Introduction

While many speech errors can be generated at either a linguistic or motoric level of production, serial order errors are generally assumed to result from disruption of phonologic encoding (PE) processes. An influential model of PE (Dell, 1986; Dell, Burger & Svec, 1997) predicts that speaking rate should affect the relative proportion of serial order sound errors (anticipations, perseverations, exchanges). An alternative perspective has been articulated by McNeil & Kent (1990) who suggested that speaking rate should selectively affect speech motor processing. The model of Dell and colleagues uses the mechanism of spreading activation which sums and decays over time during processing. Anticipation and perseveration errors are defined by whether a target sound is produced before or after its intended location, while exchange errors occur when two sounds substitute for each other. According to this model, speaking rate affects the amount of time available for phonological processing (i.e., phonological selection) to occur. Predictions regarding the effect of speaking rate on PE have been extended to persons with aphasia (PWA). Supporting evidence regarding the effect of speaking rate on phonological encoding has been provided by studies using young normal language (NL) users and computer simulations. No data are available at present using older NL users or PWA. The specific purpose of this study was to determine whether speech rate affects the relative proportions of specific phonological sequencing errors in older NL users and in PWA.

Methods and Procedures:

Participants

Participants were sixteen non-brain-damaged normal language participants (NLP), and 16 PWA. All were screened for the presence of cognitive-linguistic deficits, hearing impairment, dysarthria and apraxia of speech, and met the pre-determined criteria on a large battery of measures for their participant group. PWA met the definition of aphasia (McNeil & Pratt, 2001) as operationalized by a battery of language and cognitive tests and all produced phonologic paraphasias. NLP ranged in age from 41-75 years (M = 60, SD = 10) and PWA ranged from 36 – 77 years (M = 56, SD = 11). Summarized demographic and assessment data are presented in Tables 1 and 2.

Procedures

A laptop computer was used to present auditorily the phonologically challenging sentence stimuli. Sentences included target and filler stimuli. Participants were instructed on how to manipulate their speaking rate using a direct magnitude procedure with the use of a visual scale on which changes in speaking rate were indicated. After practicing rate manipulation at each of the target rate conditions (typical, fast, and faster) using practice sentences, participants produced the experimental stimuli in each of the three rate conditions. Speaking rate was manipulated relative to each participant's typical speaking rate. During the experiment, the examiner controlled the inter-stimulus presentation rate to allow for anticipated variability in production time among participants. The sentences were presented randomly and the condition order was counterbalanced across participants.

Data were analyzed using a repeated measures design, with two groups and three levels of the within group variable of speaking rate. All productions were transcribed with broad phonetic transcription. Perceptually identified errors were transcribed narrowly. Extensive data inclusion criteria were developed (e.g, production must include the same number of syllables as the stimulus). Coding rules were also developed and production errors were coded for error category (i.e., perseveration, anticipation, distortion, etc.). Vocal reaction time (VRT) and total utterance duration were measured and the number of syllables produced per second was calculated from acoustic traces to determine precise speaking rate for each production. Only productions that were produced at the designated rates (based upon each participant's own "typical" speaking rate) were included in the analyses. In addition to the total number of errors, the percentage of distortion errors produced was also examined to account for sound errors assumed to be generated at the motor level of the production system. Serial order error ratios (anticipation/exchange, anticipation/perseveration) served as the primary dependent variable. An alpha of $p \leq .05$ was set for all tests.

Results

The effect of speaking rate on serial order error ratios was examined with two separate two-way repeated measures mixed ANOVAs (one for each of the error ratios) with rate as the repeated factor. Results for the *anticipation/exchange error ratio* revealed non-significant main effects for rate ($F_{2,46} = 1.727$, $p = .19$, $\eta^2 = .070$), or group ($F_{1,23} = .907$, $p = .35$, $\eta^2 = .04$) and a non-significant interaction ($F_{2,46} =.329$, $p = .72$, .$\eta^2 = .01$). Results for the *anticipation/perseveration ratio* revealed a non-significant main effect for group ($F_{1,23} = .512$, $p = .48$, $\eta^2 = .02$), a significant main effect for rate ($F_{2,46} = 4.773$, $p = .01$, $\eta^2 = .17$) and a non-significant interaction ($F_{2,46} = 1.477$, $p = .24$, $\eta^2 = .06$). Results for the *percentage of distortion errors* revealed a non-significant main effect of rate ($F_{2,58} = .217$, $p = .81$, $\eta^2 = .01$) and group ($F_{1,29} = .974$, $p = .33$, $\eta^2 =.03$), and a non-significant interaction ($F_{2,58} = .037$, $p = .96$, $\eta^2 =.00$). Results for the *total number of errors* revealed a significant main effect of rate ($F_{1.667, 48.341} = 11.35$, $p = .00$, $\eta^2 = .28$), and group ($F_{1,29} = 7.10$, $p =.01$, $\eta^2 = .20$), but no significant interaction ($F_{1.667, 48.341} = 1.797$, $p = .18$, $\eta^2 = .058$). Significantly more anticipation relative to perseveration errors occurred for both groups across the three speech rates. NBDP produced fewer errors than PWA at each of the three speaking rates. Because the number of usable utterances differed between groups and speaking rates, data were also analyzed to determine if there were significant differences in the number of total errors produced relative to the number of usable utterances. Results from a two-way repeated measures ANOVA revealed no significant main effect of rate ($F_{2,58,} = .02$, $p = .98$, $\eta^2 = .00$), but a significant main effect of group ($F_{1,29} = 4.86$, $p = .04$, $\eta^2 = .14$) and no significant interaction ($F_{2,58,} = 2.13$, $p = .13$, $\eta^2 = .07$). Based on the means, NBDP produced fewer total errors per utterance than PWA at each of the three speaking rates. Results from a two-way repeated measures ANOVA on the effect of *speaking rate on VRT* revealed no significant main effect of rate ($F_{2,42,} = 1.861$, $p = .17$, $\eta^2 = .08$) or group ($F_{1,21,} = 1.628$, $p = .22$, $\eta^2 = .07$) and no significant interaction ($F_{2,42)}$ .566 = , $p = .57$, $\eta^2 = .026$).

Conclusions/Discussion

The non-significant main effects and their interactions for the serial order error ratios do not provide strong support for the predictions derived from the Dell (1986, 1997) model. However, the experimental task proved to be so difficult for both participant groups that few stimuli met the criteria for inclusion, thus substantively reducing statistical power and making the nonsignificant findings uninterpretable. The finding of a significant main effect of rate for the anticipation/perseveration error ratio does provide support for the model and challenges the proposal of McNeil and Kent (1990) regarding the motoric locus of speech rate effects within the speech production system. As anticipated, the NBDP produced significantly fewer total errors per utterance than the PWA at each speaking rate.

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Table 1

Demographic information for non-brain-damaged (NBD) participants and persons with aphasia (PWA)

NBD	Age	Education	PWA	Age	Education	Lesion Data (PWA)
1	63	14	1	51	14	L posterior temporal; inferior left parietal
2	58	12	2	52	16	
3	75	18	3	65	16	
4	72	12	4	46	18	L MCA; L fronto temporal lobes
5	55	16	5	70	14	Periventricular white matter; chronic ischemic effect
6	67	16	6	70	16	L temporal and frontal
7	73	16	7	51	16	
8	72	16	8	52	20	
9	53	16	9	50	18	L fronto-temporal extending to basal ganglia
10	66	16	10	60	12	
11	62	18	11	66	16	
12	56	16	12	53	12	L basal ganglia; posterior parietal
13	49	18	13	45	12	L MCA distribution
14	41	18	14	77	16	L posterior temporal-parietal
15	53	18	15	36	13	anterior and posterior L MCA and L putamen
16	47	22	16	48	14	
M (*SD*)	60 (10.2)	16.38 (2.45)		56 (11.08)	15.19 (2.34)	

Note. Years of education represents a minimum number of years as some participants had completed additional education that did not result in another degree (i.e., post graduate work).
[a]L = Left; [b]MCA = Middle Cerebral Artery

Table 2.

Descriptive and screening measures for non-brain-damaged (NBD) participants and persons with aphasia (PWA)

Participant	[a]PIT Percentage		[b]RTT Percentile		[c]CPM Percentile		[d]ABCD [e]Ratio		[f]SPICA
	NBD	PWA	NBD	PWA	NBD	PWA	NBD	PWA	PWA
1	100	86	35	2	75	90	100	100	79
2	100	100	75	90	95	95	100	100	77
3	100	98	14	46	95	95	100	129	66
4	100	100	59	88	50	95	106	108	88
5	100	98	3	89	90	95	100	87	92
6	100	100	68	90	95	95	107	100	70
7	92	98	59	36	90	90	100	89	57
8	100	100	50	79	95	95	100	100	72
9	100	100	74	89	90	95	100	100	91
10	98	100	2	60	25	95	88	100	71
11	98	90	79	88	95	90	100	88	96
12	94	96	38	91	95	90	93	100	82
13	100	86	14	90	95	95	100	89	89
14	100	92	62	90	95	95	100	100	91
15	100	98	47	78	95	90	100	92	83
16	100	96	100	86	95	50	100	150	89
M	98.75	96	48.69	74.50	85.63	90.63	99.61	101.95	80.81
(SD)	(2.41)	(4.92)	(29.01)	(25.75)	(19.99)	(11.09)	(4.33)	(16.24)	(11.11)

[a]PIT = *Picture Identification Task* (Wilson & Antablin, 1980); [b]RTT = *Revised Token Test* (McNeil & Prescott, 1978), percentiles for NBD participants are based on normative data from a NBD sample while percentiles for PWA are based on normative data from a sample of PWA; [c]CPM = *Coloured Progressive Matrices* (Raven, 1963); [d]ABCD = *Arizona Battery for Communicative Disorders of Dementia*, Immediate to Delayed Story Retell Performance (Bayles & Tomoeda, 1993; [e]ABCD Normative Data (Bayles, Boone, Tomoeda, Slauson, & Kaszniak, 1989); [f]SPICA = *Shortened Porch Index of Communicative Ability* (DiSimoni, Keith, & Darley, 1980).