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# Speeded verbal responding in adults who stutter: Are there deficits in linguistic encoding?

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**Abstract**

Linguistic encoding deficits in people who stutter (PWS, $n = 18$) were investigated using auditory priming during picture naming and word vs. non-word comparisons during choice and simple verbal reaction time (RT) tasks. During picture naming, PWS did not differ significantly from normally fluent speakers ($n = 18$) in the magnitude of inhibition of RT from semantically related primes and the magnitude of facilitation from phonologically related primes. PWS also did not differ from controls in the degree to which words were faster than non-words during choice RT, although PWS were slower overall than controls. Simple RT showed no difference between groups, or between words and non-words, suggesting differences in speech initiation time do not explain the choice RT results. The findings are consistent with PWS not being deficient in the time course of lexical activation and selection, phonological encoding, and phonetic encoding. Potential deficits underlying slow choice RTs outside of linguistic encoding are discussed.

***Educational objectives:*** The reader will be able to (1) describe possible relationships between linguistic encoding processes and speech motor control difficulties in people who stutter; (2) explain the role of lexical priming tasks during speech production in evaluating the efficiency of linguistic encoding; (3) describe the different levels of processing that may be involved in slow verbal responding by people who stutter, and identify which levels could be involved based on the findings of the present study.


*Keywords:* Stuttering; Phonological encoding; Semantic encoding; Reaction time; Priming

## 1. Introduction

Stuttering has been described as a speech motor disorder that disrupts the timing and/or coordination between the respiratory, laryngeal, and vocal tract subsystems of speech (Caruso, Max, & McClowry, 1999; Kent, 2000; Nudelman, Herbrich, Hess, Hoyt, & Rosenfield, 1992; Peters, Hulstijn, & van Leishout, 2000; Peters & Starkweather, 1990; van Lieshout, Hulstijn, & Peters, 2004). Evidence consistent with impairment or disruption to speech motor control in stuttering comes from studies showing differences between people who stutter (PWS) and fluent speaking controls in measures of articulation during fluent and disfluent speech (Caruso et al., 1999; Kleinow & Smith, 2000; Logan,

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2003; Max, Caruso, & Gracco, 2003; Peters et al., 2000). For example, investigations using verbal reaction time (RT) paradigms have found PWS to be slower than normally fluent speakers in the initiation of speech movements (Logan, 2003; van Lieshout, Hulstijn, & Peters, 1996a; Watson et al., 1991). Acoustic and kinematic analyses of speech in PWS have also provided evidence for difficulties in the timing of speech movements, such as of the lip and jaw (e.g., Kleinow & Smith, 2000).

However, from a theoretical point of view, research has so far failed to identify a specific locus of deficit within the speech motor control system, although arguments have been made for deficits in speech motor planning (Venkatagiri, 2004), muscle command preparation and/or execution (Peters et al., 2000; van Lieshout et al., 1996a; van Lieshout, Hulstijn, & Peters, 1996b), or in integrating segmental plans with the prosodic requirements of speech (Packman, Onslow, Richard, & van Doorn, 1996). Some authors have proposed that PWS are less skilled in their speech motor ability, as reflected in normal variation in any motor skill (van Lieshout et al., 2004), therefore, the underlying deficit may not be localizable to a specific component of speech motor control.

Part of the problem in identifying a source of deficit in speech motor control is that the disrupted motor processes responsible for stuttering may be a consequence of deficiencies in control or planning processes external to the speech motor system. One dominant hypothesis of this type is that deficiencies in linguistic processing may provide inadequate or delayed input to the speech motor control system, and stutters result as a consequence of the motor control system attempting to cope with that impoverished input (e.g., Bosshardt, 2006; Howell & Au-Yeung, 2002; Karniol, 1995; Newman & Bernstein Ratner, 2007; Peters & Starkweather, 1990; Postma & Kolk, 1993). According to the covert repair hypothesis of Postma and Kolk (1993), stutters arise because inefficient or slow phonological encoding leads to an increase in covert repairs to the phonological plan, particularly when the individual is intent on speaking at a rate exceeding the compliance of the phonological encoding mechanism. Perkins, Kent, and Curlee (1991) consider that a disruption in pre-motor planning at the point of assigning phonetic features to a syllabic frame can lead to stuttering. Similar ideas concerning the role of phonological encoding in creating asynchronies between linguistic planning and motor execution processes have been proposed as the underlying cause of stuttering (e.g., Howell & Au-Yeung, 2002; Wingate, 1988). Of course, phonological encoding might be delayed for a number of reasons, ranging from delays in higher-level semantic activation to inefficiencies within the encoding mechanism itself (Postma & Kolk, 1993).

Consistent with the above view, there is mounting evidence implicating a role for linguistic deficits in the etiology of stuttering (see discussions by Bloodstein, 2006; Hall, Wagovich, & Bernstein Ratner, 2007; Karniol, 1995; Kent, 2000; Peters & Starkweather, 1990). For example, studies have shown children who stutter tend to perform more poorly on assessments of language, particularly expressive language, than normally fluent controls (Karniol, 1995). In addition, studies have shown that stuttering frequency and measures of articulatory stability in PWS are related to linguistic variables such as grammatical complexity (e.g., Dayalu, Kalinowski, Stuart, Holbert, & Rastatter, 2002; Kleinow & Smith, 2000) and word frequency (e.g., Anderson, 2007). Although suggestive, increased levels of linguistic complexity may also be associated with increased motoric complexity or simply increased demands on cognitive resources available to the speech motor control system (Kent, 2000; Peters & Starkweather, 1990).

If stutters originate because the speech motor system must deal with asynchronies or inefficiencies in pre-motor linguistic planning, then differences between PWS and controls should be observed in tasks that are sensitive to those linguistic processes. Cognitive models of speech production, such as that proposed by Levelt and colleagues (e.g., Levelt, 1989; Levelt, Roelofs, & Meyer, 1999), provide a useful framework to consider the linguistic processes that might be deficient in stuttering. In Levelt et al.'s (1999) model linguistic encoding proceeds through a series of stages beginning with lexical concept activation, where the semantic attributes of words are retrieved, and then lemma selection where the syntactic features of words are retrieved and used for the purposes of grammatical encoding of multi-word utterances. Lexical selection is followed by word form encoding of the selected lemmas at morpho-phonological and phonetic levels, and finally articulation. A number of studies have explored the hypothesis that retrieving semantic and/or phonological information for the purposes of linguistic encoding might be a source of deficit or delay in stuttering (Newman & Bernstein Ratner, 2007; Postma & Kolk, 1993). These studies, however, have produced mixed findings.

### *1.1. Semantic and phonological encoding deficits in PWS*

Hartfield and Conture (2006) found picture naming response times were slower overall for the children who stuttered compared to age-matched controls. However, the children who stuttered also showed an inhibition effect on responding from hearing conceptually related prime words presented just before the picture. This effect was not observed in the control children. The results suggest children who stutter show greater interference from competing conceptual information and, therefore, are less efficient in lexical-semantic activation. A similar conclusion may be drawn from Pellowski and Conture's (2005) study. The young children who stuttered were not only slower overall in reaction time when naming pictures compared to children with normal fluency, but they showed significant interference from semantically related primes. The age-matched controls showed, however, faster naming in the semantically related condition compared to the unprimed condition.

Following Kempen and Huijbers (1983), Prins, Main, and Wampler (1997) assumed that the difference in RT between producing single words and short noun–verb sentences in response to action pictures reflects, at least in part, the time course of lexical selection via semantics. In their study, Prins et al. found PWS tended to respond more slowly than fluent controls, however, the difference between single words and sentences was similar for both groups, suggesting lexical selection via semantics is not less efficient in PWS. Bosshardt and Fransen (1996), however, did find evidence of slow or inefficient semantic activation in adults who stutter during sentence processing. They used a silent reading task that required participants to monitor words within the text. Both PWS and fluent controls were slower when monitoring for a category related word (e.g., a type of fruit) compared to an identical word. However, PWS were more retarded in their response times in the category monitoring condition than were the age-matched controls. Other research using sentence level tasks report linguistic deficits in PWS that may include semantic coding differences (see, e.g., Bosshardt, Ballmer, & De Nil, 2002; Weber-Fox, 2001).

Previous research has shown that naming RTs are slower when retrieving low-word frequency compared to high-word frequency picture names, and there is evidence that this word frequency effect is located at the level of accessing phonological forms during lexicalisation (Jescheniak & Levelt, 1994; Oldfield & Wingfield, 1965). Prins et al. (1997) observed a larger effect of word frequency on picture naming RT in PWS compared to controls, suggesting word form access and retrieval is less efficient in PWS. A similar finding has been reported by Newman and Bernstein Ratner (2007). Deficits in lexical selection and accessing lexical phonology cannot be the sole cause of stuttering, though; Packman, Onslow, Coombes, and Goodwin (2001) observed significant amounts of stuttering by three PWS when reading aloud written texts composed of non-words. This suggests on-line lexical selection and retrieval are not necessary for stuttering.

However, word form encoding within Levelt and colleagues' model is completed in two broad steps, one predominantly lexical and the other sub-lexical (see, e.g., Levelt et al., 1999). The first step is the activation of abstract lexical or morphemic units and the retrieval of the segmental and metrical content. In the second step the metrical structure and retrieved sound segments are utilized for prosodification, that is, the formation of phonemically encoded syllables where sound segments are assigned to positions within a syllabified metrical frame. This latter stage of word form or phonological encoding may be deficient in stuttering (Au-Yeung & Howell, 2002). However, here, too, the findings are mixed. Newman and Bernstein Ratner (2007) examined the effects of neighbourhood density and neighbourhood frequency on picture naming in adults who stutter. Both effects arguably influence the encoding of the sub-lexical content of word forms (Newman & Bernstein Ratner, 2007). Neither effect, however, distinguished PWS from fluent speaking controls. Arnold, Conture, and Ohde (2005) also examined neighbourhood density effects on picture naming RT, but in young children who stutter and young children who do not stutter. The difference in RT between words from dense and sparse neighbourhoods was similar for the two groups.

Melnick, Conture, and Ohde (2003) showed that presenting a phonologically related priming word just before picture presentation speeds the naming response in 3–5-year-old children. The magnitude of the effect, however, was no different for children who stutter, a finding also inconsistent with the notion that phonological encoding is less efficient in PWS. A similar result was reported by Burger and Wijnen (1999), but with adults. Verbal responses with shared onset phonemes were faster compared to responses with heterogeneous onsets, suggesting phonological encoding time is reduced by maintaining the onset phonemes in the phonological plan across trials (Meyer, 1991). Importantly, there was no evidence of delayed or perturbed phonological encoding in particular in PWS because the implicit priming effect was similar in magnitude and direction to the non-stuttering controls. The only difference between the two groups was that the PWS were slower overall to respond. Using adults, Weber-Fox, Spencer, Spruill III, and Smith (2004) report little difference in event related potential and behavioural measures including RT between PWS and controls on a rhyming task using congruent (e.g., *thrown*, *own*) and incongruent (e.g., *cone*, *own*) word pairs. The task was designed to test phonological processing speed on the basis that a correct response requires mapping from orthography to phonology, then segmenting and matching the phonological forms of prime and target. Bosshardt and Fransen (1996) similarly reported little difference in rhyme monitoring response times between adults who stutter and controls.

However, other studies have found differences between PWS and fluent speakers in tasks that are arguably sensitive to phonological processing. Children who stutter have been found to be worse than controls at non-word repetition (Anderson, Wagovich, & Hall, 2006; Hakim & Bernstein Ratner, 2004). Non-word repetition abilities are assumed to reflect phonological knowledge and phonological working memory capacity (Baddeley, Gathercole, & Papagno, 1998). Byrd, Conture, and Ohde (2007) found that picture naming in 5-year-old children with no stuttering was facilitated by hearing an onset fragment of the target picture name, whereas naming in 3-year-old children with no stuttering was facilitated by the rhyme portion without the onset fragment. The authors suggest this was evidence of a shift from a holistic or syllable based phonological encoding strategy at 3 years of age to a more mature incremental or segmental encoding strategy at 5 years of age (cf. Walley, 1993). This same shift, however, was not observed in children who stutter. Rather, the rhyme portion facilitated picture naming for both 3- and 5-year-old children who stutter, suggesting less mature phonological encoding skills at 5 years of age.

Using adults, Sasisekaran, De Nil, Smyth, and Johnson (2006) observed PWS to be slower than non-stuttering controls at monitoring target phonemes within the names of pictured objects (participants were instructed to say the picture name covertly to avoid the confound with articulation ability). The PWS were no different from controls on a number of other tasks including auditory monitoring of pure tones and simple RTs. The results suggest phonological encoding is slower in PWS. Sasisekaran and De Nil (2006) also found phoneme monitoring to be slower for adults who stutter compared to controls during covert picture naming. In addition, no significant difference between the groups was observed when monitoring for target sounds in spoken words, suggesting PWS do not differ in monitoring skills in general. Slower or less efficient phonological encoding in PWS might therefore explain their longer response times in the covert picture naming task.

### *1.2. The present study*

In summary, there are two broad possibilities regarding the relationship between linguistic planning and speech motor control difficulties in stuttering. One assumes a deficit at one or more stages of linguistic planning, such as word form encoding, may provide inadequate or delayed input to the speech motor control system (e.g., Melnick, Conture, & Ohde, 2005; Postma & Kolk, 1993). The second type of explanation is that the speech motor system is deficient in PWS and that the effects of this limitation are revealed particularly when the capacity of the motor system is taxed by internal demands that compete for shared resources (Kleinow & Smith, 2000; Packman et al., 2001; van Lieshout et al., 2004). Linguistic complexity, therefore, can influence or de-stabilize the speech motor system in PWS because the speech motor system is susceptible to resource constraints, not because there is any intrinsic deficit at those higher levels. Evidence of a word form or other linguistic encoding deficit in support of the first account is currently limited and inconsistent, although some studies have reported findings suggesting inefficiencies in lexical-semantic activation and phonological encoding in PWS. A number of factors might explain the inconsistencies between studies, including low statistical power associated with small sample sizes, the variety of paradigms being used making comparisons difficult, participant factors such as level of stuttering severity (most studies include a high proportion of participants with relatively mild stuttering) and whether the participants are children or adults. One reasonably consistent finding across studies, however, is that PWS tend to be slower in speeded verbal responding compared to normally fluent speakers, indicating some aspect of speech production is inefficient or delayed.

The aim of the present study was to investigate further the role of linguistic encoding deficits in chronic stuttering. Priming effects during speeded picture naming were used to compare adults who stutter and normally fluent controls on two core components of linguistic encoding, namely lexical-semantic activation and phonological encoding. Priming effects may be regarded as implicit measures of the organization of the underlying lexical system (Burger & Wijnen, 1999; Shapiro, Swinney, & Borsky, 1998). Finding a difference in priming not only enables some conclusion regarding the overall locus of the linguistic encoding deficit, but also provides confirmation of a delay or inefficiency that is intrinsic to the language system (cf. Roelofs, 2003). While some differences have been observed between children who stutter and those who do not using priming tasks (e.g., Byrd et al., 2007; Hartfield & Conture, 2006; Pellowski & Conture, 2005), there have been relatively few applications of priming paradigms to adults who stutter (cf. Burger & Wijnen, 1999).

During the picture naming task, participants named pictures (e.g., a picture of a tiger) under instruction to respond as quickly and accurately as possible while hearing spoken words that were semantically related (e.g., *lion*), phonologically related (e.g., *tiny*), or unrelated (e.g., *money*) to the target picture name. The primes were presented close to the point of picture presentation to overlap processing of the prime with lexicalisation of the target, even though the participants were instructed to ignore the primes. Participants also named pictures without any primes to examine the overall impact of hearing an auditory prime on picture naming. Previous research has shown that when the primes are semantically related RT tends to be slower relative to unrelated primes (Damian & Martin, 1999; Schriefers, Meyer, & Levelt, 1990). This semantic inhibition effect is explained by the lexical unit or lemma of the prime increasing lexical competition when retrieving the picture name and delaying lexical selection of the target word (Levelt et al., 1999; Schriefers et al., 1990). Furthermore, when the auditory primes are phonologically related to the target, picture naming RTs tend to be faster (e.g., Levelt et al., 1999; Melnick et al., 2003; Meyer & Schriefers, 1991; Schriefers et al., 1990; Truman & Hennessey, 2006). Facilitation is explained by the auditory prime contributing to the activation or retrieval of those phonemes shared with the target picture name.

The priming effects of semantic inhibition and phonological facilitation, therefore, reflect processing at different levels of the lexical system. Semantic inhibition targets lemma or lexical unit activation and selection via semantics, and phonological facilitation targets the retrieval and/or encoding of phonological units during word form encoding (Levelt et al., 1999). Furthermore, we assumed differences in the efficiency of either of these processes would be reflected in the magnitude of the corresponding priming effect. If adults who stutter are less efficient in lexical-semantic processing, it was predicted they will show not only slower picture naming RT but enhanced semantic inhibition compared to fluent speaking controls, a finding that will replicate previous studies using children (Hartfield & Conture, 2006; Pellowski & Conture, 2005). Similarly, if adults who stutter are less efficient in phonological encoding (Postma & Kolk, 1993; Sasisekaran & De Nil, 2006; Sasisekaran et al., 2006), we predicted enhanced phonological priming and longer picture naming RTs for PWS compared to controls. These predictions are based on the assumption that inefficient processes have more capacity to show the effects of interference and facilitation on processing time, similar to the notion that practice and interference effects on cognitive skills are larger at earlier stages of skill acquisition where processing is less efficient (Speelman & Kirsner, 2005; for similar rationales in relation to stuttering, see, e.g., Burger & Wijnen, 1999; Newman & Bernstein Ratner, 2007; van Lieshout et al., 1996a, 1996b).

In addition to manipulating the type of auditory prime during picture naming, we also varied word frequency of the target picture names and stimulus onset asynchrony (SOA). Based on findings by Prins et al. (1997) and Newman and Bernstein Ratner (2007), we predicted PWS would show a larger difference in RT between the low- and high-word frequency conditions. This would provide further evidence of less efficient word form retrieval during picture naming in PWS, based on the assumption that the primary location of the word frequency effect is in accessing word phonology during lexicalisation (Jescheniak & Levelt, 1994). The auditory primes were presented both 100 ms before (−100 SOA) and 100 ms after (+100 SOA) picture presentation. These two SOAs were selected from previous studies showing robust semantic and phonological priming effects (Damian & Martin, 1999; Jescheniak & Levelt, 1994; Schriefers et al., 1990). Although studies have shown semantic inhibition occurs at earlier SOAs than phonological facilitation (Schriefers et al., 1990), reflecting a difference in the time course that semantic and phonological information become available during picture naming, no specific predictions were made concerning differences in the effect of SOA between each participant group. PWS may be slower to begin activating semantic and phonological information during picture naming, however, it was beyond the scope of this paper to explore the temporal boundaries of these priming effects in each group by including a larger range of SOAs.

### *1.2.1. Phonetic encoding in PWS*

The priming effects observed during the picture naming task, however, may be limited because they fail to capture late stages of word form encoding. Within the framework of Levelt and colleagues (e.g., Levelt et al., 1999), word form encoding is completed in a number of steps including accessing and retrieving phonological units from lexical memory, a phonological encoding process that assigns the retrieved sound segments to syllable positions within a metrical frame, and then phonetic encoding or speech motor planning, where each phonologically encoded syllable is used to map to a corresponding gestural score or phonetic plan. A gestural score specifies the goals required for the subsystems of articulation (e.g., glottis, velum, tongue body, tongue tip, and lips) to produce syllables within words (Browman & Goldstein, 1990; Levelt & Wheeldon, 1994). The articulator is responsible for the determination and execution of muscle commands to realize those goals, resulting in overt speech (Levelt, 1989; Levelt et al., 1999; Peters et al., 2000).

Choice verbal RT and simple verbal RT tasks were included in the present study to investigate late stage word form encoding associated with phonetic planning. In both tasks unfamiliar visual shapes were arbitrarily paired with monosyllabic verbal responses. The choice RT task comprised of blocks of trials where two shapes were randomly presented on the computer screen and participants were required to produce the correct verbal response to each shape. During the simple RT task, only one shape was presented in a single block of trials. Choice RT tasks have previously been used to examine motor planning processes because the participant does not know which stimulus will be presented on each trial and cannot engage in advanced preparation of the response (e.g., Klapp, 1995, 2003; Sternberg, Monsell, Knoll, & Wright, 1978; van Lieshout et al., 1996a, 1996b). During the simple RT task, however, the response is known before the cue to respond is presented, and so the motor plan may be prepared in advance and stored in a short-term response buffer (Klapp, 1995, 2003; Klapp, Greim, & Marshburn, 1981; Sternberg et al., 1978). Supporting evidence that motor planning is involved during the choice RT interval, but not the simple RT interval, comes from studies that show choice RTs for single word responses increase with response complexity (e.g., increasing the number of syllables), but simple RTs do not (Klapp, 1995, 2003; Klapp et al., 1981; van Lieshout et al., 1996a).

In both the choice and simple RT task we compared word and phonologically matched non-word verbal responses as an implicit measure of phonetic encoding. According to Levelt and colleagues (e.g., Levelt & Wheeldon, 1994), the phonetic plan or gestural score for familiar or frequently produced syllables is retrieved from the mental syllabary. The gestural scores for non-words, however, require assembly or construction. This is regarded as a more time and resource consuming process (Varley & Whiteside, 2001; Venkatagiri, 2004). We predicted, therefore, longer RTs for non-words compared to words in the choice RT task. Choice verbal RT has been examined previously in adults who stutter. van Lieshout et al. (1996a, 1996b) varied the number of syllables and found the magnitude of the length effect on choice RT did not differ between PWS and controls. The authors concluded phonetic assembly or speech motor planning is not less efficient in PWS. More recently, however, Venkatagiri (2004) argued that speech motor planning deficits in stuttering may be restricted to the automatic retrieval and concatenation of familiar syllable motor plans, as opposed to the on-line assembly or construction of new or unfamiliar utterance plans. An important part of this argument is that PWS typically do not stutter under conditions of speaking that involve constructing new or significantly modifying familiar speech plans, such as changing voice register in a theatrical performance.

A comparison between words and non-words in choice RT, therefore, may be useful for detecting phonetic encoding deficits in stuttering. If PWS are inefficient at retrieving utterance plans from the mental syllabary, but not at constructing new utterance plans, then compared to fluent speaking controls, the difference between words and non-words might be reduced or absent in PWS, or PWS might be slower than controls in choice RT for words but not non-words. On the other hand, if PWS are overall less efficient at phonetic encoding regardless of the encoding pathway (i.e., retrieval vs. construction), we predicted a larger difference between words and non-words for PWS compared to controls on the basis that a less efficient encoding system will have more capacity to show the benefit from direct retrieval over the construction of speech motor plans (cf. van Lieshout et al., 1996a). We predicted, however, no difference between word and non-word responses in simple RTs for both groups based on the assumption that simple RT does not include phonetic encoding. However, simple RTs were assumed to be sensitive to differences in execution processes required to initiate verbal responses. If that is the case, a group difference in simple RT was predicted.

### *1.2.2. Summary of aims and predictions*

The present study examined the role of linguistic and speech encoding deficits in stuttering and employed a number of experimental manipulations across three different tasks to pin point where those deficits might lie. If PWS are deficient in either lexical selection via semantics or phonological encoding during word retrieval, this may be revealed by differences in the associated priming effect (i.e., semantic inhibition and/or phonological facilitation) in the picture naming task. Deficits or inefficiencies in accessing phonological forms during lexicalisation should also be revealed by a larger word frequency effect during picture naming for PWS (cf. Newman & Bernstein Ratner, 2007; Prins et al., 1997). Finally, deficient phonetic encoding in PWS may be revealed by differences in the lexicality effect on choice verbal RT. The simple verbal RT task serves as a control task to confirm that any difference between words and non-words in choice RT is associated with planning or encoding processes rather than response initiation. We predicted no lexicality effect in simple RTs for both groups. Deficits in response initiation, however, should be evident in slower simple RTs for PWS compared to controls.

Table 1
Characteristics of people who stutter and controls

| | PWS ($n = 18$) | | Controls ($n = 18$) | |
|---|---|---|---|---|
| | *M* | S.D. | *M* | S.D. |
| Age (years) | 44 | 13 | 43 | 14 |
| PPVT | 114 | 18 | 107 | 15 |
| Syllables stuttered (%SS) | 4.6 | 3.4 | – | – |
| Time since last Tx (months) | 128 | 114 | – | – |
| Fluency techniques | | | | |
| Use (hours/week) | 9 | 11 | – | – |
| Practice (hours/week) | 4 | 8 | – | – |
| Total use (months) | 14 | 19 | – | – |

*Note*: PPVT standard scores used. Tx = treatment. Dash indicates no clinical measures were obtained.

## 2. Methods

### 2.1. Participants

Eighteen men who stutter aged from 22 to 65 years, and 18 age and gender matched normally fluent controls, participated in this study. All participants were native speakers of Australian English. Stuttering participants were recruited from the self-help group, The Speak Easy Association of Western Australia. The normally fluent controls were recruited through family and friends of staff and students at Curtin University of Technology. None of the control participants had a history of speech and language difficulties. All stuttering and control participants were administered the peabody picture vocabulary test-revised (Dunn & Dunn, 1981), as a measure of receptive vocabulary. Independent samples *t*-tests indicated that the groups did not differ in terms of age, $t(34) = .05$, $p = .96$, or PPVT standard scores, $t(34) = 1.24$, $p = .22$. The latter finding, in particular, suggests that receptive ability is an unlikely confound for any group difference in auditory priming during picture naming. Table 1 gives the mean and standard deviation of ages and PPVT standard scores for both groups.

Percent syllables stuttered (%SS) was rated by a qualified speech pathologist with more than 15 years clinical experience in stuttering from audio recordings of conversational speech and picture descriptions. A minimum 5000 syllable speech sample was used. This equated to 5 min accrued real speech time. Stuttering was defined as repetition and prolongation of sounds and syllables, and audible and inaudible cessation of speech (Wingate, 1964). Stuttering participants also completed a case-history questionnaire detailing information about treatment histories and use of fluency techniques. Refer to Table 1 for summaries of these clinical measures.

### 2.2. Stimulus materials

#### 2.2.1. Picture naming task

Forty digitized black and white photographs of everyday objects were used in the picture naming RT task. The images were selected to have good name agreement from a larger set developed for a picture naming study with school-aged children. Twenty of the pictures had low-frequency names ($M = 4.5$ occurrences per million, S.D. = 3.9; Kucera & Francis, 1967), and 20 had high-frequency names ($M = 91.5$ occurrences per million, S.D. = 87.3). The stimulus pool comprised both mono- and bi-syllabic items. At each level of frequency 12 picture names were one-syllable in length and eight picture names were two-syllables in length, although word length was not included as an independent variable in the present study. Across word frequency, picture names were also matched in terms of onset sound. Four auditory primes were assigned to each target picture name. One of these primes was semantically related to the target (e.g., target = *tiger*; prime = *lion*). All semantic primes were category relations to the test items. A second prime was phonologically related to the target, sharing the onset consonant or consonant cluster and, for 80% of the items, also the vowel nucleus (e.g., target = *tiger*; prime = *tiny*). The final two primes were unrelated to the target (e.g., target = *tiger*; prime = *money*, *coach*). The test items with their primes are listed in Appendix A. An additional set of 11 pictures and corresponding primes were used for practice and as fillers. Finally, all prime words were spoken by an adult female and digitally recorded at a sampling frequency of 22,050 Hz with 16 bit samples, using Signalyze (3.12) software installed on a Macintosh Power PC computer. Each word was saved as a separate sound file and edited with a 30 ms lead in prior to speech onset.

#### 2.2.2. Choice and simple RT task

Stimuli used in the choice and simple RT tasks were identical. Sixteen black and white shapes from Microsoft Word Basic Shapes were used as visual stimuli. Shape size was approximately 2.5 cm × 2.5 cm when presented on the computer screen. Familiar shapes with common names (e.g., a simple square or circle) were avoided. The verbal responses were selected from Hennessey (1996) and consisted of eight CVC words and eight CVC non-words. Non-words were phonologically matched to the words following the procedure used by Sternberg, Wright, Knoll, and Monsell (1980). In particular, the eight words formed two quadruples: *take*, *paid*, *tide*, and *pike*, and *geese*, *keel*, *gale* and *case*. Corresponding non-words were constructed by rearranging the onset or offset consonant of each word within each quadruple (i.e., *tike*, *pide*, *tade*, & *pake*, and *gase*, *cale*, *geel*, & *keese*). Therefore, the non-word quadruples were matched to their corresponding word quadruple in terms of phonemes (including onset phoneme) and phoneme pair sequences. Within each quadruple of words and non-words, pairs were formed from those items that shared the same vowel/diphthong (e.g., *take* and *paid* formed a pair, as did *tide* and *pike*). This pairing was used in the choice RT task. Eight pairs of shapes were also formed, taking care to match up shapes that were distinct from each other (e.g., a shape with straight edges was paired with a shape with curves). These shape pairs were randomly assigned to different word and non-word pairs. Therefore, each of the 16 shapes was arbitrarily associated with a different verbal response. Eight responses were CVC words and eight were phonologically matched CVC non-words. The shapes served as visual cues for participants to say aloud the word or non-word associated with each shape.

### 2.3. Procedure

All RT tasks were administered in one session of approximately 75 min with breaks between tasks. The picture naming task was presented first because it involved the largest blocks of trials. The simple RT task was then presented ahead of the choice RT task so participants could become familiar with each of the verbal response-shape pairings one at a time. Participants were tested individually in a quiet room free from distractions either at their home or the Speech Clinic at Curtin University of Technology. The stimuli were presented using PsyScope 1.2.5 experiment software (Cohen, MacWhinney, Flatt, & Provost, 1993) loaded onto a Power 7500/100 Macintosh computer or Macintosh G3 laptop computer. RT was measured in millisecond timing from picture/shape onset to speech onset as detected by a Sony ECM-909A microphone connected to a PsyScope button box. The microphone fitted to a short stand was positioned on the desk directly in front of the participant's mouth at a distance of approximately 2 cm.

The experimenter stayed in the room with participants to monitor for errors in responding (which included incorrect verbal responses, voice key errors, hesitations and stutters). These errors were recorded on-line by clicking a mouse during the interval between trials. In some cases, participants expressed preference for the experimenter to be absent from the room and responses were recorded on a Sony TC-D5 PRO II cassette player with a Sony electret condenser lapel microphone for subsequent error analysis.

#### 2.3.1. Picture naming task

All participants were required to name each picture correctly before starting the experiment. Participants were then informed they would see the pictures on the computer screen and hear words through a set of headphones, and were instructed to name each picture as quickly and accurately as possible while ignoring the spoken words. Auditory stimuli were presented through a set of Philips SBC HL130 headphones.

Each test trial began with a blank interval of 200 ms before the appearance of the picture. The picture was positioned in the centre of the computer screen and was approximately 4 cm × 5 cm in size. The picture remained on the screen until the microphone picked up a vocal response. There was a 1500 ms wait before the start of the next trial. There were two blocks of test trials; one block presented the auditory primes at a SOA of 100 ms before picture presentation (−100 SOA), and the other presented primes 100 ms after picture presentation (+100 SOA). The order in which participants received these SOA conditions was counterbalanced across participants within each group so that half received the −100 SOA block first and the other half received the +100 SOA block first.

Within each block of trials there were four cycles of 40 test trials. Each picture was presented once in each cycle but in a different auditory prime condition. To achieve this, the 20 low-frequency and 20 high-frequency test items were randomly split into four sets of five items, and four item lists were created. Within each list each set of five items was assigned to a different auditory prime condition. This allocation was rotated across the four lists such that each item appears once in each prime condition across all four lists. The prime conditions were semantically related, phonologically related, unrelated, or no prime. In the no prime condition the volume level of the unrelated prime was set to zero. All other primes were presented at a comfortable volume when wearing the headphones. Items from each list along with their auditory primes were presented in a different pseudorandom order for each participant in a given cycle. In addition, order effects were also controlled by randomizing for each participant the presentation of the four lists within each block of trials. A practice phase consisting of the eight practice items preceded the first block of test trials only. One filler item with an unrelated prime was presented between consecutive cycles of 40 test trials. This ensured no test picture could be presented twice in a row. A break, the duration of which was determined by the participant, was provided between each block of 160 test trials.

### *2.3.2. Choice RT task*

The choice RT task consisted of blocks of test trials where two visual shapes allocated to a word or non-word pair (e.g., *take*/*paid*) were randomly presented. Each block of test trials was preceded by an instruction and practice phase. During the instruction phase the participants were told to produce the correct verbal response as quickly as possible when each shape appears on the computer screen. Participants were told they should avoid saying anything other than the target response, and that their reaction times to the visual shape would be measured. Then came a series of instruction trials where in each trial the orthographic form of a target word (e.g., "paid") or non-word (e.g., "pide") was pasted centrally on the computer screen in size 24 Chicago font for 1000 ms, followed by a blank screen for 500 ms. The assigned shape for that target was then presented and remained on the screen up until the verbal response triggered the voice key via the microphone. This was followed by a wait of 2200 ms before the next instruction trial began. Participants were told to read the word/non-word silently and then say the target word/non-word aloud as soon as the shape appears on the screen. Six instruction trials were presented, three trials for each of the two shapes appearing in a block. Piloting work showed this was enough opportunity to learn the correct response for each shape. These instruction trials were followed by four practice trials where only the two shapes were randomly presented on the computer screen two times each.

The test trials followed directly on from the practice trials without pausing. Each test trial began with the shape being pasted centrally onto the computer screen. The stimulus remained on the screen until the voice key was triggered. The screen then remained blank for the duration of the inter-stimulus interval (see below). There were 28 test trials in each block, each shape being presented 14 times. Independently of the random presentation of the two shapes per block of trials, the inter-stimulus interval ranged from 1400, 1800, 2200 to 2600 ms every four trials. The order of these intervals was randomized anew for each set of four trials for each participant. There were a total of eight blocks of test trials to account for the eight pairs of verbal responses (four word pairs and four non-word pairs).

It was not possible to fully counterbalance the order of all pairs of test items across all participants in the choice RT task. We partially counterbalanced the order of item pairs in the following way, however. Firstly, the two pairs from each quadruple were presented in succession. For example, the pair *take*/*paid* was always followed by *pike*/*tide*, and *pide*/*tike* was always followed by *tade*/*pake*. We did vary the order in which the quadruples were presented to participants within each group, subject to the constraint that word quadruples alternated with non-word quadruples. One word quadruple and the corresponding non-word quadruple were (arbitrarily) labeled set 1 words (S1W) and set 1 non-words (S1NW), respectively, and the other quadruples were labeled set 2 words (S2W) and set 2 non-words (S2NW). We formed four counterbalancing groups separately for PWS and controls based on the following four quadruple sequences: (a) S1W, S1NW, S2W, S2NW; (b) S1NW, S1W, S2NW, S2W; (c) S2W, S2NW, S1W, S1NW; and (d) S2NW, S2W, S1NW, S1W. Consequently, each quadruple appears at each point in the sequence an equal number of times across participants.

### *2.3.3. Simple RT*

The simple RT task was carried out in a similar manner to the choice RT task, except each item pair was split resulting in 16 blocks of test trials with just one shape and corresponding word or non-word target per block. Each block began with three instruction trials where the target word/non-word was presented in print for 1200 ms, followed by a 500 ms wait; the associated shape was then presented and remained on screen until the microphone picked up a vocal response. In addition to three instruction trials, there were four practice trials at speeded responding, without the target word appearing on the screen. These practice trials were followed by 20 test trials. The inter-stimulus interval was randomized during the test trials at 1200, 1600, 2000, or 2400 ms in the same way as for the choice RT task. The allocation of shape to target word or non-word was kept constant between the simple and choice RT task for each participant. The order of test blocks was the same for each participant with set 1 word quadruples appearing first, followed by set 1 non-words, set 2 words and then set 2 non-words.

## 3. Results

### 3.1. Picture naming task

Picture naming RT means for each participant for each condition were calculated after excluding errors (7.2% of trials for PWS and 5.6% for controls) and RT outliers (5.6% of trials for PWS and 5.4% for controls). An outlier was defined as a score more than 2 standard deviations below or above the mean for each condition for each participant. The resulting means and error rates were submitted to a mixed four-way analysis of variance with prime condition (semantically related, phonologically related, unrelated, and no prime), SOA (−100 vs. +100), and word frequency (low vs. high) as repeated measures factors, and group (PWS vs. control) as a between-groups factor. An alpha level of .05 was used for all comparisons including planned comparisons performed using least significant differences. The reported effect size estimate is partial eta squared ($p\eta^2$).

Table 2 gives the RT means for PWS and controls, split by each level of auditory prime, SOA, and word frequency. Overall naming responses for PWS were slower than the control group (885 ms vs. 808 ms). The main effect for group was not significant, however, $F(1, 34) = 3.36$, $p = .076$, $p\eta^2 = .09$. Both groups combined were slower to respond when the picture names were low frequency compared to high frequency (866 ms vs. 827 ms), $F(1, 34) = 46.24$, $p < .001$, $p\eta^2 = .58$. The interaction between group and word frequency was not significant, $F < 1$, $p\eta^2 = .01$, with the word frequency effect being only slightly larger for PWS (42 ms) compared to controls (36 ms).

Across both groups and levels of priming and word frequency, the mean RT for naming pictures in the +100 SOA condition (838 ms) was lower than the −100 SOA condition (855 ms). This difference was not statistically significant, however, $F(1, 34) = 1.15$, $p = .29$, $p\eta^2 = .03$. SOA, also, did not interact with group, $F(1, 34) = 1.78$, $p = .19$, $p\eta^2 = .05$, or word frequency, $F < 1$, $p\eta^2 = .005$, and there was no three-way interaction between group, SOA and word frequency, $F < 1$, $p\eta^2 < .001$.

The analysis of variance yielded a significant main effect of priming, $F(3, 102) = 40.78$, $p < .001$, $p\eta^2 = .54$. Comparisons of the marginal means collapsing across group, SOA and word frequency revealed that the semantically related mean (882 ms) was significantly larger than the unrelated mean (860 ms), demonstrating a 22 ms semantic inhibition

Table 2
Mean picture naming RT (ms) and error rates for people who stutter and controls, split by auditory prime conditions, word frequency and stimulus onset asynchrony

| | Low frequency | | | | | | High frequency | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | −100 SOA | | | +100 SOA | | | −100 SOA | | | +100 SOA | | |
| | *M* | S.E. | Error (%) | *M* | S.E. | Error (%) | *M* | S.E. | Error (%) | *M* | S.E. | Error (%) |
| PWS ($n = 18$) | | | | | | | | | | | | |
| Semantic | 972 | 37 | 9.2 | 939 | 42 | 6.7 | 920 | 33 | 7.8 | 862 | 36 | 6.7 |
| Phonological | 900 | 36 | 8.0 | 865 | 44 | 6.9 | 854 | 31 | 8.9 | 837 | 44 | 4.7 |
| Unrelated | 931 | 36 | 8.9 | 898 | 44 | 7.8 | 908 | 36 | 7.5 | 870 | 43 | 6.1 |
| No prime | 903 | 34 | 7.2 | 838 | 35 | 5.8 | 852 | 32 | 6.7 | 811 | 35 | 5.8 |
| Controls ($n = 18$) | | | | | | | | | | | | |
| Semantic | 871 | 28 | 9.4 | 864 | 36 | 8.3 | 817 | 29 | 6.4 | 814 | 31 | 6.7 |
| Phonological | 804 | 29 | 4.2 | 820 | 30 | 4.7 | 769 | 30 | 5.3 | 782 | 29 | 4.2 |
| Unrelated | 821 | 21 | 5.8 | 834 | 27 | 5.0 | 811 | 28 | 4.2 | 809 | 32 | 5.3 |
| No prime | 800 | 24 | 5.3 | 791 | 25 | 5.8 | 753 | 25 | 5.8 | 767 | 30 | 4.2 |

*Note*: −100 SOA = prime presented 100 ms before picture; +100 SOA = prime presented 100 ms after picture.

effect, $p < .001$. The phonologically related mean (829 ms) was significantly lower than the unrelated mean, demonstrating a 31 ms phonological facilitation effect, $p < .001$. The unrelated condition mean was also significantly larger than the no prime mean (814 ms), demonstrating a 46 ms inhibition effect of the unrelated auditory prime, $p < .001$.

While priming failed to interact with SOA, $F(3, 102) = 2.04$, $p = .11$, $p\eta^2 = .06$, there was a significant interaction between priming and word frequency, $F(3, 102) = 6.08$, $p = .001$, $p\eta^2 = .15$. The effect of priming was examined separately for low- and high-frequency words. There was a main effect of priming in the low-frequency condition, $F(3, 102) = 37.14$, $p < .001$, $p\eta^2 = .52$, as well as the high-frequency condition, $F(3, 102) = 24.51$, $p < .001$, $p\eta^2 = .42$. We then examined the semantically and phonologically related priming effects separately for low- and high-frequency words. The semantic inhibition effect was 40 ms for low-frequency words, $p < .001$, and only 4 ms for high-frequency words, $p = .57$. The phonological facilitation effect, however, was 24 ms and 38 ms for low- and high-frequency words, respectively. Both contrasts were significant, $p < .001$. This shows the semantic inhibition effect is restricted to low-frequency items, whereas the phonological facilitation effect was maintained across both low- and high-frequency conditions. This account of the priming by word frequency interaction was confirmed in a subsequent analysis of variance executed with only three levels of priming: phonologically related, unrelated and no prime. Without the semantically related prime condition the interaction between priming and word frequency is no longer significant, $F(2, 68) = 2.31$, $p = .11$, $p\eta^2 = .06$. It is also of interest to note that neither the three-way interaction between priming, SOA, and word frequency, nor between group, priming, and word frequency, was significant in the main analysis, $F(3, 102) = 1.64$, $p = .19$, $p\eta^2 = .05$, $F < 1$, $p\eta^2 = .01$, respectively.

Of particular importance to the present study, however, is whether the two groups differ in terms of the priming effects. The semantic inhibition effect (semantically related minus unrelated mean) was 21 ms for PWS and 24 ms for controls. The phonological facilitation effect (unrelated minus phonologically related mean), collapsing across word frequency and SOA, was 38 ms for PWS and 25 ms for controls. The inhibition effect from an unrelated prime (unrelated minus no prime mean) was also similar for the two groups, 51 and 41 ms for PWS and controls, respectively. Although phonological facilitation was numerically larger for PWS than controls, there was no two-way interaction between group and priming, $F < 1$, $p\eta^2 = .01$. The four way interaction between group, priming, SOA, and word frequency was also not significant, $F < 1$, $p\eta^2 = .02$. Furthermore, a post hoc four-way analysis of variance with group, SOA, word frequency, and only two levels of auditory priming (phonologically related vs. unrelated) also showed no significant interaction between group and priming, $F(1, 34) = 1.39$, $p = .25$, $p\eta^2 = .04$. Similar to the effect of semantic inhibition, there is nothing compelling in the data to suggest that the phonological facilitation effect is significantly different between PWS and controls.

The error rates for the picture naming task are also provided in Table 2. The error data revealed no significant group difference, $F(1, 34) = 1.53$, $p = .22$, $p\eta^2 = .04$, although there was a tendency for PWS to produce more errors than controls (7.7% vs. 5.7%). The main effect for word frequency was not significant, $F(1, 34) = 1.38$, $p = .25$, $p\eta^2 = .04$, with similar error rates for low-frequency words (6.8%) and high-frequency words (6.0%). There were higher rates of errors with responses at the −100 SOA (6.9%) compared to responses at the +100 SOA (5.9%). However, the main effect of SOA was not significant, $F(1, 34) = 3.12$, $p = .086$, $p\eta^2 = .08$. The main effect for priming was significant, $F(3, 102) = 4.53$, $p = .005$, $p\eta^2 = .12$. The percentage of errors for the semantically related condition (7.6%) was significantly larger than the errors for the unrelated condition (6.3%), $p = .032$. The percentage of errors for the unrelated condition was not significantly different to the phonologically related condition (5.9%), $p = .43$, nor the no prime condition (5.8%), $p = .40$. Across both groups there appears to be an effect of only semantically related primes on error rates in the picture naming task. None of the remaining two-way or higher order interactions in the error data were significant, however, the interaction between group and priming was close to significant, $F(3, 102) = 2.63$, $p = .054$, $p\eta^2 = .07$.

### *3.2. Choice RT task*

Participant RT means for each condition were calculated after excluding errors (7.94%) and RT outliers (3.54%). Two stuttering participants had missing data due to a high number of errors that included voice key errors and stutters. One participant had 100% incorrect for the non-words *keese* and *geel*, and the other participant had 100% incorrect for the non-words *pide* and *tike*, and also for the non-words *tade* and *pake*. To include these participants in the analysis, the missing data were replaced by the RT mean calculated from their remaining non-word conditions. Excluding these participants from the analysis did not change the results for the choice RT task. Mean RT and error rates were analyzed separately using a three-way mixed design analysis of variance with group (PWS vs. controls) as a between

Table 3
Word and non-word choice and simple RT means (ms) and error rates for people who stutter and controls

| | PWS | | | Controls | | |
|---|---|---|---|---|---|---|
| | *M* | S.E. | Error (%) | *M* | S.E. | Error (%) |
| Choice RT task | | | | | | |
| Word | 671 | 26 | 4.0 | 606 | 25 | 3.3 |
| Non-word | 695 | 19 | 14.1 | 625 | 20 | 6.6 |
| Simple RT task | | | | | | |
| Word | 440 | 18 | 2.8 | 408 | 16 | 1.6 |
| Non-word | 442 | 20 | 2.8 | 407 | 18 | 1.6 |

subjects factor, and lexicality (word vs. non-word) and item pair (four levels corresponding to two pairs per quadruple) as repeated measures factors. Pair was included as a factor in the design to increase power by removing systematic variance due to intrinsic differences between the pairs from the error terms used to test the remaining main effects and interactions. Data are presented here collapsed across pair because the results are not relevant to the aims of the present study. Please contact the first author for details on the results for individual pairs.

Table 3 gives the word and non-word RT means and error rates for each group in the choice RT task, collapsing across item pairs. Considering RT first, the PWS were significantly slower in choice verbal RT compared to the control group (683 ms vs. 615 ms), $F(1, 34) = 4.79$, $p = .036$, $\text{p}\eta^2 = .12$. Words were significantly faster to name than non-words (638 ms vs. 660 ms), $F(1, 34) = 11.87$, $p = .002$, $\text{p}\eta^2 = .26$. The lexicality effect was only marginally larger for PWS (24 ms) than controls (19 ms); the interaction between group and lexicality was not significant, $F < 1$, $\text{p}\eta^2 = .005$. There was also no suggestion that the group difference in choice RT is larger for words (65 ms) than non-words (71 ms).

Analysis of error rates did not yield a significant main effect for group, $F(1, 34) = 3.17$, $p = .084$, $\text{p}\eta^2 = .08$, although there was a trend for the stuttering group to produce a higher rate of errors than the control group (9.1% vs. 5.0%). There was a significant main effect for lexicality, $F(1, 34) = 10.60$, $p = .003$, $\text{p}\eta^2 = .24$, where non-words produced a higher percentage of errors (10.4%) compared to words (3.7%). Although the difference between words and non-words was larger for PWS (10.1%) compared to controls (3.3%), there was no significant two-way interaction between group and lexicality, $F(1, 34) = 2.72$, $p = .11$, $\text{p}\eta^2 = .07$.

### 3.3. *Simple RT task*

Participant RT means for each condition were calculated after excluding errors (2.2%) and RT outliers (4.44%). See Table 3 for the word and non-word simple RT means for each group. The overall mean simple RT for PWS (441 ms) was higher than the controls (408 ms), however, this difference was not significant, $F(1, 34) = 1.69$, $p = .20$, $\text{p}\eta^2 = .05$. RT means for words and non-words were almost identical. The main effect of lexicality and the interaction between group and lexicality were both non-significant, $F < 1$, $\text{p}\eta^2 = .001$, and $F < 1$, $\text{p}\eta^2 = .002$, respectively.

The word and non-word error rates for the stuttering and control groups in the simple RT task are also provided in Table 3. The mean error rate was numerically higher for the PWS compared to the controls (2.8% vs. 1.6%), however, this difference was not significant, $F(1, 34) = 1.99$, $p = .17$, $\text{p}\eta^2 = .06$. Error rates for words and non-words were identical (2.2%), $F < 1$, $\text{p}\eta^2 < .001$. The interaction between group and lexicality was also not significant, $F < 1$, $\text{p}\eta^2 = .002$.

### 3.4. *Correlations with clinical measures*

A correlation analysis examined the association between RT and the clinical measures for the PWS. The RT measures of interest, collapsed across SOA and word frequency, were mean picture naming RT from the no prime condition, to reflect picture naming speed without any influence of auditory primes, the semantic inhibition effect (semantic mean RT minus unrelated mean RT), the phonological facilitation effect (unrelated mean RT minus phonologically related mean RT), mean choice RT, and mean simple RT. We screened the data for univariate and bivariate outliers (Tabachnick & Fidell, 2001). Box plots were used to identify univariate outliers, and Mahalanobis distances available in multiple regression were used to identify bivariate outliers. With a relatively small sample size a single outlying case has the potential to mask an association that is present for the majority of cases. RT, also, has relatively large variability or intrinsic noise. For these reasons trimming the data to counteract the effect of outliers is appropriate (Ratcliff, 1993). No cases were excluded as outliers except for the following. When correlating amount of fluency practice per week with the RT measures, two univariate outliers were excluded for the fluency practice variable. When correlating stuttering severity (%SS) with all of the RT measures, one univariate outlier, the participant with the most severe level of stuttering (13.4%), was excluded (this case was not excluded in any of the other correlations). This case may also be classed as a bivariate outlier in the same correlation analyses at $p < .025$.

The clinical measures of time since last treatment and indicators of the use of fluency techniques did not correlate significantly with any of the RT measures ($p > .05$). %SS, however, correlated positively with the choice RT ($r = .52$, $p = .033$), and negatively with semantic inhibition ($r = -.55$, $p = .023$). The correlation between %SS and phonological facilitation was positive but not significant ($r = .29$, $p = .26$), as was the correlation between %SS and the no prime mean ($r = .13$, $p = .61$), and %SS and simple RT mean ($r = .41$, $p = .11$).

The association between choice RT and stuttering severity appears to be independent of overall speed of verbal responding. The partial correlation between %SS and choice RT, while controlling for both the no prime picture naming mean RT and simple RT mean, was significant ($pr = .52$, $p = .045$). Note, also, that the two controlled variables, no prime mean RT and simple RT mean, are themselves moderate to highly correlated ($r = .73$, $p = .001$), and both are correlated with choice RT ($r = .74$, $p = .001$, and $r = .78$, $p < .001$, for the no prime RT mean and simple RT mean correlated with choice RT, respectively). The partial correlation between %SS and semantic inhibition was no longer significant after controlling for overall speed of responding ($pr = -.48$, $p = .071$).

## 4. Discussion

The present study tested for linguistic encoding deficits in speeded verbal responding in PWS. Different of levels of processing during spoken word production were investigated through experimental manipulations involving auditory priming effects during picture naming and comparing word and non-word responses during choice and simple verbal RT tasks. The main results are that PWS were not found to differ from controls in any of the experimental manipulations we employed. PWS, however, were significantly slower to respond than fluent peers in the choice RT task, but not in the picture naming task or the simple RT task. Choice RT was positively correlated with stuttering severity, even after controlling for mean simple RT and mean picture naming RT. The implications of these findings are discussed below.

### *4.1. Semantic encoding during picture naming*

The results for the picture naming task showed, across both groups of participants, naming RT was slower when the auditory prime was semantically related to the target picture name relative to an unrelated prime, a finding replicating previous studies using the same paradigm (e.g., Damian & Martin, 1999; Schriefers et al., 1990). This semantic inhibition effect is argued to be located at the level of selecting lexical representations or lemmas via semantics (Levelt et al., 1999). In particular, lexical-semantic activation following presentation of the prime increases lexical competition during the selection of the target picture name. Therefore, more time is required for the lemma of the target to reach activation levels for selection to take place. Although the type of errors produced during picture naming were not analyzed, the fact that error rates were significantly higher in the semantically related prime condition is consistent with increased lexical competition.

The semantic inhibition effect was carried mainly by the low not high-word frequency picture names. This could suggest that lexical selection for low-frequency names is more susceptible to interference from lexical competitors than high-frequency names. Because high-frequency words are used more frequently their processing may be more efficient and insulated from external influences. For example, skill acquisition research suggests the cognitive components underlying skilled behaviour, including lexical processing, become more automated, less demanding on working memory and attention, and less subject to interference with increasing practice (see Speelman & Kirsner, 2005, for a review). A similar result might be expected for phonological priming, however, phonological priming was similar for low- and high-frequency words. It is also possible that uncontrolled item specific factors play a role. For example, if the pictures used in the high-word frequency condition tended to have faster visual object recognition speeds and/or were paired with primes with slower recognition speeds and therefore slower activation of lexical-semantics, lexical selection of the target may have already occurred by the time the semantics of the prime was sufficiently activated.

These factors may have differed between the test items appearing in the low- and high-word frequency conditions and may have contributed to the absence of semantic inhibition for high-word frequency targets.

Of more importance to the present study, however, is the finding that semantic inhibition was similar in magnitude for PWS and controls, and there was no interaction between group and auditory priming in the RT analysis. Therefore, there is no evidence to suggest lexical selection processes via semantics behave differently or are less efficient in PWS. Prins et al. (1997) also found no evidence of inefficient or delayed lexical selection via semantics in adults who stutter, although a different paradigm based on comparing word generation with sentence generation was used. These findings contrast with two studies using young children who stutter where differences in semantic or conceptual priming on picture naming response times have been observed (Hartfield & Conture, 2006; Pellowski & Conture, 2005). These studies suggest the semantic system is inefficient during on-line processing or is less well organized in younger children who stutter, leading to increased susceptibility to interference from conflicting semantic or conceptual cues. It is possible that deficits in lexical-semantic processing have either resolved (cf. Byrd et al., 2007) or are more subtle in adults who stutter. The studies with children showed that those who stuttered were also significantly slower in picture naming RT than controls. In the present study, although there was a trend for PWS to be slower and less accurate, the difference was not significant (see, also, Newman & Bernstein Ratner, 2007), suggesting that, unlike for younger children, picture naming is not markedly inefficient in adults who stutter.

If a more subtle deficit in semantic activation and lexical selection is present in adults who stutter, this difference might be expected to emerge under conditions where linguistic or cognitive demands are greater than in a picture naming task. Support for this possibility comes from Bosshardt and Fransen (1996) who did find evidence of slow or inefficient semantic activation in adults who stutter during a silent reading task that required participants to monitor printed sentences for words of a particular category (e.g., a type of fruit). Other studies providing evidence of differences in semantic coding in PWS also involve more complex language processing (see, e.g., Bosshardt et al., 2002; Weber-Fox, 2001; Weber-Fox et al., 2004). However, PWS have also been shown to be more vulnerable to increased cognitive demands generally, such as performing linguistic tasks under dual task conditions (see, e.g., Bosshardt, 2006, for a review), which might suggest broader deficits than a localized problem in lexical-semantic organization. Nevertheless, using a paradigm that provides a relatively direct or implicit evaluation of the efficiency of lexical selection and retrieval in PWS, the present study suggests that the differences in lexical-semantic organization observed in children who stutter (e.g., Pellowski & Conture, 2005) do not remain a strong feature of lexical processing in adulthood.

### *4.2. Phonological encoding during picture naming*

The results also showed naming RTs to pictures presented with a phonologically related prime were significantly faster relative to an unrelated prime. This finding replicates many studies, and is consistent with the assumption that phonological activation of a related auditory prime facilitates retrieval and/or encoding of the phonology of the target word (Levelt et al., 1999; Melnick et al., 2005; Meyer & Schriefers, 1991; Schriefers et al., 1990). For the purposes of the present study the magnitude of the phonological facilitation effect is assumed to be a function of the efficiency or rate of retrieving and/or encoding phonological units during word production. Evidence in support of this assumption comes from Truman and Hennessey (2006) who found increased phonological facilitation during picture naming for children with dyslexia – commonly regarded as having a phonological processing deficit – compared to age-matched typical readers. The present results show that the phonological facilitation effect was not significantly larger for PWS. The study, therefore, provides no compelling evidence that phonological encoding, as reflected in phonological priming, is inefficient in PWS relative to fluent speaking controls.

In addition, examination of RT's for low- and high-frequency words failed to support the prediction of a deficit in word form encoding in PWS. As expected, pictures with low-frequency names were named more slowly than pictures with high-frequency names. This word frequency effect is suggested to originate predominantly at the stage of accessing and/or retrieving lexical phonology (Jescheniak & Levelt, 1994; Prins et al., 1997), although a component may also be linked with articulatory processes, such as speech motor planning (Venkatagiri, 2004). If retrieving lexical phonology is slower or less efficient for low compared to high-frequency words, the magnitude of the word frequency effect should be sensitive to individual differences in the efficiency of word form encoding. In contrast to Prins et al. (1997) and Newman and Bernstein Ratner (2007), who reported an enhanced word frequency effect on picture naming for PWS relative to controls, the difference in RT between low- and high-frequency picture names was similar for PWS and controls in the present study. Procedural differences between studies might explain this inconsistency.

The present study repeated presentation of the same pictures under a number of conditions. The underlying lexical retrieval processes, therefore, would have been primed through repetition, a factor that is known to facilitate lexical access during picture naming and other tasks (Barry, Hirsh, Johnston, & Williams, 2001; Hennessey & Kirsner, 1999; Speelman & Kirsner, 2005). Both Prins et al. and Newman and Bernstein Ratner presented each picture for naming only once. It is possible therefore that a difference between PWS and controls in the word frequency effect is restricted to naming conditions where processing is less practiced and potentially more resource demanding, such as in retrieving a word for the first time under speeded naming instructions. The residual word frequency effect following practice observed in the present study, however, does not appear to differ to any great extent between PWS and fluent speaking controls, suggesting inefficient lexical form retrieval is not an intrinsic and stable characteristic of the language system in PWS.

The findings of the present study concerning phonological facilitation and word frequency add to a growing body of literature that has examined phonological retrieval and encoding in PWS. A number of these studies have failed to find significant differences between PWS and normally fluent speakers when using phonological priming (e.g., Burger & Wijnen, 1999; Melnick et al., 2003) or other measures assumed to reflect the operation of the phonological encoding mechanism such as rhyme monitoring (Bosshardt et al., 2002; Bosshardt & Fransen, 1996), and neighborhood density and neighborhood frequency manipulations during picture naming (Arnold et al., 2005; Newman & Bernstein Ratner, 2007). Weber-Fox et al. (2004) also used rhyme monitoring to examine phonologic processing and observed similar performance between PWS and controls in three out of four rhyming conditions. The one condition where a difference was found was the most cognitively demanding and required participants to respond to non-rhyming written word pairs that were spelt similarly (e.g., *own-gown*). In view of the overall findings in their study, the authors proposed that the PWS were delayed in this particular condition because of increased susceptibility to cognitive demands that potentially impact on post-lexical decision-making processes, rather than a phonological encoding deficit.

Of course, drawing conclusions based on null findings is problematic. Most of the above cited studies, including the present, used relatively small sample sizes, which means they had low statistical power for detecting small effects. It should be noted, however, that with small effect sizes there is likely to be considerable overlap between PWS and normally fluent speakers in their rate of phonological encoding. This suggests rate of phonological encoding is not the determining factor (Bosshardt & Fransen, 1996; Perkins et al., 1991; Postma & Kolk, 1993). A few studies have been successful in showing differences in phonological encoding in PWS (e.g., Sasisekaran & De Nil, 2006; Sasisekaran et al., 2006; Wijnen & Boers, 1994; see, also, arguments by Postma & Kolk, 1993). The present study, however, used an implicit measure of the efficiency of phonological encoding and adds to a growing body of research that reports null findings. The assumption made by some theories of stuttering, such as the covert repair hypothesis, that inefficient or delayed phonological planning processes in PWS is causally related to stuttering (e.g., Howell & Au-Yeung, 2002; Perkins et al., 1991; Postma & Kolk, 1993), therefore, does not receive strong support (Vasiç & Wijnen, 2005).

A number of authors have proposed that speech production in PWS is more prone to interference or disruption from cognitive stress or increased attention demands (e.g., Bosshardt, 2006; Caruso, Chodzko-Zajko, Bidinger, & Sommers, 1994; Weber-Fox et al., 2004). In the present study, the participants showed inhibition of picture naming when an unrelated auditory prime was concurrently presented, relative to the no prime condition. This effect has been reported in the literature before (Levelt et al., 1999) and may include an impact of the prime on strategic or executive processing during task completion, perhaps due to the partial distraction of attention away from picture naming. Nevertheless, the PWS did not show any evidence of being more highly affected by any of the auditory primes used in the present study, including unrelated primes, compared to the normally fluent controls.

### *4.3. The time course of semantic and phonological activation during picture naming*

The data relating to SOA deserve some comment. There was a trend for faster and more accurate responses in the +100 SOA condition compared to the −100 SOA condition, however, these differences were not statistically reliable. This suggests RTs were not strongly affected by when the primes were presented relative to the onset of the picture for naming. What is of interest, however, is that SOA did not interact with the effect of auditory priming. Previous research suggests that during picture naming there is an early lexical-semantic activation stage, where conceptual information associated with the pictured object is available, followed by a phonological activation stage (see, e.g., Levelt et al., 1999, for a review of this literature). While there is theoretical debate concerning the degree to which the semantic and phonological activation stages temporally overlap during picture naming (cf., Damian & Martin, 1999; Schriefers et al., 1990), it might be expected that semantic inhibition, not phonological facilitation, will dominate at the early −100 SOA, because semantic activation of the prime is more likely to coincide with the semantic activation of the target. Conversely, phonological facilitation might be expected to dominate at the later SOA, where phonological activation of the prime and target picture name is more likely to coincide.

The present results are consistent with the semantic and phonological activation stages overlapping in time, because both semantic and phonological priming occurred at both SOAs. There is some suggestion that semantic inhibition was stronger at the −100 SOA compared to the +100 SOA. Calculating the difference between the semantically related and unrelated auditory prime conditions, and collapsing across group and word frequency, showed a 27 ms inhibition effect at −100 SOA and a 17 ms inhibition effect at the +100 SOA. The reverse did not happen for phonological facilitation—phonological facilitation was 36 ms at the −100 SOA and 27 ms at the +100 SOA. Previous studies have observed phonological facilitation at negative SOAs of at least −150 ms (e.g., Jescheniak & Schriefers, 2001; Melnick et al., 2003; Meyer & Schriefers, 1991), which suggests that phonological activation from hearing the prime may linger over a period of time in short-term memory. In addition, there was no control over inter-item differences in the time course that the phonological and semantic information associated with each prime becomes available. These factors may have contributed to a mixture of trials at both SOAs where semantic and phonological priming effects occur. However, we suggest the SOA results do not compromise the interpretation of the semantic inhibition and phonological facilitation effects as being indicators of different encoding processes, namely, lexical selection via semantics and phonological encoding, respectively (Roelofs, 2005). The important finding in the present study is that these auditory priming effects were similar for PWS and the fluent speaking controls.

### *4.4. Phonetic planning and execution during choice and simple RT*

PWS were significantly slower than controls in the choice RT task. However, in the comparison between word and non-word responses the PWS were similar to the controls. According to Levelt and Wheeldon (1994, see, also, Levelt et al., 1999), during phonetic encoding, phonologically encoded syllables are transformed into abstract motor plans. Motor plans or gestural scores are retrieved from long-term memory (the mental syllabary) for familiar or frequently produced syllables or created online when the syllable is unfamiliar (see, also, Varley & Whiteside, 2001). The monosyllabic non-words used in the choice and simple RT tasks would have been unfamiliar to the participants; consequently, the gestural scores need to be computed online. Therefore, in verbal RT tasks that are sensitive to phonetic encoding, RTs for non-word responses should be slower than word responses. This prediction was confirmed in the choice RT task. That the lexicality effect is associated with response preparation is also confirmed by (a) choice RTs being longer than simple RTs, and (b) the absence of a significant lexicality effect in simple RTs. It is assumed that participants are able to plan or pre-prepare their verbal responses before the stimulus cue appears on the screen under simple RT response conditions (Klapp, 1995, 2003). Therefore, the time taken in response preparation, such as phonetic encoding, is excluded from the RT interval. Response preparation cannot be excluded from the choice RT interval because participants do not know which response to prepare and execute until the stimulus is presented.

If phonetic encoding is overall inefficient in PWS we predicted a larger difference in RT between word and non-word responses compared to controls. Alternatively, if PWS are slower to retrieve stored motor plans, but are not deficient in assembling new motor plans, as proposed by Venkatagiri (2004), then a reduced difference between words and non-words should be evident for PWS, or the PWS should be slower than controls in choice RT for words, but not for non-words. None of these predictions were confirmed. The word vs. non-word difference was similar for both groups, suggesting the efficiency of phonetic encoding is not markedly different between PWS and controls.

It might be argued that the lexicality effect in the choice RT task has a phonological rather than a phonetic origin. For example, it might take longer to retrieve non-words compared to words from phonological working memory following stimulus presentation (we assume, because only two responses are required in each block of choice RT trials, the phonology of both responses would be highly available in working memory at the time of stimulus presentation). We acknowledge that it is not possible to exclude a role of phonological encoding in the main effect difference between words and non-words in the present study. If that is the case the choice RT results support the findings for phonological facilitation in the picture naming task that the rate of phonological encoding is not markedly different between PWS and controls. We suggest, however, that there are grounds for assuming the lexicality effect is, at least in part, sensitive to phonetic encoding. The predictions are clear within the context of theories that distinguish between directly retrieved motor plans for frequent words and the construction of motor plans for unfamiliar words (e.g., Levelt et al., 1999; Varley

& Whiteside, 2001). Further, Levelt and Wheeldon (1994) provide independent evidence that syllable frequency does influence phonetic encoding. The stimuli were matched in terms of both phonological structure and diphone sequences to minimize phonological differences between the words and non-words.

The choice RT data are consistent with the findings of van Lieshout et al. (1996a, 1996b) who manipulated word length during choice verbal responding to target phonetic encoding in PWS. It was assumed that longer words take more time to prepare and that the difference between short and long words will, therefore, reflect the efficiency of phonetic encoding. In both studies the increase in RT for longer compared to shorter words was similar for both groups. To the extent that the word–non-word difference in choice verbal RT is sensitive to phonetic encoding, the present study provides support for their conclusion that phonetic/motor planning processes are not inefficient or slower in PWS.

### *4.5. Locus of deficit in verbal responding*

Verbal responding was significantly slower in PWS than controls only in the choice RT task. No differences were found in the experimental effects targeting lexical selection, phonological encoding, nor phonetic encoding, between PWS and controls. One implication we might draw from these results is that the group difference in choice RT is not associated with slower processing at those levels. Rather, we suggest some other process or combination of processes operating within the choice RT interval is responsible. Some possibilities will now be considered.

PWS may be slower to respond in the choice RT task because of inefficiencies in innervating the speech musculature during oral movement (Peters et al., 2000). Two aspects of the results are not consistent with this explanation. First, simple RT may be regarded as a more pure measure of response initiation because the RT interval excludes a range of intervening response selection and preparation processes (e.g., lexical selection, word form encoding, and speech motor planning) that increase variability and overall RT and may mask individual differences in initiation time. However, PWS were not significantly different from controls in simple RT. This concurs with previous research where differences in simple RT have not been found (e.g., McKnight & Cullinan, 1987; Sasisekaran et al., 2006). Other research has shown that the magnitude of the RT difference between PWS and controls tends to increase with linguistic complexity, suggesting other factors than differences in speech initiation are involved (Peters et al., 2000; Watson et al., 1991). Second, choice RT correlated with severity of stuttering, even after controlling for mean simple RT and mean picture naming RT. The significant association between choice RT and stuttering severity after controlling for speed of verbal responding, therefore, suggests choice RT is particularly sensitive to an individual difference in processing prior to execution that not only distinguishes PWS from normally fluent speakers, but also distinguishes severity levels among PWS.

There may be additional stages of word form encoding not tapped by the experimental manipulations used in the present study responsible for the group difference in choice RT. For example, Levelt et al. (1999) distinguish between the retrieval of phonological segments (and corresponding metrical frame) from lexical memory, and the process of phonological word encoding where phoneme segments are incrementally assigned to positions within a syllabified metrical frame. These aspects of word form encoding may even be localized in different parts of the brain (Levelt & Indefrey, 2000). Phonologically related auditory primes during picture naming may only facilitate the earlier stage of retrieving sub-lexical phonological units from lexical memory. Choice RT may be particularly sensitive to this later stage of phonological encoding. Studies investigating incremental phonological word encoding more directly, however, have used implicit priming tasks where verbal responses within a block of trials either share or do not share phonemes (e.g., Meyer, 1991). The implicit priming paradigm has been used with PWS (Burger & Wijnen, 1999), and no significant difference in the priming effect was observed relative to fluent controls (although, cf. Wijnen & Boers, 1994).

Alternatively, response preparation processes further downstream from phonetic encoding, captured within the choice RT interval but not the simple RT interval, may be involved. Levelt and Indefrey (2000) propose that subsequent to retrieving or assembling the gestural score of each planned syllable, additional planning processes are required for setting free parameters such as force and rate, to suit suprasegmental and pragmatic goals (see, also, Levelt et al., 1999). While this could be part of a completion process of phonetic encoding (Levelt et al., 1999), it might also be a function of the articulator, corresponding to the muscle command preparation stage, where gestural scores are translated into context-specific muscle activation commands (Perkell et al., 1997; Peters et al., 2000). This later stage of response preparation was not directly targeted in the present study, but could be deficient in stuttering. Peters et al. (2000) overview a number of findings consistent with such a deficit, including evidence of poorer force control when pressing lips against a force transducer (Grosjean, Van Galen, De Iong, van Lieshout, & Hulstijn, 1997), and differences in the dynamics of speech motor movement in tasks that require modification of speech rate. An explanation of this type, however, also relies on the assumption that choice RT is more sensitive to differences in muscle command preparation than picture naming. It is possible that differences in late stages of response preparation are weighted more strongly in choice RT compared to picture naming because the choice RT interval excludes variability associated with higher-level lexical search and retrieval from long-term memory. The stage of muscle command preparation, therefore, may be worthy of investigation in future choice verbal RT studies of stuttering to confirm and clarify the nature of this possible underlying deficit.

The final possibility we discuss recognizes the distinction between executive processes responsible for strategic control, including goal setting, and automatic processes employed to achieve those goals (Bosshardt, 2006; Monsell, 1996; Roelofs, 2003). For example, the central executive may be seen as responsible for coordinating and triggering automatic processes for task completion according to set goals or demands, as well as the management of attention and resource allocation to the slave systems such as those within working memory (e.g., the phonological loop, Baddeley et al., 1998) and word production (Roelofs, 2003). It is of interest to note that the components of lexicalisation we investigated may be viewed as predominantly automatic processes, as is assumed by Roelofs (2003, 2005), for instance. There is evidence to confirm that form based priming is automatic and not under strategic control (e.g., Jescheniak & Schriefers, 2001; Melnick et al., 2005; Meyer & Schriefers, 1991), and that strategic influences on semantic priming require relatively long SOAs between prime and target stimulus (e.g., something of the order of 250 ms or more, Neely, 1991, cited in Roelofs, 2003).

The increase in RT in the choice RT task observed for PWS may be associated with differences in executive or strategic control processing. PWS may take longer in response choice, that is, the decision-making process involved in flagging the correct response for output following stimulus identification (see, also, Bosshardt, 2006; Nudelman et al., 1992; Weber-Fox et al., 2004). This will slow RT without necessarily affecting the time course of the automatic speech production routines. Strategic control processes may alternatively impact more directly on the speech motor system. Self-monitoring of speech is regarded as an attention demanding control process responsible for detecting and initiating repair processes during production (Levelt, 1989). Excessive covert repairs of the speech plan triggered through pre-articulatory self-monitoring is fundamental to the covert repair hypothesis of stuttering (Postma & Kolk, 1993). Vasiç and Wijnen (2005) make a related point with the proposal that the self-monitoring mechanism in PWS may set relatively high criteria for the quality of motor plans before execution, causing a higher incidence of covert repairs and therefore speech dysfluencies. If PWS engage in excessive self-monitoring of internally generated speech before execution processes start (performing a type of a gate-keeping action), then response time will be delayed compared to normal speakers.

One limitation with the preceding suggestion regarding inefficiencies in strategic control is that PWS were not shown to be slower in picture naming (although there was a trend in that direction). Strategic control processes such as selecting lexical concepts according to task demands and self-monitoring of speech also operate during picture naming (Roelofs, 2003). In addition, some studies examining monitoring skills in PWS, as distinct from self-monitoring of internally generated speech, report no significant difference between PWS and controls (Sasisekaran & De Nil, 2006; Sasisekaran et al., 2006). Differences in cognitive load between tasks, however, might be a critical factor (cf. Bosshardt, 2006). For example, the choice verbal RT task may place stronger demands on working memory processes and require more cognitive resources for the purposes of response selection than picture naming. One challenge for future research would be to distinguish between inefficiencies in executive or strategic control and automatic linguistic/speech encoding as possible loci of slower verbal responding in PWS.

### *4.6. Conclusion*

Overall, the results of the present study have failed to confirm deficits in the automatic processes responsible for linguistic encoding in PWS. In particular, the implicit priming effects of semantically and phonologically related auditory primes on picture naming, and the word vs. non-word difference in choice RTs, were similar for PWS and controls, suggesting lexical selection, phonological and phonetic encoding processes are not inefficient. These results have failed to support the suggestion that linguistic encoding mechanisms provide an impoverished or delayed input to speech motor control thereby giving rise to disfluencies in speech. A limitation of this study is that we only examined word encoding, and so this conclusion cannot be extended to encoding larger units of speech such as grammatical sentences (cf. Cuadrado and Weber-Fox, 2003). Furthermore, these experimental effects represent just one way of targeting the functional organization of the underlying language system. Other experimental approaches may yield different findings (cf. Newman & Bernstein Ratner, 2007).

The PWS were found to be slower overall in choice RT, a finding unlikely to be due to deficits in speech initiation because differences were not found in the simple RT task. We considered a number of mechanisms involved in speech production outside of lexical selection and word form encoding that might explain this difference in choice RT. Deficient muscle command preparation immediately preceding execution is one possibility, as well as deficits in executive or strategic control impacting on higher level response selection or more directly on speech motor control, perhaps at the level of self-monitoring of speech. We acknowledge these suggestions are speculative only and not mutually exclusive. Finally, the results of this study are more consistent with language processes influencing speech production in adults who stutter by placing demands on cognitive resources, and in doing so perturbing a sensitive speech motor control system, than by providing deficient or delayed input to otherwise normal speech motor control.

## CONTINUING EDUCATION

### Speeded verbal responding in adults who stutter: Are there deficits in linguistic encoding?

## QUESTIONS

1. The notion that a linguistic *deficit* contributes to stuttering best fits with which explanation of stuttering?
   a. poor temporal coordination of the laryngeal and articulatory systems
   b. excessive self-monitoring triggers a covert repair
   c. speech motor control is susceptible to cognitive demands
   d. speaking under high-cognitive load creates anxiety that disrupts speech motor control
   e. phonological encoding is inefficient and triggers a covert repair
2. Phonologically related auditory primes can decrease picture naming reaction time relative to unrelated auditory primes because:
   a. the semantic attributes of the pictured object are more easily activated
   b. the auditory prime activates the phonemes shared with the target picture name
   c. the pictured object is more easily identified
   d. the speech motor control system is already primed for output
   e. all of the above
3. The difference in reaction time between producing words and non-words during the choice verbal reaction time task was used in this study as a measure of:
   a. lexical selection
   b. muscle command preparation
   c. phonological encoding
   d. phonetic encoding
   e. lexical-semantic activation
4. A key finding of this study is that:
   a. people who stutter were slower in choice verbal reaction time and yet they showed no difference from fluent speakers in the experimental indicators of the efficiency of linguistic encoding
   b. people who stutter were significantly slower in all reaction time tasks
   c. a difference was only found in the picture naming task with auditory primes
   d. people who stutter were not slower to produce verbal responses in any task
   e. none of the above
5. The findings of this study are consistent with which of the following conclusions?
   a. adults who stutter are not inefficient at phonological encoding
   b. processing outside of linguistic encoding is responsible for people who stutter to be slower in choice verbal reaction time compared to normally fluent speakers
   c. adults who stutter are not inefficient in their phonetic encoding
   d. linguistic encoding does not provide delayed or impoverished input to speech motor control in people who stutter
   e. all of the above

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## Appendix A

See Table A1.

Table A1
Stimuli used in the picture naming task with auditory primes

| Target picture | Auditory primes | | | |
|---|---|---|---|---|
| | Phonologically related | Semantically related | Unrelated | No prime |
| Low frequency | | | | |
| Beater | Beagle | Spatula | Football | Spinach |
| Bib | Beat | Apron | Gun | Tap |
| Button | Butter | Zip | Jelly | Princess |
| Crab | Craft | Prawn | Moor | Pole |
| Doll | Dot | Puppet | Tape | Ring |
| Drum | Drug | Cymbal | Lock | Belt |
| Flipper | Flicking | Snorkel | Hotdog | Onion |
| Gloves | Glob | Mittens | Gnome | Room |
| Hook | Who | Clip | Moon | Man |
| Jumper | Justice | Coat | Fork | Garnish |
| Kitten | Kingdom | Puppy | Journal | Ankle |
| Lamb | Latch | Calf | Night | Vase |
| Mouse | Mound | Rat | Lift | Bin |
| Parrot | Pancake | Eagle | Trolley | Spruce |
| Pig | Pill | Cow | Light | Mat |
| Tiger | Tiny | Lion | Money | Coach |
| Tongs | Toast | Scraper | Ear | Horn |
| Torch | Torn | Candle | Judge | Fig |
| Wallet | Waffle | Purse | Corner | Nail |
| Worm | Work | Snail | Ghost | Rose |
| High frequency | | | | |
| Baby | Basement | Child | Kennel | Lid |
| Bag | Bat | Sack | Den | Sun |
| Bottle | Bossy | Can | Candy | Package |
| Chicken | Chisel | Goose | Shoulder | Handle |
| Cross | Crop | Steeple | Brush | Floor |
| Dog | Dosh | Cat | Fork | Sand |
| Dress | Dread | Pants | Grape | Hip |
| Finger | Finish | Toe | Weasel | Dolphin |
| Glass | Glow | Cup | Sock | Coach |
| Head | Heat | Neck | Paint | Peach |
| Jacket | Jaffle | Blouse | Sieve | Orange |
| Leg | Left | Elbow | Kerb | Tool |
| Mouth | Mount | Nose | Nest | Yarn |
| Pencil | Penguin | Ruler | Terrace | Rhino |
| Pool | Poodle | Spa | Nerve | Germ |
| Table | Tail | Chair | Locker | Grenade |
| Train | Tray | Bus | Chalk | Pond |
| Tree | Treat | Bush | Bike | Pin |
| Wheel | Whale | Tyre | Attic | Shirt |
| Window | Whistle | Door | Coffee | Crossing |

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