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# The Use of Altered Speech Feedback in Prosthetic Stuttering Management

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## Abstract

Recent technological advancements in digital processing and miniaturization have made an inconspicuous and truly wearable prosthetic fluency enhancing device a reality. This manuscript provides an explanation of the fluency enhancing ASF phenomenon, and also discusses the prosthetic use of ASF from various theoretical perspectives. While fluency enhancing prosthetic devices have the potential of fundamentally altering how the stuttering disorder is managed, existing research already suggests that ASF is not a cure-all. Thus, it is suggested that choosing different types of stuttering managements is a personal decision based on the unique values and treatment objectives of each individual person who stutters.

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## Introduction

Although developmental stuttering is recognized as a chronic speech disorder with behaviors that are lessened or even eliminated in certain speaking conditions [4, 59, 66], a treatment offering the effortless elimination of stuttering behaviors spanning an entire lifetime has yet to be discovered [4, 59]. The use of alternative treatments, including prosthetic fluency enhancing devices -- either alone or combined with other forms of stuttering management -- may be considered as an appealing therapy alternative for some people who stutter [7, 58]. The purpose of this manuscript is to discuss the research and clinical implications regarding the use of prosthetic fluency enhancing devices in stuttering management.

## Basic Theories of Stuttering Improvement

### *Endogenous and Exogenous Fluency Induction*

A condensed, and perhaps oversimplified, explanation of the fluency induction phenomenon could propose that fluent speech can be temporarily produced in those who stutter via two basic methods: one being endogenous (or self-generated) changes in speech production, and another being exposure to specific forms of exogenous (or external) speech feedback during speech production [53, 59]. It has been suggested that a common element within the numerous endogenous fluency inducing techniques is the introduction of novel changes in speech production [4], which appear to be associated with reductions in stuttering behaviors [59]. Examples of endogenous stuttering reduction methods may include speaking in a foreign accent, syllable prolongations, easy vocal onsets, and other motorically-based speech therapies [4, 55, 59, 66]. As endogenous forms of fluency induction frequently appear to be associated with changes in speech production [59], some of the resulting (fluent) post-therapeutic speech has been documented as sounding unnatural [15, 23, 32, 50, 58], may require large amounts of cognitive effort to maintain [7, 58] and also may be difficult to apply consistently in real-word speaking situations [7, 8, 58]. Contrary to endogenous forms of fluency induction, exogenous forms use altered speech feedback (ASF), which has been documented to produce immediately, albeit

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transitory, stable and natural sounding fluent speech in those who stutter [1, 3, 32, 33]. Specifically, choral speech [CS; 4, 59], masked auditory feedback [MAF; 4, 27], delayed auditory feedback [DAF; 1, 4], frequency altered feedback [FAF; 20, 33], visual choral speech [VCS; 33, 56, 57], and delayed visual feedback [DVF; 56, 57] have been documented to reduce stuttering behaviors immediately by as much as 70 to 100% in some people who stutter [1, 33, 56]. The most efficient form of fluency enhancing altered speech feedback appears to use a 'second speech signal' [e.g., CS, DAF, FAF, VCS, DVF; 1, 33], which is a discrete speech signal presented at the same time as the speaker's primary speech signal, and contains speech gestures similar to those in the speaker's primary speech signal. For the best fluency enhancement, a second speech signal should be presented at the same time as the speaker's primary speech signal, thereby simulating choral speech [1, 53]. (This effect is achieved either by speaking in choral unison with another speaker, or from electronic alterations of the speaker's primary speech signal, which are then reintroduced to the speaker via headphones.) While exogenous forms of stuttering reduction excel at instantly producing stable and natural sounding fluent speech that requires significantly less cognitive effort than its endogenous counterpart [7], research suggests that the effects of ASF cease immediately when the speech feedback is stopped, and therefore has little, if any, carry-over of the fluency once the speech feedback has been removed [1, 4].

### *Models of Stuttering and Altered Speech Feedback*

With the absence of a universally recognized 'cause' or 'cure' for developmental stuttering [4, 55, 59, 66], it may be pertinent to discuss the use of ASF from different theoretical perspectives of the stuttering disorder. Since each theoretical perspective has its own distinct position on the various supposed etiologies and treatments for stuttering, each theoretical perspective also possesses unique attitudes and explanations of how and why the ASF phenomenon reduces stuttering behaviors. As the immediate, yet temporary, fluency enhancing effects of the ASF phenomenon have been repeatedly demonstrated in a variety of speaking situations [1-4, 7-10, 19-20, 27-34, 40-41, 53, 57-63], further discussion regarding the use of ASF should not focus on whether or not the phenomenon is effective, but instead focus on how this technology should be integrated into existing stuttering managements, or if it should be included at all. The following is a cursory discussion of certain aspects within the behavioral and neurolinguistic perspectives of stuttering, as they pertain to the ASF phenomenon. It should be noted that the two perspectives included within this manuscript were deliberately selected and artificially polarized to better highlight the issues surrounding the prosthetic implementation of ASF. In reality, these perspectives often overlap and share commonalities, as they both investigate the same disorder from differing points of view. Subsequently, the following discussion should not be viewed as comprehensive or definitive; those seeking further clarification or additional information should consider referring to the stuttering literature for a more thorough account of the various perspectives on developmental stuttering [4, 55, 59, 66].

#### *Behavioral Paradigm*

Most perspectives of the stuttering disorder associated with the behavioral paradigm share the principle that developmental stuttering most likely stems from some form of speech-motor, or speech-coordination, dysfunction [4, 6, 12, 19-17, 21, 35-36, 42-43, 54, 55, 59, 64-66, 69-70]. This perspective may suggest that the symptoms of stuttering can be reduced, if not potentially removed altogether, with corrective behavioral compensations performed during speech production [54-55]. Individual perspectives within this behavioral paradigm may also suggest that these corrective behavioral compensations could eventually habituate, and become unconsciously integrated into normal speech production, thereby greatly diminishing (or functionally eliminating) stuttering behaviors in everyday speech [54-55]. The recognition of these fundamental concepts becomes important, as certain points of view from within the behavioral paradigm may have originally cited ASF (i.e., DAF) as reducing moments of stuttering by behaviorally disrupting speech production, offering an external source of rhythm, or slowing down the rate of speech [4]. Thus, if it is to be believed that ASF induces fluency by initiating changes in motoric speaking behavior, then it could be

speculated that the use of ASF is unnecessary and redundant in the treatment or management of stuttering, as the same results can be achieved solely by behavioral methods. Furthermore, this perspective may suggest that the use of ASF is counterproductive in the treatment of stuttering, as it could deter clients from becoming self-sufficient in the execution of their stuttering management program.

### *Neurolinguistic Paradigm*

While the neurolinguistic perspective has yet to evolve into a single viewpoint that shares a common set of unified principles accounting for the etiology and treatment of developmental stuttering, this emerging paradigm does find commonalities in the belief that the etiology of stuttering most likely lies within functional neurological errors in speech preparation and/or sensory motor integration—such as linguistic processing and encoding [11, 25-26], sequential activation of linguistic planning and speech motor coding [51], speech gesture initiation [56-57], or certain aspects of speech monitoring [45-49, 52]. This perspective may label stuttering behaviors as a consequence of (or behavioral consequence to) the persistent neurolinguistic processing flaw existing at the central (neurological) level [10, 56-57] that is the stuttering disorder [10, 56-57]. Consequently, the neurolinguistic point of view might suggest that exposure to speech feedback (specifically in the form of a 'second speech signal') may enhance fluency by modifying speech-related neural activation patterns [5, 13-14, 22, 37, 44, 51-52, 67-68], which ultimately results in the execution of a neurolinguistic speech-motor program that is more compatible with the production of fluent speech [56-57]. Hypothesized restorative changes to the neurolinguistic processing may include, but are not limited to, an inhibition of the stuttered response [53], alterations of 'feedforward' and/or 'feedback' speech monitoring [45-49], activation of the auditory cortices [33, 52], or potentially bypassing endogenous speech gesture initiation altogether via an alternate premotor system [18, 56-57]. Thus, certain perspectives within the neurolinguistic paradigm may suggest that the transient nature of the ASF phenomenon is a result of alterations within speech-related neurolinguistic processing, encoding, and/or programming that take place both instantly and in real-time, thereby potentially accounting for the lack of fluency enhancing carry-over effects associated with the ASF phenomenon. While exogenous fluency enhancement (via speech feedback) lacks significant carry-over effects, the resulting stable and natural sounding fluent speech may be interpreted to suggest that ASF temporarily affects the etiology of the stuttering disorder itself, rather than its symptoms or behavioral consequences.

### *Summary of Differing Paradigmatic Views of Altered Speech Feedback*

Developmental stuttering is a very unique speaking disorder in that its symptoms are easily reduced or even eliminated, at least temporarily, by both endogenous and exogenous means. Those advocating the endogenous management of developmental stuttering may cite hundreds of successful behavioral treatment programs that have been documented over the past decades [4], and assert that endogenous forms of stuttering management can produce self-sufficient and successful results with time, effort, and practice [54-55]. The opposing view of primarily endogenous forms of stuttering management may suggest that its post-therapeutic speech often sounds unnatural, requires an unreasonable amount of cognitive effort to use, suffers from an unreasonably high incidence of relapse, and may never become automatic or habitual [7-9, 58]. Those supporting the prosthetic use of ASF will most likely note the immediate, stable, natural sounding, and relatively effortless enhanced fluency that the phenomenon produces [1-3, 7-9, 27-34, 53, 60-63]. However, individuals challenging the prosthetic use of ASF may refer to research suggesting that the fluency enhancement only occurs when the device is active and in use -- thereby potentially creating a dependence on the prosthetic aid (as stuttering behaviors will return if the prosthetic is removed), and also point out that long-term effects (i.e., adaptation and relapse) regarding the daily prosthetic use of ASF are untested.

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## **Brief History of Altered Speech Feedback**

### ***Choral Speech***

Stuttering research has repeatedly demonstrated that when a person who stutters speaks in (auditory) choral unison with other speakers, stuttering behaviors will be drastically reduced, if not completely eliminated [1-3, 10, 27-34, 60-63]. In addition, research also suggests that fluency is enhanced even if the choral 'second speech signal' is a stuttered or non-fluent speech signal [31].

### ***Masked Auditory Feedback***

Stuttering research has documented a consistent induction of fluency in those who stutter while speaking under conditions of masking noise [1, 4], and appears to gain efficiency and efficacy as the audible intensity of the masking noise rises [4]. Thus, while auditory masking is an effective fluency enhancer, it presents functional communicative obstacles (i.e., potential hearing obstruction) and possible discomfort due to the necessary intensity level auditory masking requires for significant fluency enhancement.

### ***Delayed Auditory Feedback***

While delayed auditory feedback has been documented as a significant fluency enhancer [1, 4, 27, 34, 61, 63], it may be pertinent to note that when DAF was discovered and initially researched, a prevailing view at the time suggested that stuttering was a behavioral speech disorder [4]. The initial explanations of DAF suggested that its fluency enhancing powers were a result of gross changes in speech production [4], which -- in hindsight -- probably can be associated with the extremely long delay in auditory feedback (e.g., 250 milliseconds) rather than speech feedback itself. Later research suggested that a delay as modest as 50 milliseconds was sufficient to enhance fluency in those who stutter [34, 40, 60]. More recent research suggests that the use of a shorter delay does not appear to significantly alter speech production, and appears to enhance fluency regardless of articulatory rate [34, 60-61].

### ***Frequency Altered Feedback***

The recognition of frequency altered feedback (or 'frequency shifted feedback') as a significant fluency enhancer [19, 20] was important in that it emphasized the concept that fluency was evoked via a 'second speech signal,' rather than an auditory delay. FAF has been documented to provide similar fluency enhancement to DAF [41]; combining DAF and FAF does not appear to provide any significant fluency enhancement [41].

### ***Visual Choral Speech***

Visual choral speech [33] (i.e. when a person who stutters speaks in unison with another speaker who is silently mouthing, rather than audibly speaking) is significant in that it evolved the concept of altered auditory feedback into altered speech feedback [56-57]. While this subtlety may initially appear to contribute little to the body of stuttering research, the implications include elevating exogenous fluency induction beyond the auditory sensory modality. This recognition of visual choral speech (and the fluency inducing capabilities of the visual sensory modality) is compelling some stuttering researchers to think about fluency enhancement from a different perspective; instead of associating exogenous fluency induction with the auditory sensory modality, researchers are beginning to understand the importance of the commonalities found within the speech signal, regardless of sensory modality, that may be sufficient to enhance fluency in those who stutter.

### ***Delayed Visual Feedback***

The documentation of fluency induction via delayed visual feedback [56] further supported the notion that the fluency enhancement via speech feedback phenomenon is a multi-sensory, rather than solely an auditory, phenomenon. While the ramifications of delayed visual feedback are still being researched, research suggests that both synchronous and asynchronous speech feedback enhances fluency

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regardless of sensory modality; DVF also demonstrates the potential fluency enhancing effects of common invariant characteristics found within the speech signal and speech production [56-57], such as the speech gesture [38-39].

### ***Summarizing Methodologies within Altered Speech Feedback***

While many forms of ASF have been documented to enhance fluency in those who stutter [1-3, 10, 19-20, 27-34, 41, 53, 56-57, 59, 60-63, 70], it has been suggested that ASF using a 'second speech signal' is a more efficient fluency inducer [4, 33], and therefore may be better candidates for prosthetic implementation. In addition, the 'second speech signals' associated with the auditory modality are suggested to be inherently easier to convert into a prosthetic device (such as a hearing aid) as opposed to methodologies utilizing the visual modality. (While auditory second speech signals, such as DAF and FAF, maybe the ideal candidates for prosthetic implementation, MAF may still be useful for some people who stutter, especially those who are prone to inaudible stuttering behaviors.) Although it is unknown precisely why second speech signals are such efficient fluency enhancers, early neurolinguistic theories generally contend that (externally-generated) choral speech (i.e., CS, VCS) may be a fundamental component of the fluency enhancement via a second speech signal phenomenon; other forms of (internally-generated) ASF (i.e., DAF, FAF, DVF) are theorized to functionally emulate (externally-generated) choral speech via alterations in the (internally-generated) second speech signal. Both synchronous (e.g., FAF) and asynchronous (e.g., DAF, DVF) forms of speech feedback have been found to induce fluent speech in those who stutter. Speech feedback has been documented to produce natural sounding fluent speech that remains stable in various speaking conditions, such as the telephone or in front of an audience [2, 70]. ASF also has been found to enhance fluency regardless of speech rate [19, 34, 41, 60-61], and continue to enhance fluency even when introduced monaurally, rather than binaurally [63]. While the ASF phenomenon has been repeatedly documented to enhance fluency in those who stutter, a single theory offering a commonly accepted explanation of the phenomenon has yet to emerge. In other words, despite the fact that ASF is documented as a significant fluency enhancer, current research cannot sufficiently explain how and why the stuttering behaviors are reduced.

## **Perspectives of the Prosthetic Implementation of ASF**

### ***Dependency on a Prosthetic Device***

The concern that a prosthetic fluency enhancing device would create dependency on ASF rather than a form of self-sufficient stuttering management may depend on how stuttering, as well as the daily consequences of stuttering behaviors, is perceived. If developmental stuttering is perceived as a behavioral disorder, then the use of an ASF prosthetic device would be unnecessary, and potentially detract from the effectiveness of endogenous stuttering managements. Within this perspective, some researchers or clinicians may suggest that an ASF prosthetic device is an illusive short-cut towards immediate stuttering reduction; this 'quick-fix' may ultimately inhibit a direct confrontation with a long-term self-sufficient (and self-reliant) solution to how stuttering is managed because users may become dependent on a prosthetic device to reduce their stuttering behaviors.

However, if stuttering is perceived as a chronic error in neurolinguistic processing, then a prosthetic ASF device could be perceived as a simple appliance that makes developmental stuttering significantly easier to manage. Furthermore, someone from this perspective may suggest that, despite treatment, developmental stuttering remains a chronic disorder -- and like every other chronic disorder (e.g., Arthritis; Asthma; Diabetes; Heart, Kidney and Liver disease; Multiple Sclerosis; Parkinson's disease), it may require a lifetime of constant (exogenous) management.

### ***Personal Acceptance of Self and Stuttering***

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There is little debate that the quality and enjoyment of life is associated with personal acceptance [24]. Thus, if a prosthetic ASF device is viewed as a crutch or an avoidance of stuttering acceptance, then it would be tempting to suggest that such a device would ultimately not be in the best interest for those in the stuttering population. In other words, there is a concern that the use of a fluency enhancing prosthetic device may prevent its users from coming to terms with themselves (as persons who stutter) and also their stuttering behaviors. However, there is not enough research or empirical evidence to support these notions; further testing and observation is needed. Furthermore, this perception assumes that the quality of life and personal acceptance of the stuttering disorder are directly related to stuttering severity -- a finding which research has yet to document[4].

### ***Prosthetic Implementation of ASF is in its Infancy***

Only with the recent technological advancements in digital processing and miniaturization has an inconspicuous and truly wearable prosthetic ASF device become a viable form of stuttering management. There has not been enough research or data to responsibly document the long term effects of consistent exposure to the prosthetic implementation of ASF (in the form of a second speech signal). This latter point may be exceedingly pertinent, as customized prosthetic devices often require a substantial financial investment. Even though this application of the ASF phenomenon shows promise and may drastically alter how stuttering is managed, the long term consequences (both positive and negative) are currently unknown, and currently being researched.

### ***The Divisive Nature of Prosthetic Stuttering Managements***

The development of prosthetic fluency enhancing devices for the stuttering population may be somewhat comparable to the development of cochlear implants for the deaf community in that a single device may (at least partially) obscure the very quality that creates the social minority. However, since there is no universally recognized etiology or functional 'cure' for the disorder, it seems reasonable to suggest that stuttering treatments should mirror the opinions, values, and therapeutic objectives of each individual person who stutters. Until a 'cure' for developmental stuttering is discovered, it is sensible to offer those who stutter as many treatment options as possible, thereby giving the stuttering population possibilities with which to manage stuttering behaviors.

## **Conclusions**

Without a definitive treatment for developmental stuttering, the field of speech-language pathology continues to serve the stuttering population by offering as many valid and reliable treatments as possible; however, it is ultimately the client's responsibility to become informed of the various approaches towards stuttering management, and pick specific treatments that best meets their needs. While the prosthetic implementation of ASF is compelling, research already suggests that it is a stuttering management, not a stuttering 'cure' [3]. With this in light, the inclusion of a prosthetic ASF device into a stuttering management program becomes a private choice that is determined by the personal values and treatment objectives of each individual client.

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