

A Review of Evidence for the Covert Repair Hypothesis of Stuttering

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D evelopmental stuttering is a condition that is generally considered to have a prevalence of approximately 1% and a lifetime incidence of approximately 5% (Bloodstein, 1995). Its onset, which occurs most commonly between 2 and 5 years of age, is marked by a sudden and abnormal increase in the frequency and duration of stuttering-like disfluencies (SLDs) in a child's speech (Yairi & Ambrose, 1992).¹

ABSTRACT: This review examines evidence relating to the main postulates of A. Postma and H. Kolk's (1993) covert repair hypothesis: (a) That, in people who stutter, an abnormally slow rate of phonological encoding results in the incorporation of large numbers of phonological errors into the speech plans of their intended utterances, and (b) that their attempts to repair these errors, covertly, causes the symptoms of stuttering. Related hypotheses are also evaluated, including EXPLAN and the vicious circle hypothesis. The review concludes that, although the rate of phonological encoding may, under certain circumstances, be slower in people who stutter, this slowness does not result in the production of large numbers of phonological encoding errors. Furthermore, the covert repair of errors of phonological encoding cannot account for all instances of disfluency associated with stuttering. The evidence reviewed does, however, suggest that the more general phenomenon of error repair may play an important role in the development of persistent stuttering and that the rate of disfluency in stuttered speech is, in part, dependent on speakers' perceptions of the level of accuracy that specific speaking situations require. It also suggests that this may be an area where the covert repair hypothesis and related hypotheses may have a direct relevance to the clinical management of stuttering.

KEY WORDS: stuttering, covert repair, EXPLAN, vicious circle, phonological encoding

Although sometimes severe, this early stuttering, labeled by Bloodstein (2001) as *incipient stuttering*, is usually transient, with approximately 80% of children spontaneously recovering. Its most salient feature is the repetition of whole function words, most commonly pronouns and conjunctions, at the beginning of utterances (Bloodstein, 2001). If stuttering persists, the relative frequency of symptoms gradually changes and, in particular, function word repetitions decrease and repetitions of initial segments of content words increase (Howell, Au-Yeung, & Sackin, 1999). Persistent developmental stuttering (PDS) is also characterized to a greater extent by disrhythmic phonations and tense pauses or blocks, as well as an increased number of secondary symptoms (Bloodstein, 1995).

Traditionally, stuttering has most commonly been viewed as stemming from a speech motor disorder; however, in recent years, an accumulation of data has led a number of researchers (Perkins, Kent, & Curlee, 1991; Postma & Kolk, 1993; Wingate, 1988) to explore the possibility that stuttering may stem from an impairment of language processing.

The covert repair hypothesis (CRH) of stuttering (Postma & Kolk, 1993) is based on studies of the monitoring and self-repair of linguistic errors in normal speech by Hockett (1967/1973) and Levelt (1989) and also draws from the adaptation theory of aphasia (Kolk, 1995). This hypothesis attributes the repetitions, prolongations, and blocks of stuttering, as well as many of the disfluencies of normal speech, to the side effect of speakers' attempts to repair

¹Yairi and Ambrose's (1992) use of the term "stuttering-like disfluency" (SLD) includes (a) part-word repetition, (b) single-syllable word repetition, (c) disrhythmic phonation (sound prolongation and blocks), and (d) tense pause (audible tense vocalization between words). SLDs also occur in the speech of children and adults who do not stutter, albeit less frequently.

linguistic errors before they become expressed in overt speech. It proposes a mechanism to account for these different types of disfluency and also offers an explanation for why such disfluencies should occur more in some individuals than in others.

Although a number of researchers (Bernstein Ratner, 1997; Conture, Zackheim, Anderson, & Pellowski, 2004; Nippold, 2001, 2002) have undertaken reviews of studies that examine the role of linguistic factors in stuttering, there is still a lack of consensus regarding the status of the CRH. Thus, the intention of this current review is to examine, specifically, the extent to which published studies provide evidence to support or argue against the CRH.

HISTORICAL BACKGROUND

Error Repairs and Disfluency

Sometimes there can be no doubt that a speaker has made a speech error; for example, when phonemes have been transposed between words, as in the spoonerism *you've hissed my misty lessons* or when a blend of two semantically similar words occurs (e.g., *don't shell so loud!*). On other occasions, errors are less obvious and only become evident to the listener if the speaker attempts to repair them.

Errors per se do not normally disrupt the flow of speech; however, error repairs do. The extent of the disfluency resulting from a repair depends on the speed with which the error can be detected and the repair initiated. Speakers stand to gain an advantage if they are able to detect and repair errors as quickly as possible. In this regard, Hockett (1967/1973, p. 118) noted that he often caught and edited out linguistic errors in his own inner speech "before they could be mapped into overt speech by tongue and lips."

Such prearticulatory editing is possible because the formulation of an utterance in inner speech can be completed several seconds before its overt articulation begins. If, during this interval, there is enough time for a repair to be completed, there may be no overt signs of any error or repair ever having taken place. Hockett (1967/1973) named this process *covert editing*; although exactly how covert it is depends on how far the planning is in advance of articulation.

Occasionally, a speaker may have already begun articulating the first segment(s) of a word before realizing that later segments contain an error. On perceiving the error, his natural response may be to immediately interrupt his overt speech, retrace and start again from the beginning of the word, and thus avoid articulating the erroneous segment. From a listener's perspective, all that would be heard would be a repetition of the initial (correct) segment(s) of that word. If the speaker does this several times in a row, the result may sound to the listener like stuttering. Hockett (1967/1973, p. 114) thus proposed this as the mechanism underlying many of the SLDs in normal speech. However, he suggested that it could only offer a partial explanation for the "articulatory spasms of the pathological stutterer."

The CRH of Stuttering

In their CRH, Postma and Kolk (1993) extended Hockett's (1967/1973) hypothesis to explain the full range and extent of disfluencies that are characteristic of stuttering. They hypothesized that the speech-planning process of people who stutter (PWS) is impaired and tends to result in the production of phonetic plans that contain an abnormally large number of errors. Thus, whereas a normally fluent speaker can generally successfully (covertly) repair defective speech plans at the first or second attempt, when PWS try to repair or reformulate an erroneous speech plan, they may need to make many attempts before finally succeeding. These repeatedly unsuccessful attempts at covert repair result in a much greater degree of disruption to overt speech.

Because invariably the repetitions that are characteristic of stuttering consist of words or parts of words that the speaker wants to utter, Postma and Kolk (1993) suggested that they most likely result from repairs to errors of *phonological* encoding. They did not, however, entirely rule out the possibility that other types of linguistic encoding errors (e.g., semantic, syntactic, or morphological) might also play a role.

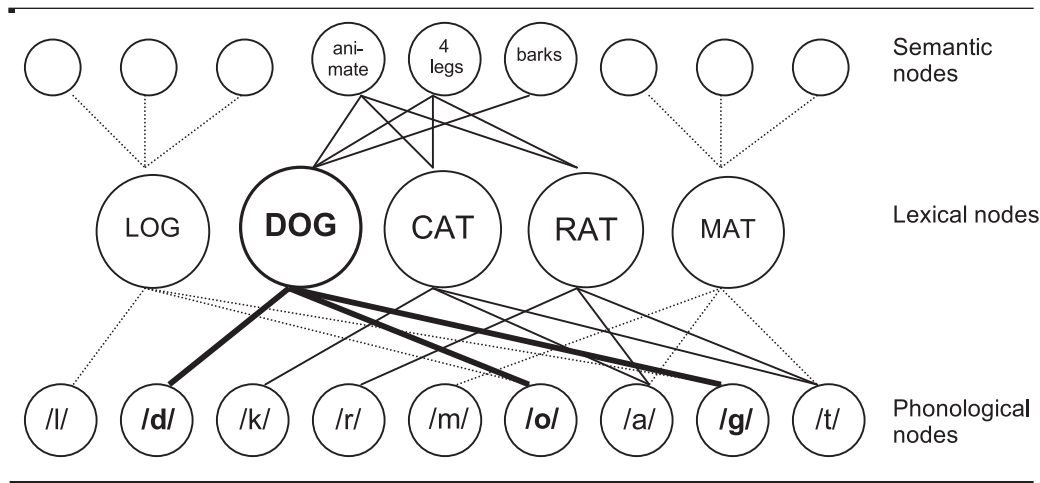
Postma and Kolk (1993) used spreading activation models by Dell (1986) and Dell and O'Seaghdha (1991) to explain a possible mechanism by which such a large number of phonological errors might arise in the speech plans of PWS. In these models, when a speaker attempts to formulate a potential utterance, a metrical frame of the planned utterance is first created and the phonological elaboration of this frame is then achieved through activation of appropriate *phonological segment nodes* in a neural network (see Figure 1). The nodes that fill the slots in that frame are those that have the highest activation levels at the moment that speech motor planning starts.

Postma and Kolk (1993) hypothesized that, with PWS, activation of phonological segment nodes is slow to build up. Therefore, it takes longer for the appropriate nodes to reach a level of activation that is unambiguously higher than that of other competing nodes (see Figure 2).

Thus, if PWS attempt to speak at a "normal" rate (whereby phoneme selection occurs, for example, at time point *s* in Figure 2), inappropriate phonological nodes are likely to be selected for the phonological frames they generate. Only by slowing their speaking rate (e.g., so node selection occurs at time point *s+*), can PWS be sure of selecting the correct phonemes for the frame and thereby ensure that the phonetic plan is error free.²

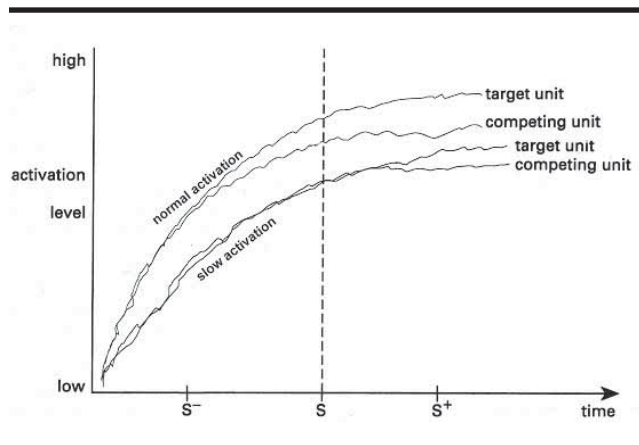
²The above model also predicts that if a normally fluent speaker attempts to speak at an abnormally fast rate (e.g., with phoneme selection taking place at *s-* in Figure 2), inappropriate phonological nodes are likely to be selected for the phonological frames that he generates. Thus, under such conditions, he would also be expected to produce either more speech errors and/or more covert error repairs, resulting in speech that closely resembles stuttering. Research that tests this prediction is outlined in the section entitled "Do the symptoms of stuttering result from speakers' attempts to covertly repair errors of phonological encoding?"

Figure 1. Structure of a spreading activation network for language processing. In this diagram, the three semantic features that are activated prime *Dog*; two also prime *Cat* and *Rat*. All of the phonological segment nodes shown are activated as a result. Backward activation is also possible, resulting in the activation of *Log* and *Mat*.



Note. From “Mediated and Convergent Lexical Priming in Language Production: A Comment on Levelt et al. (1991),” by G. S. Dell and P. G. O’Seaghdha, 1991, *Psychological Review*, 98, p. 605. Copyright 1991 by the American Psychological Association, Inc. Adapted with permission.

Figure 2. Phonological node activation and selection: comparing a normal versus a slow buildup of activation and demonstrating the impact of phoneme selection at three time points: *s-* (an abnormally fast speech rate), *s* (a normal speech rate) and *s+* (a slowed speech rate) (adapted from Kolk & Postma, 1997).



Note. From “Stuttering as a Covert Repair Phenomenon” (pp. 188–189), by A. Kolk and H. Postma, 1997. In R. F. Curlee & G. Siegel (Eds.), *Nature and Treatment of Stuttering: New Directions*. Copyright 1997 by Allyn & Bacon. Adapted with permission.

Research: Introduction

Because the CRH identifies slow phonological encoding as the underlying factor predisposing individuals to stuttering, the main focus of this review is on studies that shed light on the rate of phonological encoding in PWS and the relationship between encoding rate and phonological errors. However, fundamental to the CRH are also the presumptions that (a) the language monitoring abilities of PWS are

normal, and (b) the “errors” that they are attempting to repair are real and are not just illusions resulting from false or maladaptive beliefs regarding how accurate or precise utterances need to be. Research throwing light on these presumptions is, therefore, also outlined and evaluated.

Phonological Encoding in Children Who Stutter (CWS): Is It Impaired?

Studies documenting the prevalence of stuttering among children who have been diagnosed with phonological impairment have reported figures between 30% and 40% (Nippold, 2001). Such figures are much higher than the 5% that is commonly reported for children overall and are clearly suggestive of a link between stuttering and impaired phonological development.

Despite such reports, the observation that the symptoms of stuttering rarely appear before 2 years of age, a year or more after children have started uttering their first words (Bloodstein, 2001), suggests that children’s earliest attempts at phonological encoding do not result in stuttering.

The detailed review by Nippold (2002) of research investigating the relationship between stuttering and phonology concluded that there was still little consistent evidence to support the idea that stuttering is related to phonological impairment. Specifically, it concluded that CWS make similar numbers of systematic³ and non-systematic phonological errors as their nonstuttering peers and that the severity of their stuttering is not related to the number of systematic phonological errors that they make.

³*Systematic errors* refers to the systematic use of phonological processes, such as fronting and cluster reduction. Research by Yaruss and Conture (1996) suggests, however, that CWS do not perceive phonological processes as “errors.”

The review also failed to find evidence to suggest any significant qualitative or quantitative differences between the stuttering of children with and without phonological disorders despite the fact that the speech of children with phonological disorders contains, by definition, a higher number of phonological errors.

One possible explanation, suggested by Bernstein Ratner (1997), for the lack of hard evidence to equate stuttering with phonological impairment is that most researchers have relied on standardized tests of phonology to measure phonological impairment. Such tests, however, only measure the range of phonology used by children or the number of errors they make: They do not measure the rate at which phonological encoding takes place.

THE RATE OF ENCODING OF LANGUAGE AND PHONOLOGY IN CHILDREN

Priming Studies Involving Picture-Word Interference

Dell's (1986) spreading activation model of language encoding predicts that if phonemes, words, or syntactic structures are appropriately primed, the speed of their encoding can be increased and the number of encoding errors (and consequent opportunities for error repairs) can be reduced. Priming may thus help account for some of the well-documented fluency-enhancing effects of shadowing, choral reading, and reciting rhyming verses.

In a similar way, studies involving the experimental manipulation of priming can provide insight into the effects on participants' speech and language of variations in the rate of buildup of activation of phonological and other nodes.

In priming studies involving picture-word interference (Brooks & MacWhinney, 2000; Levelt et al., 1991), the effect of various linguistic primes on participants' speech response times during picture naming or picture description tasks is measured. This paradigm is particularly effective in controlling for the possible confounding effects of speech motor planning and execution because participants' verbal responses normally remain identical across conditions. It has also proved relatively easy to adapt for use with young children (Conture et al., 2004).

Recently, a series of such studies have compared the responses of young CWS (aged 3 to 6 years) and age-matched nonstuttering controls to phonological primes (Melnick, Conture, & Ohde, 2003), semantic primes (Hartfield & Conture, 2006; Pellovski & Conture, 2005), and sentence structure primes (Anderson & Conture, 2004).

All studies shared the same basic methodology involving presenting children with an auditory prime (i.e., a sound, word, or utterance similar or different to the target), showing them a picture of the target, and then recording the length of time the children took to initiate the required verbal response. The studies investigated whether the priming facilitated children's responses or slowed them down, and whether the responses of CWS differed from

those of age-matched controls. All of the CWS who took part in these studies had achieved normal (age-appropriate) scores on standardized tests of language and phonology.

Based on the findings of these studies (summarized in Table 1), the researchers concluded the following:

- Overall, the rate of phonological encoding is similar in CWS and in nonstuttering children (CNS). However, the differences found to exist between CWS and CNS in the relationship of articulatory mastery to speech response times suggest that the articulatory/phonological systems of CWS are less developed or less well organized than those of CNS (Melnick et al., 2003).
- CWS exhibit subtle difficulties with lexical (semantic) encoding (Pellovski & Conture, 2005) that may relate to differences in the ways they organize lexical information (Hartfield & Conture, 2006).
- CWS have difficulty rapidly and efficiently planning and/or retrieving sentence structure units—difficulties that may contribute to their inability to establish fluent speech-language production (Anderson & Conture, 2004).

A Holistic Priming Study

There is some evidence that, when first learning to speak, children process words holistically, and it is not until around the time of the vocabulary spurt that they start to switch, gradually, to an adult-like incremental form of processing in which the onset phoneme is encoded first (Walley, 1993).⁴

⁴The development of the ability to segment words into smaller units (and ultimately into phonemes) may result from the increased need to distinguish increasing numbers of phonologically similar words quickly and efficiently (Charles-Luce & Luce, 1990).

Table 1. Summary of the results of the various priming studies carried out by Conture and coworkers between 2003 and 2006.

Semantic primes (Pellovski & Conture, 2005)

CWS had significantly longer speech response times.
Priming effect on CWS: Slowing; on CNS: Facilitating

Semantic primes (Hartfield & Conture, 2006)

CWS had significantly longer speech response times.
Priming effect on CWS and CNS: Slowing (no significant difference between the two groups)

Sentence structure primes (Anderson & Conture, 2004)

CWS had significantly longer unprimed speech response times.
Priming effect on CWS and CNS: Facilitating
Primes had a significantly greater effect on CWS than CNS

Phonological primes (Melnick et al., 2003)

CWS and CNS had similar unprimed speech response times.
Priming effect on CWS and CNS: Facilitating (no significant difference between the two groups); however, controls' speech response times were related to their "articulatory mastery" (the range of phonetic realizations they have mastered), whereas CWS speech response times were not ($R^2 = .63$ for CNS, $R^2 = .01$ for CWS)

Note. CWS = children who stutter; CNS = children who do not stutter.

Influenced by the findings of Melnick et al. (2003), Byrd, Conture, and Odhe (2007) designed a further study to investigate whether the differences in the phonological systems of CWS and CNS may be related to differences in their abilities to switch from holistic to incremental processing. The study made use of a similar procedure to that used by Melnick et al., except that children's responses to both incremental primes (the initial consonant of the target word) and holistic primes (the vowel and coda of the target word) were measured and compared.

The results (summarized in Table 2) indicated that between 3 and 5 years of age, nonstuttering controls shifted from being significantly faster in the holistic priming condition to being significantly faster in the incremental priming condition, whereas the majority of CWS did not.

Conclusion

Standardized tests of phonology have repeatedly shown that the range and accuracy of the phonetic realizations that are produced by CWS and their nonstuttering peers is comparable. However, the results of the priming studies outlined above suggest that, compared to those of their nonstuttering peers, the language encoding abilities of CWS are subtly impaired. In particular, (a) CWS do not make the switch from holistic to incremental phonological encoding as early (Byrd et al., 2007), and (b) the rate with which they encode sentence structures is slower (Anderson & Conture, 2004).

The failure of the Melnick et al. (2003) study to reveal any group differences in participants' responses to phonological primes may be related to the fact that the primes used in that study contained not only the onsets but also the vowels of the target words. Thus, they may have facilitated both holistic and incremental encoding.⁵ Whatever the case, the findings of the Byrd et al. (2007) and Melnick et al. studies, when considered together, suggest that delay in making the change from holistic to incremental phonological processing does not affect the overall rate with which CWS are able to phonologically encode their words. Perhaps CWS' retained ability to encode words

⁵Priming studies by Wijnen and Boers (1994) and Burger and Wijnen (1999), covered in the following section, shed further light on this issue.

Table 2. Summary of the results of holistic priming studies that were carried out by Byrd, Conture, and Odhe (2007).

Holistic phonological primes at 3 years of age
Priming effect on CWS and CNS: Facilitating
Priming effect on CWS was not significantly different to the priming effect on CNS
Holistic phonological primes at 5 years of age
Priming effect on CWS: Facilitating; on CNS: No effect
Incremental phonological primes at 3 years of age
Priming effect on CWS: Slowing; on CNS: No effect
Incremental phonological primes at 5 years of age
Priming effect on CWS: No effect; on CNS: Facilitating

holistically compensates for and thus masks the impairment of their incremental encoding abilities, at least when their utterances consist mainly of single words.

Anderson and Conture's (2004) finding, that sentence structure encoding in CWS was slower than in controls, may help explain the observations that disfluency often increases around the time that children start attempting to incorporate syntactic structures into their utterances (Bernstein Ratner, 1997) and that young children rarely stutter on single words (Bloodstein, 2006). However, it is possible that syntactic encoding skills are dependent on the acquisition of the ability to segment words into phonemic units. Thus, poor sentence structure encoding abilities in CWS may arise as a consequence of delayed development of incremental phonological encoding skills. Further research is needed to clarify whether this is the case or whether impaired sentence structure encoding and impaired incremental phonological encoding represent two independent factors, both of which predispose children to stuttering.

Further research is also needed to clarify the somewhat more ambiguous findings of the Pellowski and Conture (2005) and Hartfield and Conture (2006) studies relating to the possibility that impairment of semantic encoding may also predispose children to stuttering.

PHONOLOGICAL ENCODING IN ADULTS WHO STUTTER (AWS): IS IT ABNORMALLY SLOW?

Three experimental paradigms have been used by researchers to examine the rate of phonological encoding in AWS: phonological priming, rhyme judgment, and phoneme monitoring.

Priming Studies

In two separate studies, Wijnen and Boers (1994) and Burger and Wijnen (1999) employed an implicit phonological priming paradigm in which AWS and nonstuttering matched controls were required to give fast verbal responses to visually presented cues. Each participant performed blocks of five such tasks in quick succession. Some blocks were *homogeneous* in that the five response words all began with the same consonant (C) or consonant-vowel (CV) combination and were thus self-priming (i.e., priming was "implicit"); other blocks were *heterogeneous* in that the five response words were phonologically unrelated and therefore not self-priming.

The speech response times of AWS and controls in the heterogeneous and the two homogeneous conditions were recorded, and the effect of implicit priming was calculated. The decision to test, separately, both C and CV primes stemmed from Wijnen and Boers' (1994) intention to structure the study to test both the CRH and Wingate's (1988) "fault-line" hypothesis.⁶

⁶Wingate's (1988) "fault-line" hypothesis posited that PWS have difficulty formulating rimes (i.e., nucleus and coda of syllables), especially if they are stress bearing.

In both studies, it was found that, under all conditions, the average speech response times of the AWS were significantly longer than those of the control group's. In both groups, CV priming significantly reduced these times.

The two studies, however, produced conflicting results with respect to the effect of C priming on participants' reaction times: In the first study, Wijnen and Boers (1994) found that the reaction times of the AWS were not significantly shortened by C primes (whereas the control group's were). This finding led Kolk and Postma (1997) subsequently to cite this study as evidence in support of the CRH.

The larger (and more rigorous) Burger and Wijnen (1999) study, however, failed to reproduce Wijnen and Boers' (1994) results. It found that, overall, both groups' reaction times benefited from C primes to a similar degree.

On the basis of their findings, Burger and Wijnen (1999) concluded that the results of the Wijnen and Boers (1994) study were unreliable and could not be considered to provide evidence of slow phonological encoding in AWS.

The reason cited by Burger and Wijnen (1999) for the discrepancy in the results of these two studies was that the AWS' responses to C primes varied widely between participants. Thus, in the Wijnen and Boers (1994) study, 6 of the 9 individuals in the AWS group responded to C primes in a similar way to the nonstuttering controls, whereas 3 did not show any significant response to C primes. The mixed responses to C primes by the AWS in the Burger and Wijnen study were similar; however, in that study, the nonstuttering controls also produced mixed responses to C primes.

Analysis. In light of the findings of the Byrd et al. (2007) study, which found that CWS are late in making the change from holistic to incremental processing, the question arises as to whether the participants who failed to respond to C primes in the Wijnen and Boers (1994) and Burger and Wijnen (1999) studies were perhaps still, even as adults, encoding some words holistically. Further studies using this paradigm are needed to throw more light on the reasons for the large degree of variation of responses to C primes.

Word and Rhyme Judgment Studies

In attempts to eliminate the possibility that AWS's longer speech response times such as those found in the above priming studies may be due to slower speech motor activity, the studies described in this and the next sections employ paradigms that do not require participants to make verbal responses.

In the first such study, Bosshardt and Fransen (1996) used a silent reading task to test whether AWS processed phonological and/or semantic information more slowly than did matched nonstuttering controls. A cue word was briefly displayed (in upper case letters) on a screen before starting and participants were then asked to monitor text (that appeared, one word at a time, in lower case letters on the screen) for (a) rhyming words, (b) categorically related words, or (c) identical words. Participants were asked to indicate matches by pressing a button. Judgments thus

involved translating graphemic representations into corresponding phonological forms and (where necessary) identifying rhimes or accessing the meanings of words.

The results showed that (a) the two groups were not different with respect to the speed of identical word identification; (b) both groups made similar numbers of errors; and (c) the AWS group was not significantly slower than the control group at identifying rhyming target words, but was significantly slower than the control group at identifying semantically similar target words.

Bosshardt and Fransen (1996) concluded that the two groups were equally efficient at lexical access and phonological encoding, but the participants who stuttered were slower at semantic processing of lexical information. Nevertheless, because the two groups' recognition-time scores for semantically similar words substantially overlapped, Bosshardt and Fransen concluded that slowness of neither semantic nor phonological processing could be considered a necessary or sufficient condition for stuttering.

In a similar study (Weber-Fox, Spencer, Spruill, & Smith, 2004), AWS and nonstuttering controls were required to judge whether or not pairs of orthographically presented words rhymed. Speech response times were measured directly by recording the time between presentation of the second word and onset of the event-related brain potentials (ERPs) caused by the rhyme judgment,⁷ thus completely eliminating the confounding effect of measurements based on any form of participants' overt motor responses. Pairs of orthographically presented words were either orthographically similar (e.g., wood-hood) or dissimilar (e.g., cone-own); half rhymed and half did not.

In three of the four conditions, the speed and accuracy of rhyme judgments made by the AWS and the controls were similar. However, in the fourth condition (identifying orthographically similar words that did not rhyme), the AWS were significantly slower than the controls.

Weber-Fox et al. (2004) interpreted these findings as indicating that phonological encoding is equally fast and accurate in both AWS and normal speakers when dealing with normal cognitive loads; but when cognitive load is increased (as in the task involving orthographically similar words that do not rhyme), phonological encoding becomes slower in AWS but not in normal speakers. Weber-Fox et al. further suggested that, as overt speech presents extra demands on cognitive resources, the speed and accuracy of phonological encoding in AWS may well be more adversely affected during overt speech than during inner speech alone. Nevertheless, they did not consider their findings to constitute evidence of any intrinsic weakness or fault in the capacity of AWS for phonological encoding itself.⁸

⁷A significant amount of normative data for rhyme judgements in fluent speakers already existed, and studies had repeatedly shown that the 350–450 ms poststimulus ERP is reliably larger for nonrhyming than for rhyming words.

⁸Smith and Weber-Fox (2007) recently cited the (as yet unpublished) results of a similar study with CWS between 9 and 13 years of age. In this study, the CWS were found to be less accurate and slower than age-matched controls in all four conditions.

Phoneme Monitoring Tasks

Phoneme monitoring involves similar processes to word and rhyme judgments, although, as individual phonemes are generally less salient than rimes, it is likely that monitoring them requires greater attention and more cognitive resources. Moreover, phoneme monitoring is entirely dependent on incremental phonological processing, whereas rhyme judgments may be possible on the basis of a more holistic phonological processing.

Two studies (Sasisekaran & De Nil, 2006; Sasisekaran, De Nil, Smyth, & Johnson, 2006) of (consonant) phoneme monitoring abilities of AWS have recently been carried out. Both involved silent picture naming in which the speed and accuracy of phonological encoding in AWS and non-stuttering controls was compared by asking them to monitor for specific consonant phonemes in the (bisyllabic CVCCVC) picture names in inner speech and indicate positive identifications by pressing a button. Probe-target matches were equally likely to occur in any of the four consonant positions.

In the first study, by Sasisekaran et al. (2006), participants were also tested for the speed at which they were able to (a) name a picture (using overt speech), (b) identify a 0.5 kHz pure tone among a selection of four serially presented tones (by pressing a button), and (c) respond to a single tone by pressing a button.

The main finding of this study was that, although the AWS group was as fast as the control group at identifying pure tones, the AWS group took significantly longer to identify phonemes in the picture names (see Figure 3). In both groups, target phonemes that occurred at the onset of words were detected significantly faster than in the other three positions, as is normal for incremental processing (Wheeldon & Levelt, 1995). Error rates and latencies for overt picture naming and simple motor tasks were similar in the two groups.

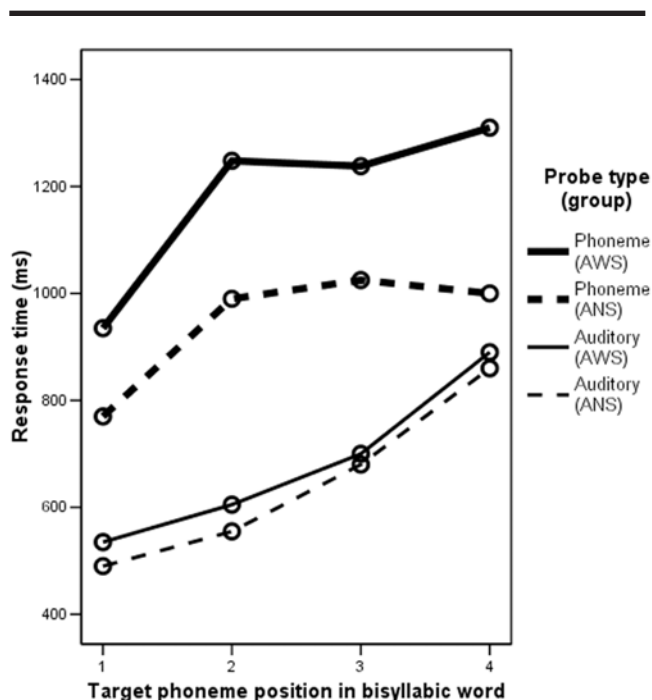
Sasisekaran et al. (2006, p. 15) concluded that “the poorer performance of the AWS group appeared to be specifically linguistic and attributable to processes involving the selection of phonological segments during encoding.” However, they did not rule out the possibility that it could be attributed to slower lexical access or a problem with the ability to store information in the speech buffer for comparison.

Sasisekaran and De Nil (2006) subsequently performed a study in which, in addition to performing the same silent phoneme monitoring and overt picture-naming tasks, participants were timed monitoring tape-recorded words for the same phonemes.

As the tape-recorded target words could be monitored without the need for phonological encoding, it was hypothesized that any difference between the two groups of participants on this test must result purely from differences in monitoring speed and not from differences in the speed of phonological encoding.

For the phoneme monitoring in silent speech condition, the results were similar to those of the Sasisekaran et al. (2006) study. In the phoneme monitoring in tape-recorded speech, a significant main effect for participant group was *not* found.

Figure 3. Time course of phoneme and auditory (pure tone) monitoring across four target positions in adults who stutter (AWS) and nonstuttering adults (ANS).



Note. From “Phonological Encoding in the Silent Speech of Persons Who Stutter” by J. Sasisekaran, L. F. De Nil, R. Smyth, and C. Johnson, 2006, *Journal of Fluency Disorders*, 31, p. 12. Copyright 2005 by Elsevier Inc. Adapted with permission.

Although Sasisekaran and De Nil (2006) did not entirely rule out the possibility of a delay in self-monitoring of the output of phonological encoding, they concluded that the lack of a significant main group effect for speed of phoneme identification in tape-recorded speech suggested that the general phoneme monitoring skills of the AWS group were in fact normal, and that the AWS group had “(delayed) activation and encoding of sound segments during silent speech production or... (delayed) self-monitoring of the output of phonological encoding” (Sasisekaran & De Nil, 2006, p. 295). They suggested that the results were fully in line with the CRH.

Analysis. The findings of the above two phoneme monitoring studies appear, at first sight, to contradict those of the rhyme judgment studies that failed to find a significant difference between the speed of phonological encoding in AWS and in fluent speakers. However, perhaps the different findings of these two paradigms could reflect the fact that the monitoring of individual consonant phonemes is, cognitively, a more demanding task and, as Weber-Fox et al. (2004) suggested, AWS only become slower at phonological encoding under increased cognitive load. It is also noteworthy that the probe consonants in these two phoneme monitoring studies were presented without any accompanying vowels, suggesting that the phoneme monitoring tasks relied entirely on participants’ phoneme segmentation abilities. In contrast, it is likely that rhyme

judgments can be made on the basis of a more holistic processing.

Nonword Reading Abilities of Adults With PDS

Packman, Onslow, Coombes, and Goodwin (2001) designed a study to explore whether or not lexical retrieval was a necessary condition for stuttering. The study employed a design in which 3 AWS read out loud a passage that was made up entirely of (phonotactically legal) nonwords, a passage of normal English prose, and then another passage of nonwords.

All 3 participants stuttered during the reading of the nonword passages, although the severity varied within and between subjects, being sometimes less and sometimes more than when reading the prose passage. All participants read the nonword passage more slowly, and although the participants clearly found the nonword passages difficult to read, there was no relationship between reading speed and stuttering rate.

Packman et al. (2001) interpreted the study results as providing evidence that stuttering can take place in the absence of lexical retrieval. They also suggested that the lack of a correlation between reading speed and stuttering rate meant that stuttering was not caused by the motor complexity of the speech task. In a commentary to the research, Au-Yeung and Howell (2002) subsequently added that, as nonword repetition involves phonological encoding, the study did not rule out the possibility of impaired phonological encoding being a necessary condition for stuttering.

Analysis. Despite its small sample size, this study appears to provide evidence that stuttering can occur in adults in the absence of syntactic and semantic processing and that these are, therefore, not necessary conditions for stuttering.⁹ This finding is especially relevant in light of Bosshardt and Fransén's (1996) finding that AWS are slower than controls at accessing semantic information and Anderson and Conture's (2004) finding that CWS encode syntactic information more slowly than do CNS.

Packman et al.'s (2001) argument for ruling out motor demands as a causal or contributory factor overlooks the possibility that at higher speech rates, participants may have paid less attention to repairing errors. Unfortunately, they did not publish details of the number of overt errors that were made by the participants.

Conclusion

Due to the covert nature of phonological encoding, all of the above studies have had to adopt indirect approaches to its measurement, and the accuracy of all of the studies' results are likely to have been compromised by difficulty controlling for the large number of potential confounding factors. Despite this, on balance, the studies outlined in this section suggest that, under conditions of normal

cognitive load, the overall rate of phonological encoding is probably not slower in AWS than in nonstuttering adults (see Table 3).

The tendency for AWS, as a group, to perform less well than nonstuttering controls at phoneme monitoring tasks may be because these tasks place greater demands on participants' linguistic processing capacities, and phonological encoding in AWS functions less well when language tasks are cognitively more demanding (Weber-Fox et al., 2004). An alternative possible explanation is that AWS continue to rely more on holistic processing, perhaps because, in AWS, the incremental processing skills needed to monitor phonemes are still relatively poorly developed.

The findings of Packman et al. (2001), that adults stutter even when reading strings of random nonwords, suggest that stuttering in adults can occur in the absence of semantic and/or sentence structure encoding.

DO THE SYMPTOMS OF STUTTERING RESULT FROM SPEAKERS' ATTEMPTS TO COVERTLY REPAIR ERRORS OF PHONOLOGICAL ENCODING?

A testable prediction of the CRH is that SLDs will be precipitated in normally fluent speakers whenever two conditions are fulfilled: (a) the speaker attempts to speak at a rate that is faster than his or her ability to encode phonetic plans accurately, and (b) the speaker attempts to repair the phonological errors that arise as a result. Conversely, when only the first of the above two conditions is fulfilled, the speaker's overt speech error rates should increase, but his or her disfluency rates should decrease. The following three studies test these predictions.

The Effect on Fluent Speakers of the Need to "Hold the Floor"

Blackmer and Mitton (1991) analyzed recordings of the conversations of (normally fluent) speakers while discussing emotive topics over a live radio chat line. Because speakers risked losing their conversation turn if they paused, they came under strong pressure to continue speaking regardless of whether or not they had had enough time to plan their next words.

It was found that utterances made under these conditions were characterized by very rapid multiple repetitions of short function words such as *is* and *I*. Although Blackmer and Mitton (1991) acknowledged that these rapid repetitions could theoretically be accounted for by a covert error repair mechanism, they suggested that they could more parsimoniously be accounted for by a primitive automatic restart mechanism, perhaps located within the articulator, that is activated whenever the speaker, for one reason or another, runs out of a new speech plan to articulate. In such circumstances, this type of mechanism would cause speakers automatically to continue repeating an already available word, thereby eliminating silent pauses and

⁹The possibility that nonword reading involves some rudimentary form of syntactic and semantic processing cannot, however, be ruled out entirely.

Table 3. Summary of processes occurring concurrently with phonological encoding in the reviewed studies of phonological encoding abilities of adults who stutter.

<i>Study</i>	<i>Condition</i>	<i>Articulation & voicing</i>	<i>Lexical access</i>	<i>Cognitive processing of semantic info</i>	<i>Holding info in working memory</i>	<i>Implicit priming</i>	<i>Findings</i>
Wijnen & Boers (1994)	Reciting with: Zero priming	yes	yes	no	yes		AWS slower than controls
Implicit priming	C & CV priming	yes	yes	no	yes	phonological	AWS slower than controls (less so with CV priming)
Burger & Wijnen (1999)	Zero priming	yes	yes	no	yes		AWS slower than controls
Implicit priming	C & CV priming	yes	yes	no	yes	phonological	AWS slower than controls
Bosshardt & Franssen (1996)	Identification of identical words phonologically	no	yes	no	yes		No difference between groups
Word monitoring	similar (rhyming) words	no	yes	no	yes		AWS group not significantly slower
	semantically similar words	no	yes	yes	yes		AWS group slower
Weber-Fox et al. (2004)	Rhyme judgments 1, 2, & 3	no	yes	no	yes		No difference between groups
Rhyme judgments	4 (nonrhyming orthographically similar words)	no	yes	no	yes		AWS group slower
Sasisekaran et al. (2006)	Phoneme monitoring	no	yes	no	yes		AWS group slower
Phoneme monitoring	(in inner speech) Overt picture naming	yes	yes	no	no		No difference between groups
Sasisekaran and De Nil (2006)	Phoneme monitoring	no	yes	no	yes		AWS group slower
Phoneme monitoring	(in inner speech) Phoneme monitoring (in recorded speech)	no	no	no	yes		No difference between groups

helping them maintain their conversation turn while further speech planning is completed.¹⁰

In an experiment designed to test this hypothesis further, Howell and Sackin (2001) asked 4 fluent speakers to tell a series of 3-min spontaneous stories. After two trials without feedback, the speakers were presented with a light bulb and were told that it would light up whenever their performance was judged to be poor. The bulb, in fact, lit up automatically whenever a silent pause of more than 600 ms occurred. Under these conditions, 3 of the 4 participants displayed a significant increase in the number of function word repetitions they made. They appeared to be using these easily accessible words as “fillers” to prevent any silent pauses in their utterances, thereby preventing the bulb from lighting up without needing to increase the rate at which they formulated new words. The pattern of rapid function word repetitions that emerged in both the Blackmer and Mitton (1991) and the Howell and Sackin (2001) studies resembled incipient stuttering.

The Effect of the Need to Speak Quickly on the Speech of Fluent Speakers

In another study (Howell & Sackin, 2000), 12 normally fluent participants were asked to give a running commentary to a fast-moving silent cartoon. It was found that whenever the speakers needed to formulate words and sentences more quickly in order to keep up with the cartoon, they produced increased numbers of part-word repetitions of *content* words similar to those that were made by people with PDS.¹¹ Howell and Sackin interpreted this finding as suggesting that the part-word repetitions that are characteristic of PDS result from responding to time pressure by attempting to begin articulation of content words before the speech plans for those words are sufficiently complete.

Howell and Au-Yeung (2002) subsequently suggested that the most parsimonious explanation for the above findings is that SLDs (in both normal and stuttered speech) arise when the speech plan for a word to be uttered is simply *incomplete* at the time when the speaker needs to begin speaking. Specifically, whole-word repetitions result from a “stalling strategy” that involves repeating an already available speech plan in order to avoid silent pauses, whereas part-word repetitions (and perhaps also blocks) result from an “advancing strategy” in which, in an attempt to increase speech rate, a speaker commences execution of incomplete speech plans in the hope that his or her final segments will have become complete by the time they are needed. Howell

¹⁰Although Postma and Kolk (1993) also acknowledged that such an automatic restart mechanism may exist, they suggested that it can only account for a small proportion of SLDs. Moreover, they stated (1993, p. 480) that “diadochokinetic rates are undoubtedly under the speakers’ executive voluntary control,” implying that even the fastest repetition rates were within the limits that could be accounted for by the CRH.

¹¹Part-word repetitions occurred in 8.5% of the tone units uttered at a rate of less than 4 syllables/s and in 17% of those uttered at a rate of greater than 5 syllables/s.

and Au-Yeung named this the “EXPLAN” hypothesis to highlight the fact that it attributed SLDs to dissynchrony between speech execution and planning.

Analysis. The CRH predicts that SLDs arise when an individual monitors his or her inner speech, finds errors in it, and attempts to repair those errors. If such error monitoring is prevented, SLDs should largely disappear and, instead, *overt* error rates should substantially increase. In contrast, EXPLAN predicts that SLDs will occur whenever the articulation rate exceeds the planning rate irrespective of whether or not phonological errors are encoded into the phonetic plan and irrespective of whether or not monitoring for errors takes place.

The conditions that were encountered by speakers in the three studies described above required them to focus their attention on factors other than the phonological accuracy of their words. The CRH predicts that under conditions such as these, where error monitoring is not a priority, the number of SLDs that speakers produce should *decrease* and the number of overt speech errors should increase. The fact that SLDs *increased* in the Howell and Sackin (2000, 2001) studies, despite the probable diversion of attention away from error monitoring, thus appears to support the EXPLAN hypothesis rather than the CRH.¹²

The extent to which the disfluencies produced by the participants in the fast speech rate experiment (Howell & Sackin, 2000) resembled stuttering is, however, questionable. Although numbers of part-word repetitions increased dramatically, blocks, the other salient symptom of PDS, did not.

DUAL-TASK PARADIGMS

A number of studies involving dual-task paradigms have been devised with the specific intention of distracting speakers’ attention away from their inner speech and thus preventing them from monitoring it for errors. These studies have the potential to provide further evidence relating to the role that covert error repair plays in the generation of SLDs.

In one of the earliest such studies, Arends, Povel, and Kolk (1988) compared AWS’ and controls’ ability to just speak (the single-task condition) with their ability to speak while simultaneously performing a visual tracking task (the dual-task condition). Although the study involved speech tasks with various levels of difficulty, only the most demanding speech task (which involved reciting a fairy tale) precipitated significant levels of disfluency.

It was found that, with the most demanding speech task, the frequency of disfluency and percentage of time disfluent under dual-task conditions was significantly less than under single-task conditions. Differences between single- and dual-task scores were not significant for easier speech tasks or with participants whose stammering was less severe. Arends

¹²Unfortunately, none of these studies reported the effect of pressure to hold the floor or speak quickly on the number of overt speech errors or the SLD/overt error ratio.

et al. (1988) concluded from these results that stuttering occurred when participants adopted a less automatic (and more controlled) way of speaking that focused more attentional resources on the production of speech.

A study by Vasić and Wijnen (2005) that compared disfluency rates in AWS when speaking with and without a visual distracter produced a similar decrease in disfluencies under the dual-task conditions. However, when the visual distracting task was replaced by a *linguistic* distracting task,¹³ although again the overall frequency of disfluencies (most of which were blocks) decreased, the frequency of word repetitions increased.

Vasić and Wijnen (2005) interpreted this finding as indicating that the mechanism underlying the production of blocks is different from that underlying the production of (part- and whole-word) repetitions. Specifically, they suggested that blocks are the result of error repairs, whereas repetitions are the result of EXPLAN-type automatic restarts. Thus, Vasić and Wijnen suggested that, in the linguistic distracter task, participants' ability to monitor their speech for errors was reduced, causing them to make fewer error repairs and hence fewer blocks; but the increased load on linguistic resources caused them to formulate their speech plans more slowly and thus make more automatic repetitions in a way similar to that proposed by EXPLAN.

In two other dual-task studies (Bosshardt, 1999, 2002) involving secondary linguistic tasks (mental calculations and silent reading/word memorization) while repeating word strings, it was found that AWS were more disfluent under dual-task conditions, whereas controls remained unaffected. The increase in disfluency in the AWS was especially pronounced when words to be silently memorized were similar to those to be read out loud. Bosshardt (2002) interpreted these findings as indicating that phonological encoding in AWS becomes more error prone when other phonological information is processed concurrently. Unfortunately, exactly what types of disfluency increased under the dual-task conditions in these two studies was not specified, so it is not possible to determine whether or not the increase in disfluency was due specifically to an increase in repetitions, as found in the second of the two Vasić and Wijnen (2005) experiments. Moreover, because the types and rates of (overt) speech error were not recorded in any of the above studies, they do not inform us regarding the CRH's other prediction—that as monitoring of inner speech decreases, overt phonological error rates should increase. (However, see Postma & Kolk, 1990, 1992 in the following section.)

Conclusion

Although both the CRH and EXPLAN appear to provide plausible explanations for the occurrence and attributes of SLDs in both normal and stuttered speech, EXPLAN is better able to account for the finding that whole- and part-word repetitions continue to occur even when speakers'

¹³The linguistic distracter involved participants monitoring their speech for instances of a particular word.

attention is distracted away from error monitoring. Conversely, the CRH may better explain why pressure to speak quickly does not appear to induce normally fluent speakers to block.

It is possible that covert error repair mechanisms and autonomous restart mechanisms of the type described by EXPLAN operate side by side, although further research is needed to confirm (or reject) Vasić and Wijnen's (2005) suggestion that blocks are related specifically to error repair mechanisms whereas word repetitions result from autonomous restart mechanisms.

None of the research findings described in this section provides any firm evidence that SLDs arise specifically as a result of errors or delay in the encoding of the phonetic plan. Rather, the possibility that SLDs can occur in the absence of error monitoring suggests that they may be caused by impairment of processes that occur downstream from the encoding of the plan, such as its retrieval from the articulatory buffer or its parameterization in preparation for execution.¹⁴

LANGUAGE MONITORING: DOES THIS FUNCTION NORMALLY IN PWS?

The CRH posits that language monitoring mechanisms function normally in PWS and that the linguistic errors that are detected are real and not just imagined. An alternative view expressed by Vasić and Wijnen (2005) is that (a) the focus of language monitoring in PWS is too rigid, (b) PWS pay too much attention to language monitoring, and/or (c) PWS entertain linguistic acceptability criteria that are so strict that they lead to the initiation of unnecessary error repairs.

A number of models have been developed to explain the mechanisms by which monitoring for errors may be carried out (Laver, 1969/1973; Levelt, 1989; Levelt, Roelofs, & Meyer, 1999; MacKay, 1987; Motley, Camden, & Baars, 1982). Each of these models leads to different predictions regarding which aspects of speech and language are available for monitoring and how quickly monitoring can be accomplished (see Blackmer & Mitton, 1991, and Postma, 2000, for an overview).

Because the CRH uses Levelt's (1989) "perceptual loop" model of speech production to account for covert error repair, the methods of language monitoring suggested by this model will first be briefly outlined.

Levelt's (1989) Perceptual Loop Model

In this model, the detection of one's own speech errors first requires speech to be parsed by the "speech comprehension system." It thus involves processes similar to those used to understand the speech of other people. Importantly, it is considered to be (a) at least partially under conscious

¹⁴Kolk and Postma (1997) originally ruled these possibilities out on the basis that the stages of motor programming are not available for monitoring by a perception-based monitor.

control, (b) mediated by attention, and (c) dependent on the availability of sufficient cognitive or attentional resources. The extent to which such monitoring occurs is thus seen as being largely context dependent.

Messages are generated in a number of stages, each of which takes place in discrete and independently functioning modules (see Figure 4). First a preverbal message is generated in the “conceptualizer.” It is then passed to the “formulator,”¹⁵ where it is converted, via a number of linguistic encoding processes, into a phonetic plan (frequently referred to simply as the “speech plan”). This plan may then be passed to the articulatory system.

Monitoring is believed to be carried out consciously by a monitor located within the conceptualizer (the same module that generated the original message), which allows individuals some flexibility over which aspects of speech or language they focus their attention on for monitoring purposes. Information to be monitored can be conveyed to the conceptualizer via any of three different feedback loops: (a) the *conceptual loop*, which enables preverbal messages (ideas) to be monitored for appropriacy; (b) the *inner loop* (usually equated with “inner speech”), which enables early detection of linguistic errors. It also offers a

¹⁵The network of semantic, lexical, and phonological nodes described by Dell (1986) could also be seen as comprising a formulator.

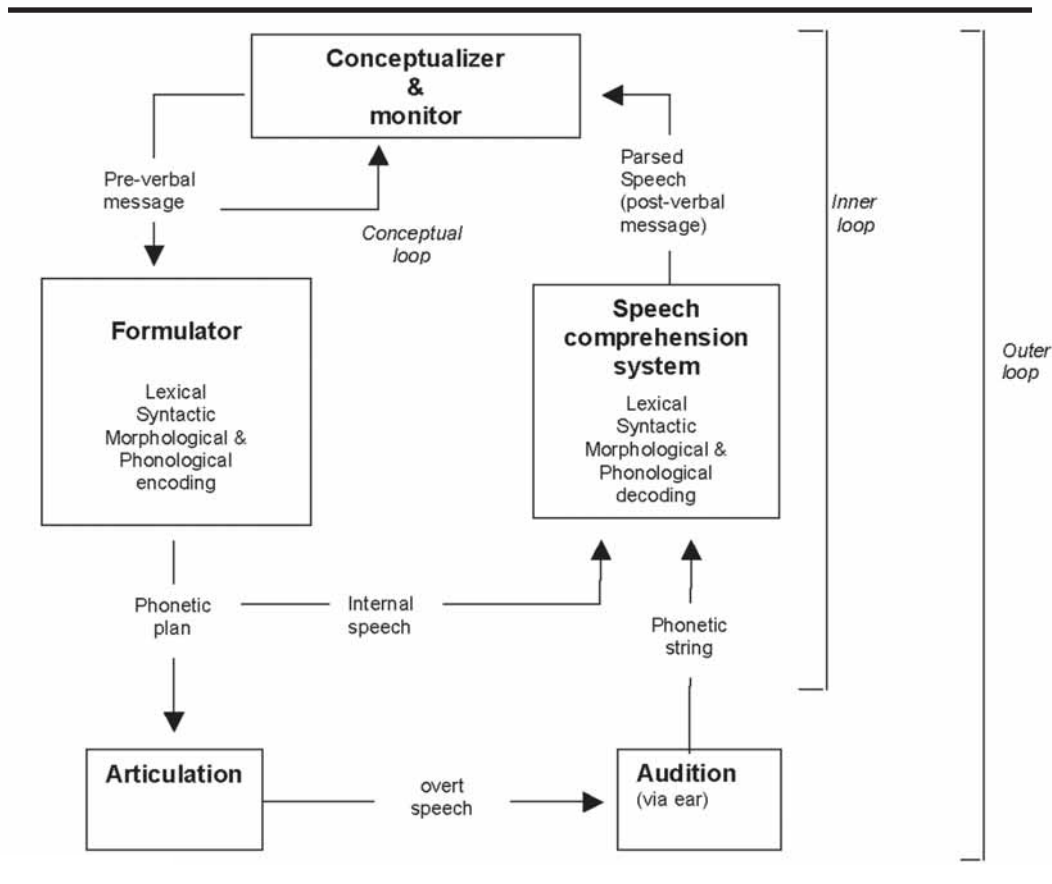
second chance for inappropriate messages to be detected; and (c) the *outer loop*, which enables detection of motor execution errors as well as linguistic and appropriacy errors. The covert editing or repair of linguistic errors is, however, only possible through the inner loop.

The “speech comprehension system” effectively does the opposite to the formulator: It converts both inner and overt speech into the same format as the original preverbal message before forwarding it to the conceptualizer. In so doing, it enables a direct comparison to be made between the original preverbal message and the message that was decoded from inner and overt speech and, if necessary, repairs/replacement messages can then be generated.

Outline and Evaluation of Relevant Research

Overt errors and error detection abilities of AWS and controls. To assess the language monitoring abilities of AWS and, in particular, to examine the functioning and relative importance of the outer (auditory) and inner loops in speech error detection, Postma and Kolk (1992) carried out a study in which 18 AWS and 18 matched controls had to first memorize and then repeat out loud, as fast as possible, a variety of 4-syllable strings and press a button whenever they noticed themselves uttering syllables in the wrong order or with incorrect sounds. The two groups then

Figure 4. Levelt’s (1989) model of speech production and monitoring



performed the same task while they were subjected to white noise. Finally, participants listened to a recording of someone else reciting the same syllable strings and were asked to press a button on noticing such speech errors in the recording. It was hypothesized that these three conditions, respectively, tested participants' use of (a) both inner and outer loops combined, (b) inner loop only, and (c) outer loop only.

The main findings noted by Postma and Kolk (1992) were that, in both the normal speech and the noise-masked conditions, error detection and false alarm rates of AWS did not differ significantly from those of controls. Also, the two groups' error detection latencies were similar, in both their own speech and recorded speech. However, the AWS achieved a significantly poorer error detection rate when listening to recorded speech. On the basis of these findings, Postma and Kolk concluded that the monitoring of self-produced speech by AWS is not defective. They also suggested that the failure of the AWS to identify as many errors in recorded speech was related to their poorer ability to remember the original syllable strings when they were not required to repeat them themselves.

Analysis. Despite the similar responses noted above, the AWS did respond differently to the controls when auditory masking was applied. In particular, the disfluency and (overt) error detection rates of the AWS decreased whereas those of the controls did not (see Figure 5). The reason that Postma and Kolk (1992) failed to find a significant group by noise masking interaction effect with respect to speech error detection rate is unclear.¹⁶

The decrease in disfluency rate of the AWS under auditory masking conditions reflects the well-documented observations that (a) stuttering diminishes under auditory

masking conditions (see Bloodstein, 1995, and Wingate, 1970, for reviews), and (b) this increased fluency is achieved without any loss of speed or accuracy (Maraist & Hutton, 1957; Sutton & Chase, 1961). These effects of auditory masking are not predicted by the CRH. Indeed, as speech rate generally increases under auditory masking conditions, the CRH predicts that either disfluency rate or overt error rate (or both) should also increase. This inability of the CRH to offer a parsimonious explanation for the fluency-enhancing effects of auditory masking represents a significant weakness of the hypothesis.

Should future research confirm that error detection rates in AWS also decrease under auditory masking conditions, this would suggest that, unlike normally fluent speakers, AWS rely strongly on the monitoring of auditory feedback for the detection of linguistic errors.

Maladaptive monitoring for disfluencies in PWS. The idea that AWS are hypersensitive (or hypersensitized) to disfluencies has been a recurrent theme in stuttering theory, having been stated in various forms by Johnson (1943), Sherrard (1975), Kamhi and McOsker (1982), and Vasić and Wijnen (2005).

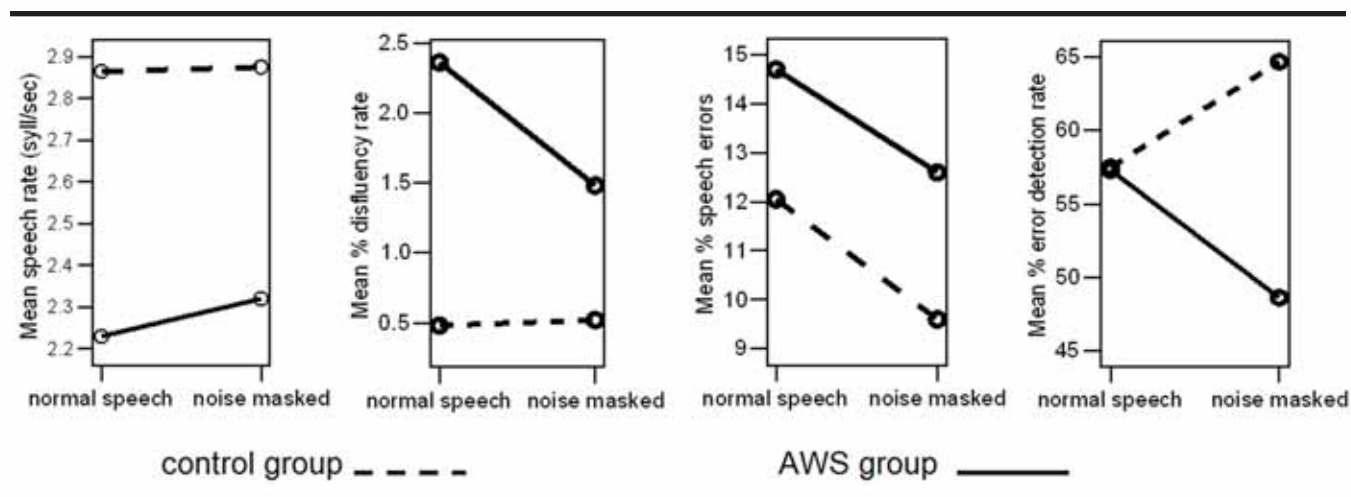
In this regard, a recent study by Russell, Corley, and Lickley (2005), which compared disfluency ratings made by stuttering and nonstuttering raters of speech samples spoken by both AWS and fluent speakers, found that raters who stutter tend to rate disfluencies more harshly than do raters who do not stutter, regardless of whether the samples they listened to were spoken by AWS or fluent speakers.

A study by Postma and Kolk (1990) investigated the impact of speakers' subjective judgments regarding what constitutes an acceptable level of disfluency on their speech. It compared the number of overt speech errors and disfluencies uttered by 12 AWS and 12 controls (a) when they were instructed to speak normally and (b) when they were instructed to speak as accurately as possible.

Analysis of the results showed that, in the normal speech ("low accuracy") condition, both groups made a similar

¹⁶Postma and Kolk (1992, p. 1027) commented that "Chi-square tests for overall (error) detection percentages revealed several significant group and speech condition differences," but did not specify which differences were significant.

Figure 5. Graphs showing (a) average speech rate, (b) percentage of syllable strings uttered disfluently, (c) percentage of actual speech errors, and (d) percentage of errors detected. These graphs have been derived by the current author from data presented in Postma and Kolk, 1992. (Originally CV and VC scores were presented separately; here, they have been combined)



number of speech errors, and the AWS produced approximately 2.5 times as many disfluencies as the controls. When trying to speak with high accuracy, compared to the controls, the AWS produced many more disfluencies (see Figure 6). The ratios of disfluencies to (overt) speech errors were found to increase significantly when high accuracy was required: This increase was significantly greater in the AWS group than in the control group.

Postma and Kolk (1990) concluded that these results could best be explained as resulting from two factors: (a) Focusing on high accuracy increased the cognitive resources allocated to phonological encoding, thus reducing errors; and (b) When trying to speak accurately, the AWS engaged in a greater number of covert self-repairs. This kept their overt speech error rate similar to that of the controls but led to an elevated level of disfluency. Thus, by attempting to speak more accurately, the AWS made fewer overt speech errors but were more disfluent.

Postma and Kolk (1990) did not specify the extent to which speech rate was slowed in the high accuracy condition. Nevertheless, they ruled out the possibility that a slower speaking rate had been responsible for the reduction in errors on the basis that that would have caused a corresponding reduction in disfluencies. Such a reduction was not found.

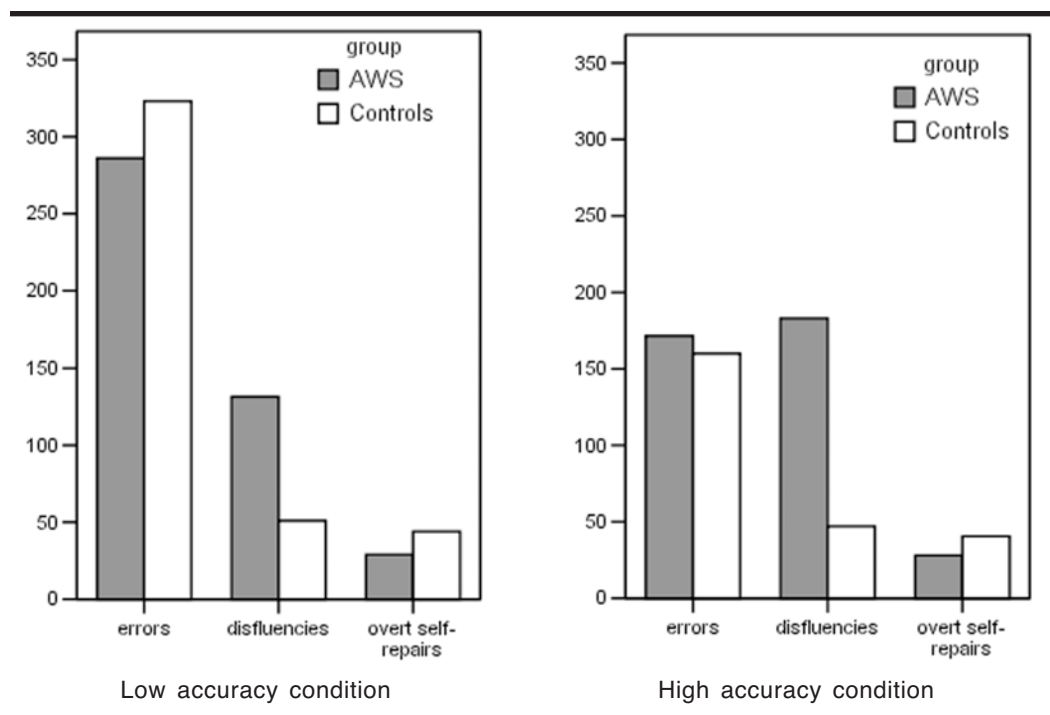
The findings of this study support the hypothesis that PWS sometimes make maladaptive judgments concerning the best strategy for them to achieve an optimal level of fluency and accuracy and, as Postma and Kolk (1990) suggested, PWS may benefit from being less concerned about the accuracy of their speech.

An error prevention hypothesis. An alternative explanation suggested by Howell (2003) for why increased accuracy requirements may lead to increased levels of disfluency involves the idea that node activation levels need to rise above a certain minimum threshold before they can be selected. Increased accuracy can thus be achieved by raising this threshold (see Figure 2). Howell suggested that this threshold regulation process operates at the level of the speech output buffer where phonetic plans are stored before execution (i.e., a level downstream from phonological encoding) and that only when activation levels of the contents of this buffer rise above a certain point can they be released for motor execution.

According to this hypothesis, the speaker's perception that a particular situation requires an increase in the level of speech accuracy would result in an automatic rise in the threshold. This would have an effect of slowing the rate at which words became available, thus reducing the number of phoneme selection errors in those words. Disfluencies could then be explained by the EXPLAN hypothesis.

Analysis. In addition to providing an alternative explanation for how accuracy requirements can affect repetition rates, this "error prevention hypothesis" also provides a parsimonious explanation for the occurrence of blocks. Specifically, if the activation threshold is raised too high, the release of words that are stored in the output buffer may be completely prevented. Importantly, the ascribing of a threshold requirement to the phonological output buffer, rather than to any of the processes of phonological encoding, implies that changes made to the threshold would not have any effect on inner speech. Thus if, due to the

Figure 6. Number of errors, disfluencies, and overt self-repairs made by AWS and controls while speaking in low and high accuracy conditions (data for normal sentences and tongue twisters combined) (derived from data in Postma & Kolk, 1990)



perception of a need for increased accuracy, a speaker's buffer output threshold suddenly rises, his inner speech would remain unchanged (i.e., it would remain equally fluent), whereas his overt speech would become less fluent but relatively free from errors.¹⁷ This hypothesis is, then, compatible with phenomenological evidence discussed below.

Monitoring of other aspects of speech production.

Monitoring of timing irregularities: The vicious circle hypothesis. If phonological errors are identified by a perceptual monitor in inner speech, as postulated by the CRH, it would be expected that PWS would report experiencing many such errors in their inner speech. This is, however, not the case. Moreover, the CRH has difficulties explaining the fact that successful subvocal rehearsal of a word in no way guarantees that stuttering will not occur during its subsequent overt articulation, even if articulation is attempted just a fraction of a second later.

This lack of reports of phonological errors in the inner speech of AWS led Vasić and Wijnen (2005) to suggest that stuttering may result from attempted repairs to some other aspect of speech or language and that, in particular, AWS may pay undue attention to subtle irregularities in the timing of words in their inner and/or overt speech. This excessive focus of attention on timing might predispose PWS to interpret such irregularities (that would otherwise have gone unnoticed) as "errors" and may result in the initiation of error repairs in a way similar to that originally proposed by the CRH.

Although at present, there is little experimental evidence to back up this hypothesis, a study by Lickley, Hartsuiker, Corley, Russell, and Nelson (2005) demonstrated that listeners perceived greater numbers of phonetic irregularities in recordings of fluent utterances made by AWS than in recordings of similar utterances made by nonstuttering controls. Moreover, listeners who stutter were more sensitive to such irregularities.

Clearly, stalling strategies and error repairs themselves both cause distortions of the originally intended timing of utterances, and it is therefore also possible that PWS may become trapped in a "vicious circle" in which minor timing irregularities lead to (unnecessary) repairs, which themselves cause further disruption to timing and thus precipitate further repairs.

This "vicious circle hypothesis" by Vasić and Wijnen (2005) potentially provides an explanation of why many of the more severe stuttering events continue to prevent speakers from moving forward despite their inner speech indicating to them that the phonetic plan, at the time of the disfluency, is free of phonological errors. Its postulate, that PWS monitor the timing of their utterances, implies, however, that they monitor *phonetic* representations (which are realized in time and reflect the real-time characteristics of the spoken words), and not phonological (phonemic) representations (which consist of discrete timeless segments), as originally posited by Kolk and Postma (1997).

In this regard, it is noteworthy that Kolk and Postma's (1997) rejection of the possibility that PWS monitor

phonetic representations for the detection of errors in inner speech was based on findings of a study involving phoneme monitoring in inner speech by Wheeldon and Levelt (1995).¹⁸ The participants in the Wheeldon and Levelt study were, however, all nonstuttering adults, so it is questionable whether the study's findings are applicable to PWS.

Monitoring of motor commands. A theoretical perspective developed by Max, Guenther, Gracco, Ghosh, and Wallace (2004) has recently challenged the Kolk and Postma (1997) conclusion that prearticulatory detection of errors of motor programming is not possible. According to this theoretical perspective, whenever a motor command is generated, a copy of the command (commonly known as efference copy or corollary discharge) is forwarded to a mechanism that uses a series of internal models to predict the commands' outcomes in advance, thereby enabling errors to be detected and adjustments to be made. Thus, it is possible that through the mechanism of corollary discharge, covert (prearticulatory) repairs to motor programming errors can indeed be made and may also act as an important source of SLDs. Because such errors occur downstream from the phonetic plan, they would be unlikely to affect inner speech, and the speaker might have no conscious awareness of this error repair process until (and unless) its effects became apparent in overt speech.

Max et al. (2004) also hypothesized that instability of these internal models (that interpret the corollary discharge from speech motor commands) may result in the production of "false alarms" and unnecessary attempts at error repair; the end result being the creation of abnormally large numbers of SLDs in overt speech. This theoretical perspective may be compatible with the vicious circle hypothesis but is not compatible with the CRH.

Conclusion. Contrary to the CRH, evidence reviewed in this section suggests that language monitoring in PWS does not function normally. Research by Lickley et al. (2005) has demonstrated that PWS are highly sensitive to minor phonetic irregularities in the speech of other people, and the lack of reports from PWS of errors in their inner speech supports Vasić and Wijnen's (2005) hypothesis that the errors that PWS are hypersensitive to are likely to involve minor phonetic irregularities rather than segmental phonological errors.

Such phonetic irregularities may be detected before their overt articulation as a result of monitoring the phonetic plan, or perhaps as a result of internal modeling from efference copy of motor commands (Max et al., 2004). Alternatively, they may be detected in overt speech as a result of the monitoring of auditory (external) feedback. They cannot, however, be detected through monitoring of abstract phonological representations. Unlike the CRH, the alternative hypotheses by Howell (2003), Max et al. (2004), and Vasić and Wijnen (2005) do not predict the occurrence of large numbers of segmental phonological errors in the inner speech of PWS. In this regard, they all provide

¹⁷Dell (1986) stated that, for reasons of simplicity, he did not include thresholds in his spreading activation model.

¹⁸Wheeldon and Levelt (1995) found that speakers monitored abstract phonological representations in their inner speech and, in so doing, achieved monitoring rates up to twice as fast as is possible through monitoring of phonetic representations.

explanations that are more compatible with the phenomenology of the condition.

Evidence reviewed in this section does, however, support the CRH's postulate that the requirements of specific speaking situations lead PWS to attempt levels of accuracy that are beyond their processing capacity (Postma & Kolk, 1990). Thus, PWS' attempts to adhere to standards of speech accuracy that they perceive as appropriate lead to excessive disfluency and possibly result in levels of functional communication that fall below what they are potentially capable of.

There is a need for future research to clarify these issues and perhaps also to explore the possibility that sensitivity to the phonetic qualities of speech may be related to the (Byrd et al., 2007) finding of delayed development of phoneme segmentation abilities.

SUMMARY

The Speed of Phonological Encoding

This review first examined evidence from key experimental studies relating to the speed of phonological and other forms of linguistic encoding in CWS and AWS. Studies involving young CWS have shown that most CWS use an age-appropriate range of phonetic realizations (Nippold, 2001, 2002) and are able to encode phonological information at a comparable rate to that of their peers (Melnick et al., 2003). They are, however, late in making the shift from holistic to incremental phonological encoding (Byrd et al., 2007), and they also tend to encode sentence structures more slowly than their peers (Anderson & Conture, 2004).

Rhyme judgment studies (Bosshardt & Franssen, 1996; Weber-Fox et al., 2004) and CV priming studies (Burger & Wijnen, 1999; Wijnen & Boers, 1994) that have investigated the rate of phonological encoding in AWS have generally found it to be normal. However, phoneme monitoring studies (Sasisekaran et al., 2006; Sasisekaran & De Nil, 2006) have repeatedly shown phonological encoding in AWS to be slower than in controls. These apparently contradictory findings may be explained on the basis that phoneme monitoring may be a cognitively more demanding task and, unlike rhyme judgments, it requires participants to encode words incrementally.

Evidence from Bosshardt (2002) and Weber-Fox et al. (2004) also suggests that phonological encoding in AWS becomes slower and more error prone under conditions of increased cognitive load, and especially when other phonological information is processed concurrently.

Taken together, these findings suggest that, perhaps due to a delay in making the switch from holistic encoding, the phonological encoding abilities of CWS and possibly also of AWS are less well developed than those of their normally fluent peers. When producing single word utterances, slowness of incremental processing may, however, be compensated for by a retained ability to make use of holistic encoding. The large degree of overlap in the rates of phonological encoding in PWS and normally fluent speakers indicates that slowness of phonological encoding

can, at most, only be a contributory factor in stuttering, not a sufficient cause.

Errors and Error Repairs

Although both Arends et al. (1988) and Vasić and Wijnen (2005) have produced evidence suggesting that AWS may habitually make more covert error repairs than normally fluent speakers, studies by Blackmer and Mitton (1991), Howell and Sackin (2000, 2001), and Vasić and Wijnen all suggest that the process of covert error repair is likely to account for only a proportion of the disfluencies that characterize stuttering. Thus, many of the repetitions and prolongations that are found in stuttered speech can be more parsimoniously accounted for as the result of a simple automatic restart mechanism that is activated when phonetic plans are incomplete at the time of articulation. More specifically, studies by Blackmer and Mitton and Howell and Sackin (2001) demonstrated that rapid repetition of function words, characteristic of incipient stuttering, can be triggered in normally fluent speakers by the need to hold the floor, whereas a study by Howell and Sackin (2000) demonstrated how externally imposed time pressure can trigger part-word repetitions of content words similar to those characteristic of PDS.

The relative importance of covert error repair in the generation of disfluencies remains unclear because studies that manipulate the frequency of stuttering have tended not to record co-occurring changes in the frequencies of overt phonological errors. However, phenomenological reports from AWS suggest that their speech plans do not contain excessively large numbers of phonological errors and stuttering can still occur even when speech plans are perceived to be complete and free of phonological errors. This lack of phenomenological support for the CRH suggests that, at least in adults, the impairment leading to stuttering may occur downstream from phonological encoding. A number of alternative hypotheses (Howell, 2003; Max et al., 2004; Vasić & Wijnen, 2005) that attribute the symptoms of stuttering to error repair or error prevention mechanisms downstream from phonological encoding are thus better able to explain the phenomenology of the disorder.

Monitoring

The CRH posits that self-monitoring for speech errors in PWS functions normally, and that PWS (correctly) identify abnormally large numbers of errors of phonological encoding in their inner speech. A study by Postma and Kolk (1992), however, found that, when listening to recorded speech, AWS identified fewer segmental phonological errors than did normally fluent speakers. In contrast to this, Lickley et al. (2005) and Russell et al. (2005) found that AWS were highly sensitive to subtle phonetic irregularities in recorded speech and, compared to normally fluent speakers, tended to judge all forms of disfluency more harshly.

These findings, together with the observation that AWS do not report being aware of abnormally high levels of

segmental phonological errors in their inner speech, suggest that stuttering is more likely to be related to self-monitoring for subtle phonetic irregularities (as posited by Vasić and Wijnen's (2005) vicious circle hypothesis) than to self-monitoring for segmental phonological errors (as posited by the CRH).

Monitoring of the phonetic aspects of speech is also likely to occur downstream from the encoding of the phonetic plan. A mechanism by which this may be achieved has been suggested by Max et al. (2004), who posit that prearticulatory monitoring of speech motor commands occurs through the interaction of internal models and corollary discharge. Such prearticulatory monitoring would enable the prearticulatory detection and repair of phonetic errors arising as a result of impaired motor programming. Moreover, instability of internal models themselves may result in the production of excessive numbers of phonetic errors due to the instigation of unnecessary error repairs.

CONCLUSION

Taken as a whole, the evidence presented in this review does not support the CRH in its strongest form. It does, however, suggest that error repair and/or error prevention mechanisms operate alongside more primitive automatic restart mechanisms, all of which play important roles in the production of the core symptoms of stuttering. A consideration of stuttering from these perspectives may provide a valuable theoretical framework around which future therapeutic approaches to stuttering therapy can be developed. A better understanding of these phenomena may also enable people with PDS to gain a greater degree of insight into (and hence control over) their disfluencies and to strike a more adaptive balance between the fluency and accuracy of their utterances.

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