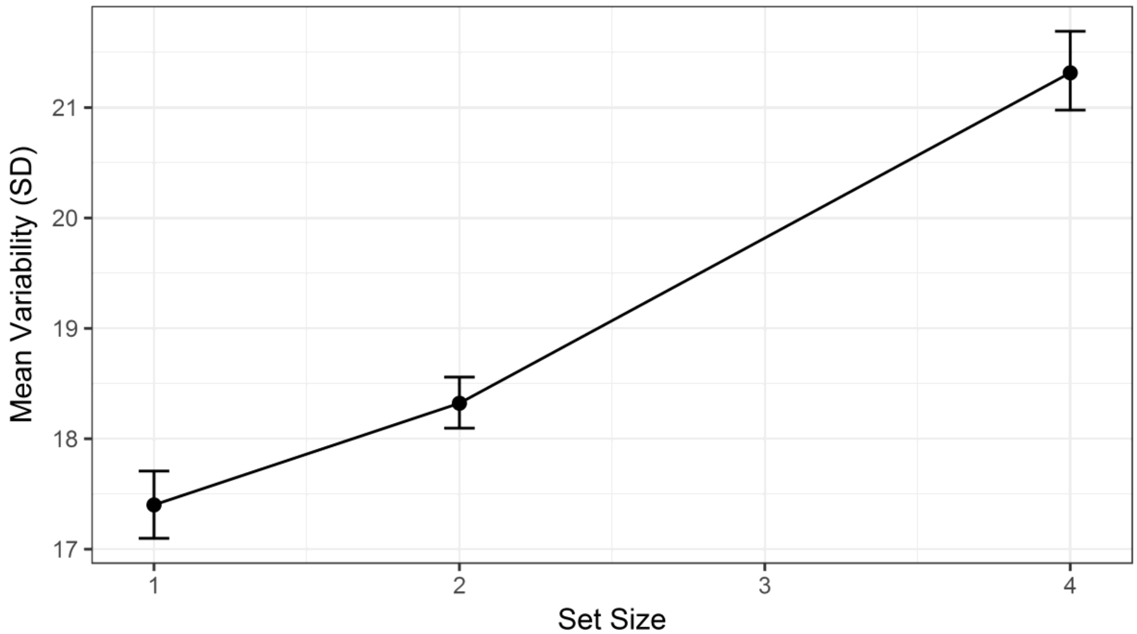
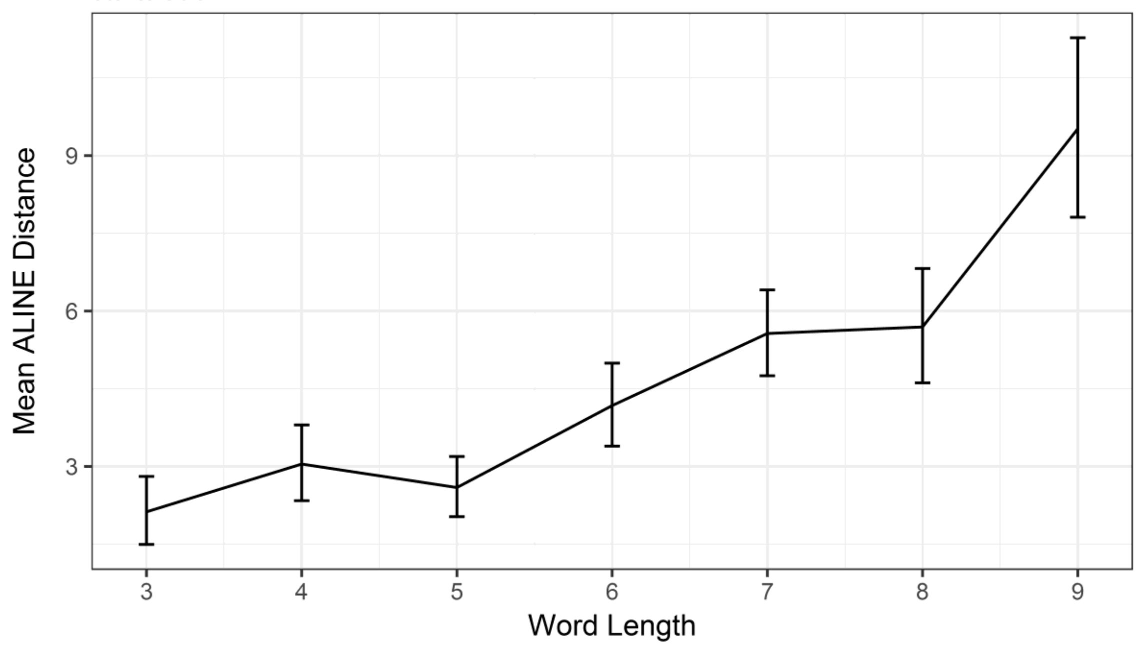


Figure 2

Variability (measured as ALINE distances) ± 95% CI in production as a function of word length. Because the shortest picture name was a CVC, the length measure of the x-axis starts at 3.



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