When Less Can Be More: Dual Task Effects on Speech Fluency

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Abstract

Minimizing cognitive resources while executing well-practiced motor tasks has been shown to increase automaticity and enhance performance (e.g., Beilock, Carr, Macmahon, & Starkes, 2002). Based on this principle, we examined whether more fluent speech production could be induced through a dual task paradigm that engaged working memory (WM) while speech was produced. We also considered whether effects varied for speakers who differed in their habitual degree of attentional control during speech production. Twenty fluent adults and 19 adults who stutter performed (1) a baseline speaking task, (2) a baseline WM task with manipulations of domain, load, and inter-stimulus interval (ISI), and (3) a series of dual tasks in which the speaking task was combined with each unique set of WM conditions. Results indicated a fluency benefit under dual task conditions, which was specific to atypical forms of disfluency but comparable across speaker types and manipulations of the WM task. Findings suggest that WM is associated with atypical forms of disfluency and that suppressing these resources enhances speech fluency, although further research is needed to specify the cognitive mechanism involved in this effect and clarify the nature of this association.

Keywords: cognitive control; dual task; working memory; speech production; fluency; stuttering

Introduction

Many studies demonstrate enhanced motor performance when available attentional or WM resources are suppressed (Beilock et al., 2002; Masters, 1992; Poolton, Maxwell, Masters, & Raab, 2006). This effect is explained by the principle that the amount of cognitive effort and optimal mode of processing for a given task depends on the nature of the task and skill level of the performer. Rule-based, analytic tasks benefit from explicit forms of processing that rely upon conscious awareness and WM. In contrast, motor performance, particularly for expert performers, is better served by implicit modes of processing that are experience-based, involve content that is not available for representation in WM, and are less vulnerable to stress or distraction. In situations of pressure, many performers tend to increase their attention to the internal process of performance, resulting in a disruption of automaticity and breakdown of skills, often referred to as *choking* or *freezing* (Baumeister, 1984; Beilock & Gray, 2007). Inward focusing results in explicit processing of proceduralized knowledge, causing movement sequences to be *dechunked* into independent units, which is ultimately counterproductive for skilled performers.

Consistent with this account, experienced athletes (golfers, soccer players, baseball batters) perform more poorly during experimental conditions requiring skill-focused attention (e.g., attending to timing of golf swing) (Beilock & Gray, 2012; Beilock et al., 2002; Gray, 2004); skilled typists become slower and less accurate when attending to performance details (Snyder & Logan, 2013); and rock climbers in high-anxiety conditions exhibit more rigid movements, slower climbing, and longer grasped holds (Pijpers, Oudejans, & Bakker, 2005). Collectively, these findings indicate that situations involving pressure or that call attention to processes underlying motor performance negatively influence movement precision and fluidity.

Related studies have shown that suppressing explicit processing resources in skilled performers and forcing them to employ implicit control systems enhances the accuracy and efficiency of motor outcomes (Beilock, et al., 2002; Masters, 1992). This shift in control is typically achieved through dual task paradigms in which participants perform a primary motor task with a simultaneous secondary task that continuously engages WM (e.g., Beilock et al., 2002; Masters, 1992; Poolton et al., 2006). Similarly, manipulating attention by instructing participants to focus on movement effects (external focus) rather than on movements themselves (internal focus) results in greater automaticity. This effect has been replicated across a variety of motor tasks, and as explained by the *constrained action hypothesis (CAH)* (McNevin, Shea, & Wulf, 2003), indicates that conscious attention to internal movements constrains the movement system. Based on these findings, the present study examined predictions of the CAH and attention-performance interactions in relation to the process of speech production. We anticipated that conditions in which speakers were forced to rely on implicit modes of processing (dual task conditions) would result in more effortless speech production, as reflected by a reduction in specific forms of speech disfluency.

We also considered whether effects would differ in speakers who varied in the degree of attentional control they typically exerted during speech production. Although motoric aspects of speech production are normally effortless for most adult speakers, numerous studies indicate that speech (as well as nonspeech) processes are less automatized for people who stutter (Saltuklaroglu, Teulings,

& Robbins, 2009; Smits-Bandstra & Gracco, 2013). For example, a dual task study involving simultaneous tracing and production of choral speech (a condition which normally yields spontaneous fluency) revealed more manual disfluency on the tracing task in stuttering adults compared to controls, even when stuttering was virtually eliminated (Saltuklaroglu et al., 2009). These results indicate that stuttering speakers may expend greater amounts of effort when speaking, perhaps in response to, or in anticipation of, stuttering. People who stutter also show limited practice effects in trained motor sequences (Smits-Bandstra & De Nil, 2013; Bauerly & De Nil, 2011; Smits-Bandstra & De Nil, 2009), suggesting an association between stuttering and difficulty achieving automaticity. Based on this literature, the present study compared dual task effects on speech fluency for speakers with different degrees of speech automaticity. We predicted fluency benefits in all speakers, but greater benefit for those who stutter, as these individuals may be more dependent on explicit (vs. implicit) representations of motor speech patterns.

Finally, we considered three critical factors related to dual task interference patterns. Considerable evidence suggests that concurrent tasks relying on similar processes result in more interference than tasks involving different domains or modalities (Allport, Antonis, & Reynolds, 1972; Cocchini, Logie, Sala, MacPherson, & Baddeley, 2002; Duff & Logie, 2001; Leclercq, 2002). Tasks with a greater degree of temporal overlap also result in greater interference, with the extent of interference depending on how frequently each task must access central resources (Dux, Ivanoff, Asplund, & Marois, 2006; Pashler, 1992). A final factor influencing dual task interference is the degree of automaticity associated with each task (Pashler, 1999; Poldrack et al., 2005). Performance is considered automatic when it requires minimal capacity demands and is not affected by a concurrent secondary task (Poldrack et al., 2005). As discussed above, studies within the stuttering literature indicate that adults who stutter perform more poorly than controls on secondary tasks executed while speaking (Saltuklaroglu et al., 2009; Smits-Bandstra & De Nil, 2009), suggesting that speaking is less automatized for this group.

Thus, the present study combined a speaking task and secondary WM task with manipulations of domain (verbal vs. spatial), WM load, and inter-stimulus interval (ISI). Our goal was to examine how interference associated with each manipulation affected aspects of speech production in adult speakers and whether this effect varied for speakers who differed in their level of speech automaticity. We predicted that speaking under dual task conditions would impact fluency across participants with varying effects based on speaker group, disfluency type, and dual task condition. We expected that atypical disfluencies, generally associated with stuttering (see Methods for details), would occur less frequently under dual vs. baseline conditions, and that this effect would be greater in adults who stutter compared to fluent speakers. We further anticipated that dual task effects on fluency would be stronger in secondary tasks involving verbal compared to spatial WM (due to the similarity in resources required for speaking and verbal WM tasks) and in conditions with a higher WM load and shorter ISI.

Methods

Participants

Participants included 20 self-identified adults who stuttered (AWS) and 20 adults who did not stutter (AWNS), all between the ages of 18-35, with at least average nonverbal intelligence (based on Test of Nonverbal Intelligence – 4th Edition; TONI-4) and expressive vocabulary (based on Expressive One-Word Picture Vocabulary Test – 4th edition; EOWPVT), and no significant medical history, learning disability, hearing loss, or head injury. Stuttering diagnosis was confirmed for AWS based on two standardized measures of stuttering severity (Stuttering Severity Instrument - 4th Edition, Overall Assessment of the Speaker's Experience of Stuttering) and ranged from very mild to severe. All participants spoke English as their primary language. Computerized operation- and symmetry-span tasks (Unsworth, Heitz, Schrock, & Engle, 2005) were administered to measure working memory capacity for verbal and spatial stimuli. See Table 1 for participant demographics, standardized scores on cognitive and language measures, and span task results (absolute score).

Table 1: Participant characteristics. Mean (SD)

	AWNS	AWS
Age	25.60 (4.58)	27.21 (4.18)
Males/Females	11/9	12/7
Right-/Left-Handed	17/3	16/3
TONI-4	107.85 (12.90)	107.56 (12.54)
EOWPVT-4	104.60 (9.81)	102.11 (12.45)
Symmetry Span	20.65 (7.04)	19.61 (12.52)
Operation Span	45.85 (16.16)	42.56 (17.39)

Procedures

Procedures included three sets of tasks, administered in the same sequence to all participants: (1) three baseline tasks, (2) two dual tasks, and (3) a final baseline speaking task. Tasks within each set and trials within each task were presented in a random order. All tasks were administered on a desktop computer, with E-Prime 2.0 software. Spoken output was recorded via an adjustable headworn unidirectional microphone (Shure SM10A) connected to a preamplifier (Switchcraft 308TR), with supplementary video recordings during all speech production tasks.

Baseline Speaking Task In the baseline speaking task, participants produced spontaneous speech over a 60-second period for each of 4 topic prompts (e.g., *Describe a recent vacation*). Prompts for each trial were presented in a set of three, allowing participants to select topics based on personal preferences and experiences. Once a prompt was selected, it was not presented again on subsequent speaking trials throughout the experiment. Spoken output for each trial was automatically recorded by E-Prime, saved in individual audio files, and subjected to extensive off-line coding and analysis. The baseline task was administered once at the beginning of the experiment and once at the end (following dual task conditions) to help account for possible order and practice effects.

Baseline WM Task WM tasks were modeled after Salthouse, Babcock, & Shaw (1991) and adapted to examine effects of three experimental manipulations: WM domain (verbal vs. spatial), WM load (2, 3, and 4), and ISI (long vs. short). In the verbal domain, participants viewed a start number, followed by a series of individually presented, single digit addition operations (e.g., +3), and a prompt to enter the correct numeric outcome. In the spatial WM task, a single colored circle was presented in one cell within a 2x2 grid. This stimulus was followed by a series of individually presented, directional arrows and a prompt to enter the number representing the final location of the circle, based on a numbered on-screen grid. WM load was manipulated by varying the number of sequential operations (2, 3, or 4) to be performed on the initial number or circle stimulus. ISI varied between individual operations, with intervals of 3000 ms and 1000 ms for the long and short ISI conditions, respectively. The ISI manipulations varied the relative frequency with which WM resources were accessed, creating more or less competition between the WM and simultaneous speaking task. Sixty test items were presented within each WM domain, with 10 items for each unique combination of WM load and ISI.

Dual Task In the dual task conditions, participants performed the speaking task and each WM task (verbal and spatial) simultaneously. Speech was recorded continuously and keyboarded responses to the WM task were entered twice per speaking trial. Five speaking trials were provided for each combination of WM load and ISI, with a total of 30 speaking trials and 60 WM trials for each WM domain.

Data Processing

Audio output was orthographically transcribed and coded for disfluencies. Disfluencies were categorized as (1) typical disfluencies, which included fillers, revisions, repetitions of phrases, and repetitions of multisyllabic words; or (2) atypical disfluencies, which consisted of repetitions of monosyllabic words, repetitions of sounds or syllables, prolongations, blocks, and broken words. This categorization system was based on widely accepted typologies within the stuttering literature which classify forms of disfluency as being more or less characteristic of pathological stuttering (e.g., Ambrose & Yairi, 1999; Ratner, Rooney, & MacWhinney, 1996; Vasić & Wijnen, 2005; Yaruss, 1998). Categorization was also confirmed by actual data, which indicated similar patterns of effects for individual disfluency types within each category. A customized script utilizing the qdap package (Rinker, 2013) in *R* was used to generate frequency counts of all spoken syllables and counts of each disfluency type for individual speaking trials.

Data Analysis

Data were analyzed to examine effects of experimental manipulations and speaker types on speech fluency and secondary task performance. Fluency variables consisted of counts of typical and atypical disfluencies; performance on the WM task was scored as correct (1) or incorrect (0) for each trial. A coding scheme was developed to examine six contrasts of interest based on a priori hypotheses. These included: (1) Disfluency type (typical vs. atypical); (2) Task type (baseline vs. dual); (3) Domain (spatial vs. verbal); (4) ISI (long vs. short); (5) extreme WM loads, termed Load1 (2 vs. 4); and (6) intermediate WM load compared to extremes, termed Load2 (3 vs. 2 and 4). Generalized multilevel linear models were utilized as they provide maximum flexibility and robustness when analyzing multi-level experimental data with non-normally distributed dependent variables (Hoffman & Rovine, 2007). Preliminary analyses of fluency data indicated that a nonzero inflated negative binomial distribution best fit disfluency counts; therefore, all multilevel generalized linear models for disfluency counts utilized a negative binomial link function (Hardin, Hilbe, & Hilbe, 2007). Performance on the WM task was scored as correct (1) or incorrect (0) for each trial and was therefore analyzed using a multilevel logistic regression model. Successive models were compared using log-likelihood ratio, Akaike Information Criterion (AIC), and Bayesian Information Criterion (BIC) statistics.

Results

Preliminary Analyses

Comparison of pretest and posttest baseline measures for typical and atypical forms of disfluency within each group (calculated as a proportion of syllables) indicated no significant difference between the two baseline measures: for typical disfluencies, $t(19) = -1.44$, $p = .17$ and $t(18) = 0.77$, $p = .45$ within AWNS and AWS, respectively; for atypical disfluencies, $t(19) = -0.16$, $p = .86$ and $t(18) = 0.93$, $p = .36$ within AWNS and AWS, respectively. Disfluency measures for both tasks were therefore included in models as baseline measures without further differentiation.

Speech Fluency

As described above, dual task effects on fluency were analyzed via multilevel generalized linear models with a negative binomial link function (Hardin et al., 2007). Models were offset by the total number of syllables produced during each speaking trial (thus, the dependent variable represented the ratio of disfluencies to fluent syllables). Results indicated that a model including Speaker (AWNS vs. AWS), Disfluency (typical vs. atypical), Task (baseline vs. dual) and two two-way interactions (Speaker x Disfluency and Disfluency x Task) provided the best fit (see Table 2). The final model included the random effect of an individual-level intercept (variance = .27) with residual variance of 1.11. Examination of the coefficients indicated that controlling for number of syllables (speech rate), atypical disfluencies were significantly less frequent than typical disfluencies and occurred at 28% of the rate observed for typical disfluencies (β=-1.26, *SE*=.06, *t*=20.96, *p*<.00001). The interaction between Disfluency and Speaker was also significant, with AWS producing approximately four times more atypical disfluencies compared to AWNS (β=1.43, *SE*=.03, *t*=41.83, *p*<.00001). Most importantly, the interaction between Disfluency and Task indicated a significant reduction in the frequency of atypical disfluencies under dual compared to baseline tasks. This was true regardless of speaker type (AWS vs. AWNS) and regardless of experimental condition (Domain, ISI, Load) within the dual task. During dual tasks, atypical disfluencies occurred at a rate that was 70% the rate at which these disfluencies occurred under non-dual task conditions (β=-0.35, *SE*=.06, *t*=6.04, *p*<.00001). Thus, for every 100 atypical disfluencies produced during baseline conditions, 70 were produced during dual task conditions. Typical forms of disfluency did not show any change as a result of experimental manipulations.

Table 2: Results of final model of disfluencies

Fixed Effects	β	*SE*	*t*	*p*
Intercept	-3.34			
Disfluency	-1.26	.06	20.96	<.00001
Speaker	0.21	.16	1.30	.19
Task	0.03	.04	.90	.37
Disfluency*Speaker	1.43	.03	41.83	<.00001
Disfluency*Task	-0.35	.06	6.04	<.00001

Secondary Task Performance

Secondary task performance was measured based on WM response accuracy and analyzed via multilevel logistic regression modeling. Models included the random effect of an individual-level intercept (variance of final model = 1.22). Coefficients for the final model (Table 3) indicated that each experimental manipulation showed an overall effect on secondary task performance. Accuracy on the secondary task was 18% lower under dual compared to baseline conditions (β=-1.69, *SE*=.08, *t*=20.46, *p*<.00001); 72% lower in verbal compared to spatial WM tasks (β=-0.33, *SE*=.04, *t*=7.71, *p*<.00001); 113% higher under short compared to long ISI conditions (β=.12, *SE*=.04, *t*=2.92, *p*=.004); and 75% lower under the highest WM load (load of 4) compared to the lowest load (load of 2) condition (β=-.28, *SE*=.05, *t*=5.36, *p*<.00001). However, there were no interactions between these predictors and no differences between speaker groups.

Table 3: Results of final model of WM task performance

Fixed Effects	β	*SE*	*t*	*p*
Intercept	3.72			
Task	-1.69	.08	20.46	<.00001
Domain	-0.33	.04	7.71	<.00001
ISI	.12	.04	2.92	.004
Load1 (2 vs. 4)	-.28	.05	5.36	<.00001
Load2 (3 vs. 2, 4)	.08	.04	1.75	.08

Discussion

The primary goal of the study was to examine whether engaging WM resources during speech production resulted in enhanced speech fluency and whether this effect varied for speakers with different habitual levels of speech automaticity. The critical finding was that dual task conditions had a facilitative effect on speech fluency, which was specific to atypical forms of disfluency but was not influenced by speakers' fluency status or by specific manipulations within the secondary task (WM domain, load, ISI). Secondary task performance was poorer in dual compared to baseline conditions and showed expected effects for each manipulation within the WM task; however, there were no interactions between effects and no group differences in performance.

Consistent with the *constrained action hypothesis*, our findings demonstrate that minimizing cognitive control and relying on more implicit modes of processing benefit speech performance. The results also support the central premise of the *matched filter hypothesis* (Chrysikou, Weber, & Thompson-Schill, 2013), which proposes that optimal levels and patterns of resource allocation vary based on task demands, goals, and contexts. According to this framework, efficient filtering of sensory information via top-down control (associated primarily with prefrontal cortex [PFC] activity) supports performance across a variety of tasks that are rule-driven, involve conflict, or require abstraction of concepts. The same form of control, however, hinders performance on tasks that are habitual and best served by subcortical (e.g., basal ganglia) neural systems. Thus, optimal performance relies on dynamic adjustments to the filtering mechanism based on task requirements.

Results of the present study suggest that greater dependence on explicit forms of control during speech production disrupts automaticity and contributes to stutter-like behavior. The ability to delegate control of routine tasks from the cortex to lower neural circuits (such as the basal ganglia) is critical for motor performance that is highly efficient and resistant to stress (Shine & Shine, 2014). Whereas early stages of task learning are characterized by engagement of frontal regions and specific subcortical areas (associative striatum) that receive input from PFC, these regions show less activation once a task has been automatized (Ashby, Turner, & Horvitz, 2010; Poldrack et al., 2005). Similarly, regions within the basal ganglia show less activity on trials that form a sequence compared to pseudorandom trials, reflecting the effective chunking of information that accompanies automatization (Poldrack et al., 2005).

Neuroimaging studies within the stuttering literature suggest that stuttering is associated with differences in this neural circuitry. Giraud and colleagues (Giraud et al., 2008) found a positive correlation between basal ganglia activity and stuttering severity, implying that representations were less efficiently organized and resembled early stages of motor learning in these speakers. Imaging studies further demonstrate increased anterior cingulate cortex activity in stuttering compared to fluent speakers during conflict tasks, indicating that individuals who stutter demonstrate excessive monitoring activity, even when behavioral performance does not show impairment relative to controls (Arnstein, Lakey, Compton, & Kleinow, 2011; Liu et al., 2014). These findings suggest that stuttering may be associated with inappropriate matching of task demands with the extent or types of cognitive resources utilized to meet these demands.

Although our results demonstrated enhanced speech fluency under dual task conditions, no differential fluency effects were observed as a result of secondary task manipulations (WM domain, load, ISI), even though these manipulations all affected performance on the WM task itself. Thus, similar fluency changes occurred when WM was taxed, regardless of the nature of the stimuli being processed and frequency with which WM resources were accessed. Alternatively, it is possible that the spatial task unintentionally taxed verbal WM (circle movements could have been verbally rehearsed), that more extreme changes in WM load and ISI were needed to observe expected effects of these manipulations on speech fluency, or that fluent speech and verbal WM rely on different resource pools.

The finding that fluency effects were comparable across speaker types was unexpected and suggests that atypical disfluencies in all speakers arise from a similar underlying process in which maladaptive attentional tendencies interfere with automaticity. This interpretation is consistent with recent studies within the stuttering literature suggesting that stuttering is associated with an attentional bias to threat stimuli (Hennessey, Nang, & Beilby, 2008) and tendency to respond to stress by adapting motor patterns in ways that are ultimately counterproductive (Lieshout, Ben-David, Lipski, & Namasivayam, 2014). Based on the CAH and results of the present study, adjustments reported by Lieshout and colleagues (2014) may reflect recruitment of WM resources in an effort to consciously control movements involved in articulatory processes.

Dual task effects on speaking rate were considered; however, details related to these analyses are outside the scope of this paper. Briefly, results indicated that fluency benefits under dual task conditions were accompanied by a reduction in speech rate, which was greater in fluent compared to stuttering speakers. Overall, rate reduction may be related to dual task effects on linguistic productivity; however, the smaller reduction in AWS likely reflects combined effects of a habitually slower speech rate (due to excessive disfluency) and enhanced fluency under dual task conditions.

In conclusion, the present study demonstrated a significant benefit to speech fluency as a result of dual task conditions that taxed WM resources. Despite differences in their habitual levels of speech automaticity, stuttering and fluent speakers benefited similarly from dual task conditions, suggesting that similar processes may contribute to atypical disfluencies in both types of speakers. These findings contribute to the growing literature on attention and performance by extending the concept of *less is more* to the process of speech production. Further research is needed to more precisely identify the cognitive mechanism involved in this effect and clarify the nature of the association between WM and speech disfluency.

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