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Effects of concurrent cognitive processing on the fluency of word repetition: comparison between persons who do and do not stutter

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Abstract

This study investigated how silent reading and word memorization may affect the fluency of concurrently repeated words. The words silently read or memorized were phonologically similar or dissimilar to the words of the repetition task. Fourteen adults who stutter and 16 who do not participated in the experiment. The two groups were matched for age, education, sex, forward and backward memory span and vocabulary. It was found that the disfluencies of persons who stutter significantly increased during word repetition when similar words were read or memorized concurrently. In contrast, the disfluencies of persons who do not stutter were not significantly affected by either secondary task. These results indicate that the speech of persons who stutter is more sensitive to interference from concurrently performed cognitive processing than that of nonstuttering persons. It is proposed that the phonological and articulatory systems of persons who stutter are protected less efficiently from interference by attention-demanding processing within the central executive system. Alternative interpretations are also discussed.

Educational objectives: Readers will learn how modern speech production theories and the concept of modularity can account for stuttering, and will be able to explain the greater vulnerability of stutterer’s speech fluency to concurrent cognitive processing.

Keywords: Stuttering; Dual-task; Speech production

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1. Introduction

The effects of a secondary task on the fluency of word repetition were compared for persons who do and who do not stutter. This experiment is part of a more extensive research program investigating the effects of concurrent cognitive activities on the speech of stuttering and nonstuttering persons and the neuroanatomical basis of such dual-task performances (Bosshardt, 1999, 2000; De Nil & Bosshardt, 2000). The present study is based on two theoretical assumptions which can be derived from current theories of speech production (for overviews, see Bosshardt, in press; Garrett, 1990; Herrmann & Grabowski, 1994; Levelt, 1989). First, speech production is generally seen as the end product of a series of processes that are taking place simultaneously at several levels. The second assumption is that speech is produced incrementally, with later parts of an utterance being planned while earlier parts are being articulated.

Such a multilevel incremental system of speech planning and production raises questions as to how each subsystem can be protected from interfering influences by other parts of the system. Fodor's modularity concept (1983) provides an answer to this question. He assumed that the brain is organized in highly automatic, informationally encapsulated neurophysiological systems. Modular systems are "encapsulated" in the sense that their activity is not influenced by concurrent activities in other parts of the system. Although, the modularity assumption was originally proposed for stimulus input systems, it can be extended to speech production. It is assumed here that modular systems are not only associated with a "fixed neural architecture," but that they can also be acquired in the course of language acquisition. The main assumption underlying the present study is that stuttering and disfluency result from processing difficulties within a particular speech-related subsystem while other systems are concurrently active or while concurrent processing is being performed within the same system.

The results of so-called "loci research" (Bernstein Ratner, 1997) can be cited as evidence supporting this assumption. It has been shown that the probability of stuttering is increased at those loci which are assumed to increase the processing demands on the speech planning and production system. A relationship between sentence (or utterance) length and stuttering has been found for children (Bernstein Ratner & Sih, 1987; Logan & Conture, 1995, 1997; Melnick & Conture, 2000; Yaruss, 1999) and for adults (Bosshardt, 1995; Jayaram, 1984; Tornick & Bloodstein, 1976; see also Silverman & Bernstein Ratner, 1997). This effect can only originate from a level of speech processing where the content of the sentence or utterance is completely represented. Likewise, it has been found that the probability of stuttering is also related to word length and other phonological and phonetic indicators of articulatory difficulty (Howell, Au-Yeung, & Sackin, 2000; Wingate, 1988). However, this kind of evidence is weakened by difficulties in determining the processing demands at particular loci independently of stuttering probability (see Bosshardt, 1995). Dual-task experiments, by contrast, allow the experimenter to induce additional processing loads during certain portions of speech and observe their effect on stuttering and other parameters of speech.

Continuous word repetition was used as the speaking task. When the same sequence of three words is continuously repeated, only those parts of the speech production system that are related to phonological encoding and articulation are used. The cognitive processing demands of word repetition have been investigated extensively in short-term memory experiments (Baddeley, 1997). This task is based on a phonological store in which traces decay within 2 s. Phonological information can be stored over longer time intervals if it is retrieved and refreshed before it has decayed. Silent and overt rehearsal are alternative ways of encoding verbal phonological information in the phonological store.

Within the context of the present study, word repetition is a particularly attractive task because (a) its processing demands vary little, if any, over repeated rehearsals, (b) it can be performed with minimal attentive control, (c) it can be performed almost exclusively within the phonological and articulatory subsystems. Disadvantages of this task are that disfluencies occur relatively infrequently and stuttering adapts after repeated productions of the same words (for a review, see Bloodstein, 1995, pp. 327–336; for recent empirical evidence, see Max, Caruso, & Vandevenne, 1997).

The present experiment manipulated the phonological similarity of the repeated words and the words of the secondary task. Sevald and Dell (1994) found that word-initial similarity determines speaking rate and speech errors in repetition sequences. Therefore, in the present experiment, the similarity of the first syllables of the repeated words and of the words in the secondary task was manipulated. Similar words had identical consonantal onsets and vowels in the first syllable but differed in the rest (e.g., “Tauchboot” [submarine] and “Taufe” [baptism] are similar words using these criteria).

Study participants were instructed to read and to memorize words while concurrently performing the word repetition task. It was assumed that these secondary tasks temporarily increase the amount of information processing in the phonological system as the secondary words are phonologically encoded. In the reading condition, participants were instructed to “silently and inwardly” read the words, whereas in the memorizing condition participants retained secondary task words in memory until the word repetition task was finished. It was hypothesized that under the reading and memorizing conditions the words for the secondary task are phonologically encoded and that in the memorizing condition they are also stored.

Performing the word repetition task in the presence of additional phonologically encoded material, subjects must prevent the secondary task material from being included in overt rehearsal. Based on Baddeley’s working memory model (1996, 1997), it was assumed that the central executive is responsible for scheduling. In the memorizing condition, secondary task material has to be stored until word repetition ends, whereas it can passively decay after being read in the reading condition. These cognitive differences in the reading and memorizing tasks tend to suggest that memorizing will have longer lasting effects on word repetition than will the reading condition.

The reading and memorizing tasks not only increase the amount of phonological information stored in the phonological system but also involve the central executive system. The effects of the secondary tasks can be attributed to increases in phonological processing and storage and to processes within the central executive system. Phonologically similar material involves a conflict between rehearsed and unrehearsed words which is more difficult to resolve than for dissimilar material. If the phonological similarity of the repeated words and the secondary task material affects word repetition performance, this effect is related to difficulties in resolving this conflict.

Based on published results of secondary task effects on speech fluency (Bosshardt, 1999), it was anticipated that persons who stutter would generally speak more disfluently under dual-task conditions than would members of the nonstuttering comparison group and that secondary tasks would interfere with their fluent word repetition more than with that of the nonstuttering comparison group.

2. Method

2.1. Subjects

Findings from 14 persons who stutter (11 male and 3 female) and 16 persons who do not stutter (13 male and 3 female) with average ages of 33.9 (SD = 10.0) and 33.3 (SD = 8.1) years, respectively shall be reported. All participants spoke German as their native tongue. They were recruited by means of newspaper advertisements, flyers and posters on the university campus; some of those who stutter were also recruited from self-help groups. The two groups were matched for age, education, sex, and scores on a working memory test (repeating numbers forwards and backwards, a written version of a subtest HAWIE-R (Tewes, 1991)) and a vocabulary test (Schmidt & Metzler, 1992). Originally, a total of 41 persons participated in the experiment. But 11 persons (five persons who do and six who do not stutter) were excluded from data analyses to improve the match between the two groups. Analyses of variance with the data of the remaining 30 participants did not show significant group differences in working memory and vocabulary test scores (error probabilities of all effects $P > 0.19$). The average forward digit span for persons who do not stutter was 8.4 (SD = 1.9) and 8.1 (SD = 1.5) for persons who stutter; the average backward digit spans were 7.4 (SD = 2.1) and 7.6 (SD = 1.1), respectively. The average vocabulary test scores for persons who do not stutter amounted to 33.8 (SD = 3.5) and for persons who stutter 32.8 (SD = 2.3). There was no indication that any of the persons who did not stutter ever had been diagnosed as persons who stutters or as having any other disturbance of speech, and none had ever received speech therapy. All persons who stuttered had received speech therapy in the past, but none had received treatment in the year prior to participating in the experiment. They stuttered, on average, on 5.04% of the words (SD = 7.33) or 2.35% of the syllables (SD = 3.41) during an oral reading of a 200-word newspaper article. Their stuttering was defined as prolongations and repetitions of sounds, syllables and single-syllable words and observable tension in articulatory structures during speech.

2.2. Material

Seven sequences of three words were constructed from 21 two-syllable compound nouns having a plosive consonant as initial and final consonants for the word repetition task. All nouns referred to concrete objects from different semantic fields. Within each sequence, all syllables were different and had different onsets and vowels. Primary stress for each word was on the first syllable. The three words within a sequence began with different plosive consonants, and all word-final and -initial consonants were different. Additionally, the sequences were constructed so that standard pronunciation of the words required one word to be produced with lip-rounding.

Each repetition sequence was combined with two two-syllable nouns for the secondary task. For similar sequences, these nouns were similar to the last two words in the word repetition sequence. In similar sequences, the initial consonant and vowel of the first syllables were identical. In dissimilar sequences, care was taken to insure that every syllable occurred only once in both the repetition sequence and the words of the secondary task and that all words had different initial sounds. For word sequences that were used for practice and instruction, three sequences with similar words and three with dissimilar words were used for the secondary task.

2.3. Apparatus

A newspaper text was typed in 14 point characters on one page to be handed over to the participants for oral reading. Reading of the newspaper text was recorded with a DAT-recorder (Sony TCD-D3, with Sony microphone ECM-S220). The stimuli for the experiment were presented on a laptop (Toshiba T 3100SX) plasma screen which was placed at a viewing distance of about 50 cm from the participants. Subjects' speech was digitally recorded using the computerized speech lab program (CSL 4300B, Kay Elemetrics) and a microphone (Shure SM 48) at a distance of about 10 cm from the participants' lips. Speech was digitized with a sampling frequency of 10 kHz. The computerized speech lab program was also used for off-line, auditory analyses of the speech. For interactive auditory and visual analysis of speech the time by amplitude signal and its spectrum (bandwidth of 146 Hz) were displayed in segments of 1.2 s.

2.4. Procedure

Each participant was seen individually by two experimenters. Before the experiment began, each completed a questionnaire about age, sex and past speech therapy, tests of short-term memory and vocabulary, and performed a counting task and reading and free report tasks with a newspaper text of 200 words.

The words for the experiment were then presented. The same material was presented on a computer screen three times to every participant, once for each experimental condition (i.e., word repetition as single task, and with reading and memorization as two secondary tasks). The order in which the three experimental conditions were presented followed a latin square design for independent groups (see Winer, 1971, p. 712ff.). Each experimental condition was preceded by one practice trial during which the task was explained and the instructions were given to the participant.

Table 1 displays the time course of one trial that used similar secondary task material. At the beginning of each trial, the three words scheduled for the word repetition task were presented successively for 1.5 s each, preceded by a 400 ms fixation point; the participants were instructed to read each word aloud. Four hundred milliseconds after the presentation of the third word, a short tone cued participants to begin continuous oral word repetitions. Participants were instructed to repeat the three words as fast and as clearly as possible until they were stopped by the experimenter after the 12th repetition. When the experimenter had the impression that, immediately after the first presentation, participants had forgotten parts of the repetition material, she presented the words orally again so that participants knew what to say. Under dual-task conditions, secondary task words were presented by the experimenter between the third and fourth repetition. The first syllable of the last word of the third repetition was the cue to present them. Secondary task words were exposed for 3 s and — depending on the speech rate of the participant — usually remained visible during the fourth and the beginning of the fifth repetition. Participants were instructed either to read the secondary task words silently or to retain them in memory for recall after the word repetitions. The experimenter indicated the end of each word repetition trial by saying “stop”. Secondary task material was not presented in the control condition, and participants were simply instructed to repeat the word sequence as fast and as clearly as possible until the experimenter stopped them after the 12th repetition.

2.5. Dependent variables of secondary task

When silent reading was the secondary task, participants were instructed to do nothing other than read these words. Their compliance with these instructions, was assessed by asking them to recall as many words as they could without prior warning after completion of all six silent reading trials. The total number of correctly reproduced similar and dissimilar words was determined for each participant. In the memorization condition participants were asked to reproduce the memorized

Table 1
Time course of a dual-task trial (from top to bottom) using similar secondary task material (see text)

Fixation points (FP) and stimuli	Speaking task	Secondary task	
		Read	Memorize
FP (0.4 s) Kühlschrank[a] (1.5 s)	Pronounce "*Kühlschrank*"[a]		
FP (0.4 s) Tauchboot[b] (1.5 s)	Pronounce "*Tauchboot*"[b]		
FP (0.4 s) Bremslicht [c] (1.5 s)	Pronounce "*Bremslicht*"[c]		
Auditory signal (0.4 s)			
	1. Repeat the three words		
	2. Repeat the three words		
	3. Repeat the three words		
Taufe Brecher[d] (3 s)	4. Repeat the three words	Read silently "*Taufe Brecher*"[d]	Memorize "*Taufe Brecher*"[d]
. . .	. . .		
	12 Repeat the three words		
Experimenter: "stop"		–	Reproduce "*Taufe Brecher*"[d]

[a] Refrigerator.
[b] Submarine.
[c] Brake light.
[d] Baptism, breaker.

words after every trial. Thus, the number of correctly reproduced similar and dissimilar words was counted for each participant for both the reading and the memorization condition. Words were scored as correct if no more than one phoneme differed from the original (i.e., "Decke" [blanket] was accepted as a correct reproduction of "Deckel" [lid], or "Becher" [cup] instead of "Brecher" [breaker]).

2.6. Dependent variables of speaking task

2.6.1. Disfluency rate

All repetitions and exchanges of sounds, syllables and words, together with prolongations of vowels and consonants, and all auditorily identifiable indications of tension (indicated by a silent pause followed by a syllable spoken with enhanced intensity) were counted as disfluencies. In accordance with the Lidcombe data language (Packman & Onslow, 1998, p. 41) repetitions of words were also counted as disfluencies. With the exception of word repetition, these disfluencies can be subsumed to Yaruss (1998) less typical disfluencies[1]. For every participant, the total number of stuttered or disfluent syllables was determined for each block and condition and the percentage of syllables stuttered was then calculated in each block of three repetitions for each condition.

2.6.2. Pause rate

All silent pauses with durations of at least 250 ms between words (see Goldman-Eisler, 1968) and at least 150 ms within words, and all filled pauses were counted if they were produced without audible signs of tension. The number of pauses was determined for each block of three repetitions and each condition. These scores were summed over three sequences for similar and dissimilar secondary material, respectively then transformed into syllable percentages.

2.6.3. Number of words recalled from secondary tasks

The total number of words correctly reproduced from similar and dissimilar sequences was determined for every participant, as was the total number of correctly reproduced words in the memorizing secondary task condition.

2.7. Reliability

Two experienced raters independently scored the verbal productions of each participant for disfluencies, pauses, and audible signs of inhalation. Inter-rater

[1] The operationalization of disfluencies in the present article differs from the definition of "stuttering rate" in Bosshardt (1999). Some reviewers found these changes necessary to avoid a conceptual confusion between stuttering as a characteristic of persons and as a summary term for various kinds of disfluencies. In the group of stuttering persons the type of disfluencies, in which both syllables of a word are involved, occur in 0.09% and in nonstuttering persons in 0.19% ($N = 33,880$) of the syllables. These kinds of disfluencies were so infrequent that differences between groups and conditions could not be statistically tested.

agreement was 99.3% for disfluencies, 98.7% for pauses and 99.1% for inhalations ($N = 38,880$). The corresponding kappa-coefficients giving the percentages of chance-corrected concordant scores (Bortz, Lienert, & Boehnke, 1990) were 73.7% for disfluencies, 67.7% for pauses and 93.5% for inhalations (all kappa-coefficients were significant at $P < 0.000$). In spite of the fact that all words started and ended with a stop consonant, the reliability of pause measures was comparatively low. Because pauses almost exclusively begin at the end of words, the lower reliability of pause scores may reflect raters' difficulties in identifying the end of words. For example, the easily identifiable final stop consonants of words frequently were not articulated, which allowed both stuttering and nonstuttering speakers to avoid the production of two stop consonants directly following each other. When final consonants were produced, they were frequently aspirated, which sometimes made it difficult to localize the end of the word as well. Discussions between the two raters revealed that a higher percentage of one rater's scores were agreed on consensually than those of the other rater. Thus, scores of the former rater were used for final data analysis.

2.8. Design and statistical analyses

The dependent variables were analyzed using a mixed between- and within-subjects design. Group (persons who stutter versus persons who do not stutter) and task order (1: control, reading, memorizing; 2: reading, memorizing, control; 3: memorizing, control, reading) were the two between-subjects factors. Condition (control, reading and memorizing), similarity (similar and dissimilar secondary material), and block (blocks of three repetitions) were within-subjects factors. Mixed five-factorial univariate analyses of variance were calculated for each dependent variable. Because task order was used only to control for possible effects of task order, the results of this factor will not be reported. Statistical analyses were calculated with the general linear and manova modules of SPSS (1999) (Version 9.0).

Statistical significance of main effects and interactions was determined at $\alpha = 0.05$. For repeated measurement factors with more than one degree of freedom, the Greenhouse–Geisser corrected probabilities together with ϵ-values are reported throughout. Statistical decisions were based on the corrected probabilities. Significant main effects and interactions were analyzed in a second step by calculating simple effects and contrasts between means. The criterion of significance for k post-hoc comparisons was adjusted to the number of comparisons ($\alpha^* = \alpha/k$).

3. Results

3.1. Word repetition task

Disfluency rate was significantly influenced by the main effect of block ($F(3, 72) = 7.65$; MSe $= 14.54$; $P < 0.000$; $\epsilon = 0.83$) and by the four-factor interaction of group, similarity, block and condition ($F(3, 72) = 3.75$; MSe $=$ 8.76; $P < 0.004$; $\epsilon = 0.79$). The latter interaction was further analyzed by breaking it down to some of its simple interactions. The three-factor interaction between similarity, block and condition was significant ($\alpha^* = \alpha/2 = 0.025$) only for persons who stutter ($F(6, 156) = 4.13$; MSe $= 7.21$; $P < 0.002$; $\epsilon = 0.79$), but not for persons who do not stutter ($F(6, 156) = 0.89$; MSe $= 7.21$; ns; $\epsilon =$ 0.79). Further tests of the simple interactions similarity $\times$ condition at the level of each block and within each group of persons ($\alpha^* = \alpha/8 = 0.006$) showed that it was significant only within the group of persons who stutter for Block 2 ($F(2, 52) = 7.92$; MSe $= 828$; $P < 0.001$; $\epsilon = 0.92$), but not for any of the other blocks (Block 1: $F(2, 52) = 0.15$; MSe $= 6.52$; ns; $\epsilon = 0.93$; Block 3: $F(2, 52) = 1.60$; MSe $= 5.46$; ns; $\epsilon = 0.78$; Block 4: $F(2, 52) = 2.09$; MSe $= 7.61$; ns; $\epsilon = 0.86$). Neither interaction was significant for persons who do not stutter (Block 1: $F(2, 52) = 0.02$; MSe $= 6.52$; ns; $\epsilon = 0.93$; Block 2: $F(2, 52) = 2.98$; MSe $= 8.28$; ns; $\epsilon = 0.92$; Block 3: $F(2, 52) = 0.70$; MSe $=$ 5.46; ns; $\epsilon = 0.78$; Block 4: $F(2, 52) = 0.15$; MSe $= 7.61$; ns; $\epsilon = 0.86$). From these results it can be concluded that similarity and speaking conditions significantly affected the disfluency rates only of persons who stutter but not those of the comparison group and that their effects were observed only in Block 2. Therefore, the following analyses further explore the simple interaction between condition and similarity for stuttering persons within the second block of word repetitions.

The pattern of results is depicted in Figs. 1 and 2. It can be seen that for similar words in Block 2, the disfluency rates of persons who stutter were higher in both dual tasks than in the control condition (see Fig. 2). Within Block 2, the disfluency rate in each of the two dual-task conditions was compared to that during the control condition. These two contrasts were calculated within the stuttering group for each level of similarity ($\alpha^* = \alpha/8 = 0.006$). The disfluency rate for similar words in the control condition was significantly lower than in both the reading ($F(1, 24) = 12.17$; MSe $= 39.94$; $P < 0.002$) and memorizing condition ($F(1, 24) = 10.28$; MSe $= 59.64$; $P < 0.004$). For dissimilar words, however, these differences did not meet the Bonferroni-corrected criterion of significance (reading: $F(1, 24) = 1.42$; MSe $= 108.43$; $P < 0.25$; memorizing: $F(1, 24) =$ 5.80; MSe $= 59.64$; $P < 0.024$). Although the difference in the disfluency rate between the control and memorizing conditions did not meet the corrected criterion of statistical significance, it was 1.7% higher SE $= 0.7$ in the memorizing than in the control condition (cf. Figs. 1 and 2), which is relatively similar to the corresponding significant difference of 1.9% found for similar words SE $= 0.6$.

In summary, disfluency rates of persons who stutter but not of persons who do not stutter increased during word repetition when they concurrently read or memorized similar words. Reading or memorizing of dissimilar words did not produce statistically reliable increases in the disfluency rates of stuttering persons, however they did display higher disfluency rates when they concurrently memorized dissimilar words. In contrast, disfluencies of nonstuttering persons were not

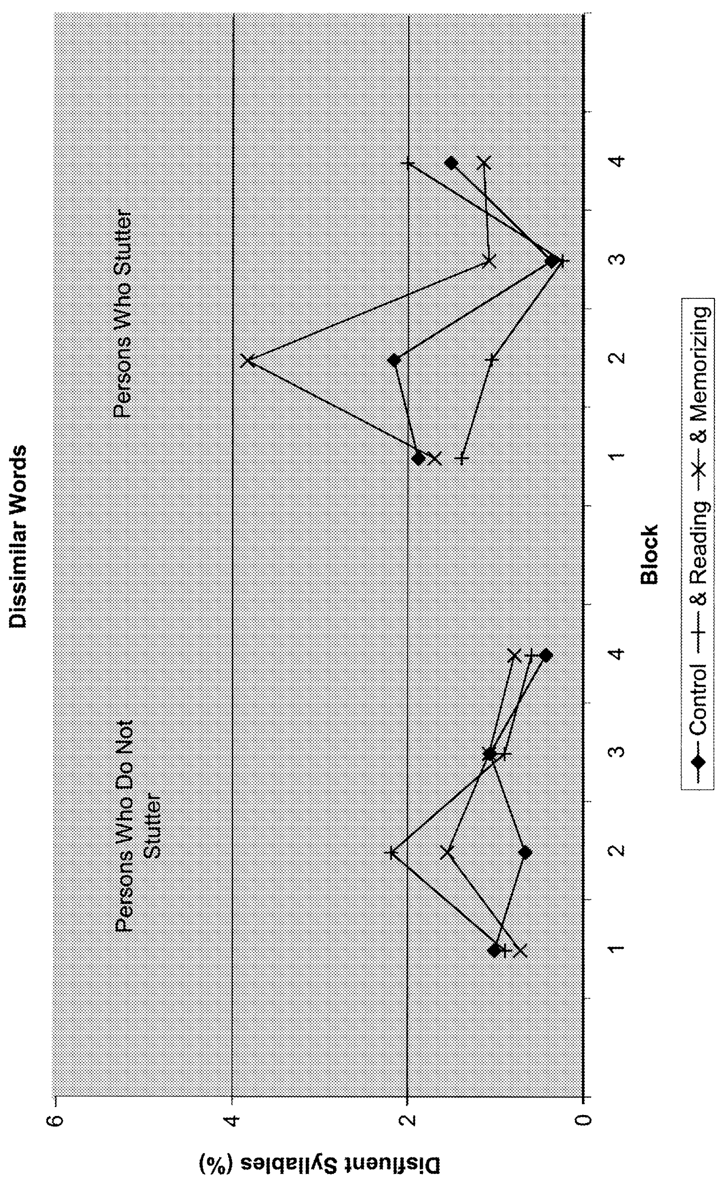

Fig. 1. Average percentage of disfluent syllables for each condition and group as a function of blocks of repetition with dissimilar secondary task material.

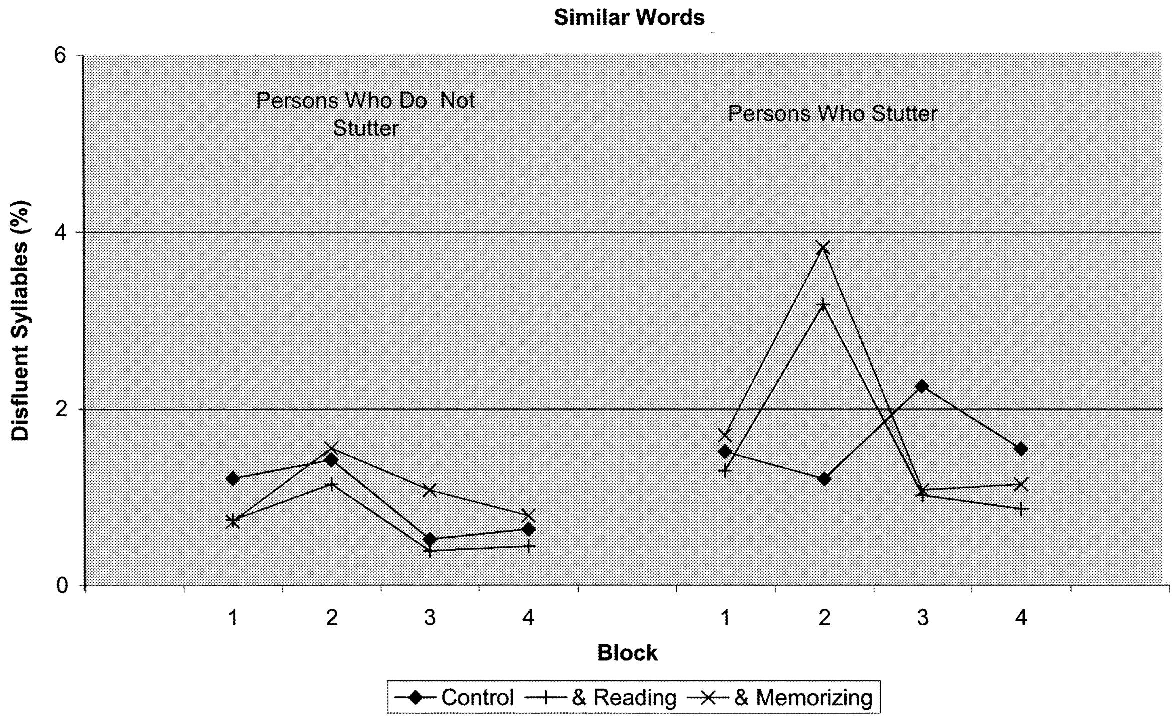

Fig. 2. Average percentage of disfluent syllables for each condition and group as a function of blocks of repetition with similar secondary task material.

significantly influenced when they concurrently processed similar or dissimilar words during silent reading or memorizing conditions.

Pause rates significantly decreased over blocks ($F(3, 72) = 5.31$; $\text{MSe} = 24.36$; $P < 0.008$), as was indicated by a significant linear trend ($F(1, 24) = 7.45$; $\text{MSe} = 30.94$; $P < 0.012$), but second- and third-order trends were not significant ($F(1, 24) = 3.97$; $\text{MSe} = 6.56$; $P < 0.056$; $F(1, 24) = 0.05$; $\text{MSe} = 10.88$; $P < 0.83$). The other main effects and interactions between-group, similarity, condition, or block were not significant.

Inhalation rate was also significantly influenced by block ($F(3, 72) = 9.7$; $\text{MSe} = 122.29$; $P < 0.001$) and by the block by similarity interaction ($F(3, 72) = 3.86$; $\text{MSe} = 14.76$; $P < 0.02$). Inhalation rate was significantly smaller in the first than in subsequent blocks of repetition. The significant two-way interaction of similarity × block results from the fact that inhalation follows a different trend over blocks for similar and dissimilar words. The third-order trend over blocks interacted significantly with similarity ($F(1, 24) = 6.77$; $\text{MSe} = 16.20$; $P < 0.016$) and was significant only for similar and not for dissimilar material (similar words: $F(1, 24) = 4.38$; $\text{MSe} = 36.47$; $P < 0.047$; dissimilar words: $F(1, 24) = 0.30$; $\text{MSe} = 15.69$; $P < 0.59$). Trend differences were not further analyzed, because such information is beyond the interest of the present study.

3.2. Recall of secondary task words

The upper half of Table 2 presents the average number of correctly recalled similar and dissimilar words for the total sample of each group and secondary task

Table 2
Average number of correctly reproduced secondary task words and standard deviations for each group

Secondary task	Nonstuttering persons			Persons who stutter		
	n	*M*	SD	*n*	*M*	SD
	Total sample					
Memorizing						
Dissimilar	16	5.3	1.3	14	5.5	0.9
Similar	16	5.1	1.3	14	5.8	0.6
Reading						
Dissimilar	16	1.2	1.3	14	1.8	1.3
Similar	16	1.1	1.2	14	2.1	1.6
	Sub-samples					
Memorizing						
Dissimilar	12	5.9	0.3	13	5.7	0.5
Similar	12	5.7	0.7	13	5.9	0.3
Reading						
Dissimilar	8	2.0	1.3	9	2.3	1.0
Similar	8	1.9	1.0	9	2.3	1.0

The sub-samples comprise of participants having higher recall of secondary task items (see text for details).

condition. Persons who stutter generally recalled more items than did the nonstuttering comparison group, especially for similar words in the reading task. For each secondary task, separate analyses of variance were evaluated with group and task order as between-subject factors and similarity as a repeated-measurement factor. A significant group effect was found in the reading but not in the memorizing task (reading task: $F(1, 24) = 4.47$; $P < 0.045$; memorizing task: $F(1, 24) = 2.12$; $P < 0.16$). Similarity and its interaction with group were not significant in either analysis (all F-values smaller than 1.0). In the reading condition 13 participants (eight persons who do not stutter and five who do) recalled no similar, no dissimilar, or no items.

In order to control for group differences in the recall of secondary task items, sub-samples of each group were selected which were comparable with respect to their recall performance (see bottom half of Table 2). In the memorizing condition only those participants who recalled at least four of the six similar and dissimilar items were selected. In the reading condition the sub-samples consisted only of participants who recalled at least one similar and dissimilar item, however, the data of one stuttering participant were excluded, because her perfect reproduction of similar items in the reading condition was considered an outlier ($z = 3.1$; $P < 0.000$). Thus, these criteria restrict the data to those participants who most efficiently recalled secondary task words. Table 2 (bottom half) shows that the sub-samples appear to be better matched for their secondary item recall both in the reading and the memorizing conditions. This general impression was confirmed by analyses of variance of the recall performance of the sub-samples: the main effects group (reading task: $F(1, 11) = 0.57$; MSe $= 1.63$; ns; memorizing task: $F(1, 19) = 0.11$; MSe $= 0.26$; ns), similarity (reading task: $F(1, 11) = 0.08$; MSe $= 0.45$; ns; memorizing task: $F(1, 19) = 0.08$; MSe $= 0.16$; ns), and the interaction group by similarity were statistically insignificant (reading task: $F(1, 11) < 0.00$; MSe $= 0.45$; ns; memorizing task: $F(1, 19) = 2.03$; MSe $= 0.16$; ns).

3.3. Post-hoc analysis of disfluency rate within selected sub-samples

In order to control for possible between-group differences in secondary word recall, the disfluency rates of the sub-samples were also analyzed. The contrasts between the disfluency rates under control and each of the secondary task conditions were tested within Block 2 for similar and dissimilar material ($\alpha^* = \alpha/2 = 0.025$). The disfluency rate of persons who stutter was significantly higher in Block 2 during reading similar words ($M = 2.9$; SD $= 2.79$; $n = 9$) than under control conditions ($M = 0.8$; SD $= 0.98$; $n = 9$; $F(1, 11) = 8.58$; MSe $= 40.69$; $P < 0.014$), but not when reading dissimilar words (control condition: $M = 2.5$; SD $= 2.45$; $n = 9$; reading condition: $M = 0.8$; SD $= 0.98$; $n = 9$; $F(1, 11) = 4.41$; MSe $= 61.50$; $P < 0.06$). The corresponding differences in the disfluencies of the nonstuttering group (similar: $F(1, 11) = 0.61$; MSe $= 40.69$; $P < 0.45$; dissimilar: $F(1, 11) = 0.90$; MSe $= 61.50$; $P < 0.36$) were insignificant. Thus, after matching the two groups on their recall in the reading condition, the disfluency of stuttering subjects was significantly increased in Block 2 when reading similar words but not when concurrently reading dissimilar words. In contrast, The disfluencies of nonstuttering persons were not significantly affected when they concurrently read either similar or dissimilar words.

Corresponding analyses were also performed for sub-samples that were matched for recall in the memorizing condition. Within Block 2 the sub-sample of the persons who stutter had significantly higher disfluency rates in memorizing than in control conditions. This contrast was statistically significant for similar (control condition: $M = 1.0$; $SD = 1.79$; $n = 13$; memorizing condition: $M = 2.7$; $SD = 0.98$; $n = 13$; $F(1, 19) = 8.24$; $MSe = 43.94$; $P < 0.01$) as well as for dissimilar words (control condition: $M = 2.1$; $SD = 2.37$; $n = 13$; memorizing condition: $M = 3.6$; $SD = 3.58$; $n = 13$; $F(1, 19) = 9.02$; $MSe = 47.81$; $P < 0.007$). For nonstuttering persons, however, the corresponding effects were not significant (similar words: $F(1, 19) = 0.59$; $MSe = 43.94$; $P < 0.45$; dissimilar words: $F(1, 19) = 1.09$; $MSe = 47.81$; $P < 0.31$). Thus, the sub-group of stuttering persons having a comparatively high recall performance for memorized words evidenced significantly higher disfluency when they concurrently memorized both similar and dissimilar words than in the control condition. Thus, the statistical decision for similar words was identical to that of the total sample, whereas the contrast between the memorizing and control conditions for dissimilar material did not reach significance in the complete sample but was significant in the selected sub-sample.

4. Discussion

Analyses of the recall of secondary task words indicated that the two groups differed in the way they processed secondary task material (see Table 2). These differences were primarily due to the fact that comparatively more persons who do not stutter had low recall performances than did persons who do stutter. This was particularly true for the reading condition in which eight nonstuttering but only four stuttering participants failed to recall a single similar or dissimilar word. Moreover, four nonstuttering persons recalled fewer than four similar or dissimilar items under memorizing conditions whereas only one person who stutters had such a low recall performance. These observations may indicate that more stuttering than nonstuttering participants complied with secondary task instructions. It seems highly unlikely that the lower recall performance of nonstuttering persons under reading conditions reflects poorer memory performance when no significant group differences in recall performance were found under memorizing conditions. Since failure to comply with secondary task instructions could invalidate the results of the speaking task, sub-samples of participants with recall performance at comparably high levels were selected from both groups. The results of the total sample will be discussed first because of their higher statistical power, then evaluated against the background of the sub-samples' results.

The disfluency rates of persons who stutter were found to increase when phonologically similar material was concurrently read or memorized (see Figs. 1 and 2); however, this increase did not last longer than the three-word repetitions of Block 2. This transient increase suggests that it was caused by concurrent processing and encoding of secondary task material and not by increases in memory load lasting from the presentation of secondary task words at the transition between Blocks 1 and 2 until the end of Block 4. The disfluency rates of persons who stutter, however, were not significantly influenced beyond Block 2.

Thus, even though continuous word repetition is a highly automatized task that should be relatively insensitive to interference effects, significant group differences were found for similar secondary task words. The nonstutterers' smaller and insignificant increase in disfluencies during secondary task conditions cannot be explained by assuming that nonstuttering participants were less compliant with secondary task instructions. The inadequacy of this explanation was demonstrated in separate analyses in which only the data of those stuttering and nonstuttering participants with comparably high secondary word recall performances were analyzed. For these selected sub-samples, too, the disfluency rates of stuttering but not of nonstuttering persons were significantly increased relative to control conditions when processing similar secondary task words.

When dissimilar words were used as secondary task material, the disfluency rates of stuttering persons were not significantly increased in the memorizing than in the control condition. For the selected sub-sample, however, stuttering persons also had significantly increased disfluency rate in Block 2 when dissimilar words were concurrently memorized.

In sum, these results suggest that concurrent reading and memorizing of similar words increased the disfluency of stuttering but not of nonstuttering persons. Concurrent memorizing of dissimilar words also increased the disfluency of the sub-sample of stuttering persons who recalled many of the words to be memorized.

When secondary task words were phonologically similar to repetition words, it was more difficult for speakers to select the correct words for overt word repetition and to prevent secondary task words from being included in the overt repetition sequence. Because both sets of words had similar initial syllables, both activation and inhibition of a repeated word spreads automatically to its counterpart in the secondary task or vice versa. Therefore, selection of words for overt rehearsal is a more difficult task when secondary task material is similar to the words of the repetition task. According to Baddeley (1996), coordination of two tasks is one of the attention-demanding functions performed by the central executive system. If so, the central executive system must be more involved in the selection of similar material for repetition than in the selection of dissimilar material. These findings suggest that the phonological and articulatory systems of persons who stutter are more vulnerable to interference from attention-demanding processing within the central executive than are those of nonstuttering persons.

The differences found between the reading and memorizing conditions can be explained similarly. It is plausible that more elaborate coding processes are required for storing than silent reading of secondary task words. If so, the higher processing demands of memorizing would explain why disfluency rate was also increased for dissimilar words — at least when the sub-sample of stuttering persons with higher secondary word recall is taken into consideration.

To sum up, the present word repetition results suggest that concurrent attention-demanding coding and decision processes increase the disfluency of persons who stutter, whereas the disfluencies of nonstuttering speakers seems to be largely independent of concurrent processing load.

The results of the present experiment extend earlier findings of stuttering increases under secondary task performance (Bosshardt, 1999), but they shed little light on the underlying neurophysiological mechanisms. Although Webster (1997) used experimental methodologies which differ considerably from those of the present study, the brain mechanisms he proposed are pertinent to the present results. When subjects performed sequential finger tapping (Webster, 1986) or a motor sequence reproduction task (Webster, 1989) with the right hand while performing a different manual task with the left hand, Webster found that stuttering persons showed more concurrent task interference than did nonstutterers. These results suggest that left hemisphere speech motor mechanisms, specifically involving the supplementary motor area are more fragile in people who stutter and susceptible to interference from other on-going brain activation (Webster, 1997, p. 119). The results of Webster (1990) and Forster and Webster (1991) indicated that stuttering persons are more flexible in task-dependent activation of either of the two hemispheres, as well as displaying greater vulnerability of the supplementary motor area.

Other areas, in addition to the supplementary motor area, might also be involved in the sensitivity of stuttering speaker's speech to interfering events. Fox, Ingham, Ingham, Zamarripa, Xiong, and Lancaster (2000) found that the brain regions correlated with the occurrence of stuttering events were those implicated in speech production (i.e., primary and supplementary motor areas, inferior lateral premotor cortex, anterior insula, and the cerebellum). In a silent reading task De Nil, Kroll, Kapur, and Houle (2000) found higher activation in the left inferior prefrontal cortex, including Broca's area, for stuttering than for nonstuttering persons. In a dual-task experiment De Nil and Bosshardt (2000) found that some of the brain areas in stuttering speakers activated during speech planning were also involved in overt sentence production. From Webster's results (1997) and those of brain imaging studies, it can be hypothesized that stuttering speaker's greater sensitivity to concurrent cognitive processes may originate from the fact that some of the brain areas implicated in speech production and stuttering (Fox, Ingham, Ingham, Zamarripa, Xiong, & Lancaster, 2000) are also active during cognitive processing.

In the present study, no information about the neuro-functional bases of word repetition, reading, and memorizing performance was obtained. Therefore, an information processing interpretation of the present results can be given, which is less specific about its neuro-physiological foundation. The results of the present study suggest that the phonological and articulatory sub-systems of stuttering speakers can be characterized as being organized in a less modular way (cf. Fodor, 1983) than are those of nonstuttering speakers.

Another interpretation of the present results that implicates processes within the phonological system would hypothesize that the phonological system of persons who stutter is more error-prone than that of persons who do not stutter (e.g., Postma & Kolk, 1993, 1997) and that the inclusion of additional words increases the probability of errors, particularly when similar words are added. This interpretation cannot be completely excluded on the basis of presently available evidence. However, it is incomplete because, without additional assumptions, it cannot account for the present finding, that concurrent processing interfered only temporarily with the fluent speech of stuttering persons. At least in the memorizing condition, secondary task material is stored phonologically until the end of word repetition but increases disfluency only during repetitions that immediately follow presentation of the secondary task material. The present findings, therefore, suggest that persons who stutter are more susceptible to cognitive processing interference, because their phonological and articulatory systems are less modularized. Because of such low modularity, these systems are more error-prone when attention-demanding processes are being performed concurrently.

It was also found that pauses decreased over blocks of word repetitions. Pauses are more "typical" forms of disfluencies (Yaruss, 1998), because they occur quite commonly in nonstuttering speakers. In a word repetition paradigm, they can be viewed as indications of failures of item retrieval. The inter-rater reliability of pause rate was comparatively low, which could be one reason for the absence of statistically significant treatment or group effects for this dependent variable.

Inhalation rate was determined by auditory perception which implies that only those inhalations creating enough turbulent noise were identified. These measures did not show any indication that breathing activity was significantly influenced by group, condition or their interaction. But they were influenced by block and the interaction between block and similarity. Similar and dissimilar words were matched for syllable length and stress pattern. Therefore, their production should consume comparable amounts of air. Overall inhalation rate did not differ significantly for the two sorts of words, which is consistent with this assumption. The significant interaction between block and similarity indicates that inhalations were differentially distributed over word repetitions. At present, no theoretical interpretation can readily account for this result.

The present experiment investigated only the effects of phonological similarity, and its findings suggest that the occurrence of stuttering may be related to stuttering speakers' difficulty in maintaining concurrent coding and selection processes within the central executive, phonological, and articulatory systems. However, it remains to be determined if this effect also occurs when repeated words have to be selected from among semantically similar alternatives.

The second question is related to the functional implications of these results to understanding stuttering. Because word repetition can be performed in a highly automatic way and is subject to the adaptation effect, it is relatively insensitive to secondary task influences. However, a recent experiment (De Nil & Bosshardt, 2000) used sentence production as a speaking task and found that persons who stutter were less efficient than a nonstuttering comparison group in generating and producing a sentence while concurrently performing other cognitive tasks. It is plausible, therefore, that the group differences in word repetition found in this study are also relevant to other less automatized and more complex speaking tasks.

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CONTINUING EDUCATION

Effects of concurrent cognitive processing on the fluency of word repetition: comparison between persons who do and do not stutter

QUESTIONS

1. What are the basic assumptions shared by many modern theories of speech production?
   a. Speech is the end result of interactions between cognitive and physiological processes
   b. The neurophysiological basis of speech planning is largely unknown
   c. Speech has a segmental structure resulting from the interconnectivity of the brain
   d. Speech is the end result of incremental planning at multiple levels
   e. Speech planning processes should be computationally modeled
2. What are the loci at which the probability of stuttering is enhanced?
   a. Subject phrases
   b. Initial parts of longer utterances
   c. Short syllables
   d. Final parts of longer utterances
   e. Initial parts of shorter utterances
3. What are basic assumptions in Fodor's concept of modularity?
   a. Modules of mind are informationally encapsulated processing units
   b. A module is an inherited bio-physical unit representing speech
   c. Modules are inherited processing units specialized for speech production
   d. Modules are inherited processing units specialized for speech acquisition
   e. Modules are elementary units of the mental lexicon
4. How did the secondary memorizing task of the present experiment influence the speech fluency of speakers who stutter?
   a. Disfluency rates of stuttering speakers were hardly affected by the memorizing task

b. Disfluency rates of stuttering speakers were increased as long as the secondary task information was being kept in short-term memory
c. Disfluency rates of stuttering speakers were increased as long as the secondary task information was being encoded in short-term memory
d. Disfluency rates of stuttering speakers were increased as long as the secondary task information was being retrieved from short-term memory
e. Disfluency rates of stuttering speakers were reduced as long as the secondary task information was being encoded in short-term memory

5. How did the secondary memorizing task of the present experiment influence the speech fluency of speakers who do not stutter?
    a. Disfluency rates of speakers who do not stutter were increased as long as the secondary task information was being retrieved from short-term memory
    b. Disfluency rates of speakers who do not stutter were increased as long as the secondary task information was being kept in short-term memory
    c. Disfluency rates of speakers who do not stutter were increased as long as the secondary task information was being encoded in short-term memory
    d. Disfluency rates of speakers who do not stutter were hardly affected by the memorizing task
    e. Disfluency rates of speakers who do not stutter were reduced when the secondary task information was being encoded in short-term memory