The Role of Sensory Modality in Fluency Enhancing Speech Feedback

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Abstract:

Speech feedback stimuli (e.g., metronomic pacing, auditory masking, side tones, second speech signals) is documented to enhance the production of fluent speech in those who stutter. In addition, this fluency enhancing speech feedback phenomenon often remains effective when presented across a variety of sensory modalities, including audition, vision, and tactition. However, although there is substantial research examining various speech feedback stimuli, little research has focused on the role sensory modality within the fluency enhancing speech feedback phenomenon. Therefore, the purpose of the present study is to investigate the role of sensory modality in the fluency enhancement phenomenon, and to document any differential effects that it may have in the enhancement of fluent speech production. Accordingly, this study measures the effects of a single speech feedback stimulus, when presented over a combination of productive and sensory modalities, on overt stuttering frequency in those who stutter. Specifically, syllabic gestural priming, as approximated by opening and closing manual gestures, serves as the fluency enhancing speech feedback stimulus. This stimulus is presented to study participants via manual production, simultaneous manual production and visual perception, and visual perception. Results reveal that all conditions served as effective fluency enhancers, with no significant differential fluency enhancement between speaking conditions documented. However, results suggest that combining multiple sensory modalities may be more efficient at enhancing fluency in those

who stutter when compared to any single sensory modality. Ancillary findings are also discussed.

Educational objectives:

The reader will be able to summarize, discuss and evaluate: (1) Recent research relative to the nature and etiology of stuttering. (2) The production of enhanced fluency speech in those who stutter via exposure to speech feedback. (3) The multi-sensory nature of fluency enhancing speech feedback. (4) The role that sensory modalities may play in the production of enhanced fluency speech in those who stutter.

1. Introduction

1.1 Neurological and genetic components of stuttering

Stuttering is generally considered to be a speech disorder that usually surfaces between two and four years of age, and is characterized by part- and whole-word repetitions, prolongations, and inaudible postural fixations during speech production (Bloodstein & Bernstein Ratner, 2008; Guitar, 2006; Yairi & Ambrose, 2005).

Although approximately 5% of all children exhibit stuttered speaking behaviors (often called "incipient stuttering") at some point during their speech and language development, roughly 80% of children demonstrating incipient stuttering behaviors spontaneously recover from the stuttering phenomenon (Yairi & Ambrose, 2005). The remaining 20% of children (representing approximately 1% of the global population) will continue to demonstrate stuttered speaking behaviors into adulthood, where it is diagnosed as persistent stuttering (Bloodstein, 2001; Bloodstein & Bernstein Ratner, 2008; Yairi & Ambrose, 2005).

Stuttering can also be acquired at any time during life resulting from a traumatic brain injury (Balasubramanian, Max, Van Borsel, Rayca, & Richardson, 2003; Bijleveld, Lebrun, & van Dongen, 1994; Byrne, Byrne, & Zibin, 1993; Conture & Curlee, 2007; Doi, et al., 2003; Helm-Estabrooks & Hotz, 1998; Heuer, Sataloff, Mandel, & Travers, 1996; Manaut-Gil, 2005; Theys, van Wieringen, & De Nil, 2008; Van Borsel & Taillieu, 2001; Yeoh, Lind, & Law, 2006), and is often referred to as neurogenic stuttering (Conture & Curlee, 2007); moreover, stuttering can result from consuming certain drugs (Bloodstein & Bernstein Ratner, 2008)—a condition which is sometimes reversible when the medication is discontinued (Brady, 1998; Christensen, Byerly, & McElroy, 1996; Duggal, Jagadheesan, & Nizamie, 2002; Ebeling, Compton, & Albright, 1997; Gerard, Delecluse, & Robience, 1998; Margetic, Aukst-Margetic, & Krajinovic, 2009; Nissani & Sanchez, 1997; Supprian, Retz, & Deckert, 1999).

Although the nature and etiology of stuttering remains unknown, substantial evidence indicates that the etiology of the stuttering phenomenon has a genetic genesis (Ambrose, Cox, & Yairi, 1997; Dworzynski, Remington, Rijsdijk, Howell, & Plomin, 2007; Lan, et al., 2009; Suresh, et al., 2006; Wittke-Thompson, et al., 2007) and is a neurological in nature (Brown, Ingham, Ingham, Laird, & Fox, 2005; Chang, Kenney, Loucks, & Ludlow, 2009; Cykowski, et al., 2008; de Andrade, Sassi, Juste, & de Mendonca, 2008; Fox, et al., 1996; Fox, et al., 2000; Giraud, et al., 2008; Hampton & Weber-Fox, 2008; Lu, Ning, et al., 2009; Lu, Peng, et al., 2009; Salmelin, Schnitzler, Schmitz, & Freund, 2000; Salmelin, et al., 1998; Sommer, et al., 2009; Wu, et al., 1995; Wu, et al., 1997), with the possibility of environmental factors contributing to the development of the pathology as well (Yairi & Ambrose, 2005).

1.2 The stuttering phenomenon is manifested in multiple expressive modalities.

Although stuttering is generally cited and commonly believed to be a disorder that is unique to speech (Yairi & Ambrose, 2005), the stuttering phenomenon is exhibited in a number of expressive modalities, including prominent behavioral manifestations within speech (Bloodstein & Bernstein Ratner, 2008), but also in the production of sign language (Backus, 1938; Harms & Malone, 1939; Liles, Lerman, Christensen, & St. Ledger, 1992; Montgomery & Fitch, 1988; Voelker & Voelker, 1937; Wingate, 1970), hand-writing (Roman, 1959; Saltuklaroglu, Robbins, Kalinowski, Guntupalli, & Nanjundeswaran, 2005; Saltuklaroglu, Teulings, & Robbins, 2008; Scripture, 1909) and even various forms of musical expression (Meltzer, 1992; Scripture, 1909; Silverman & Bohlman, 1988; Snyder, 2006). Remarkably, some mainstream medical and stuttering researchers still commonly misconceive stuttering as solely a speech disorder, despite these century-old data suggesting otherwise.

1.3 Exposure speech feedback enhances the production of fluent speech

Research reliably documents that overt stuttered speaking behaviors are dramatically, albeit transiently, reduced with the use of various forms of speech feedback (Bloodstein & Bernstein Ratner, 2008; Starkweather, 1987). For example, rhythmic or metronome-timed speech (which paces the initiation of the syllable or word with a rhythmic beat from an exogenous auditory, visual or tactile stimuli) is well-documented as enhancing the production of fluent speech (Bloodstein & Bernstein Ratner, 2008). Interestingly, fluency-enhancement via the metronome effect remains effective at both normal and fast speech rates (Hanna & Morris, 1977). Although data suggest that metronome-timed speech results in increased subglottal pressure rise time, as well as decreased vowel intensity and peak pressure (Stager, Denman, & Ludlow, 1997), such a finding may simply reflect the presence of enhanced speech fluency, rather than the cause of the fluency enhancement. In either event, rhythmic or metronome-timed speech is known to enhance the production of fluent speech in those who stutter, although the precise mechanics underlying the subsequent fluency enhancement remain unknown (Bloodstein & Bernstein Ratner, 2008).

Fluency-enhancing speech feedback also includes exposure to auditory masking noise and white noise (Bloodstein & Bernstein Ratner, 2008). Existing research documents significant reductions in overt stuttering frequency in the presence of auditory masking noise (Cherry & Sayers, 1956; Shane, 1955). Significant (speech) fluency-enhancement via auditory masking noise is documented to occur with exposure to both low (<500 hertz) and high (>500 hertz) frequency masking noise (Cherry & Sayers, 1956; Conture, 1974; May & Hackwood, 1968). However, research also reveals that even the monaural presentation of moderately intense white noise (i.e., 50 dB) enhances fluency in those who stutter (Maraist & Hutton, 1957).

In summary, while auditory masking noise has been documented to enhance fluency in those who stutter, simple monaural (and binaural) exposure to white noise (as low as 50 dB) also serves as a significant fluency-enhancer (Barr & Carmel, 1969; Yairi, 1976). Although researchers have tried to account for how and why exposure to either auditory masking or white noise significantly enhance fluency in those who stutter, the relationship between these two feedback conditions, as well as their mechanisms of efficacy, remain unknown (Bloodstein & Bernstein Ratner, 2008).

The production of enhanced fluent speech can also be stimulated via exposure to speech feedback of a second speech signal (Guntupalli, Kalinowski, Saltuklaroglu, & Nanjundeswaran, 2005; Kalinowski & Dayalu, 2002; Kalinowski, Stuart, Rastatter, Snyder, & Dayalu, 2000; Saltuklaroglu & Kalinowski, 2006). A second speech signal (SSS) is the speech feedback of a second gesturally similar and concurrent speech signal relative to the (primary) spoken speech signal (Andrews, Howie, Dozsa, & Guitar, 1982). Relatively synchronous SSSs that are documented to significantly enhance fluency include methodologies such as frequency altered feedback (FAF), auditory choral speech (ACS), visual choral speech (VCS) and synchronous visual feedback (SVF); in these methodologies, the primary and second speech signals are in relative unison. Asynchronous forms of a SSS include delayed auditory feedback (DAF) and asynchronous visual feedback (AVF), with data revealing that delays from 50 ms to over 250 ms are sufficient to significantly enhance fluency in those who stutter (Bloodstein & Bernstein Ratner, 2008; Kalinowski & Stuart, 1996; Kalinowski, et al., 2000; Snyder, Hough, Blanchet, Ivy, & Waddell, 2009).

In summary, a variety of speech feedback stimuli, employing an array of sensory modalities, are sufficient to enhance the production of fluent speech in those who stutter. Such stimuli include (but are not limited to) metronomic or syllabic pacing, auditory masking or side-tones, as well as second speech signals. Although all these speech feedback stimuli are documented as sufficient to enhance the production of fluent speech in those who stutter, how or why fluency is enhanced by such diverse stimuli remains a point of speculation (Howell, 2002; Howell & Au-Yeung, 2002; Kalinowski & Saltuklaroglu, 2003b; Saltuklaroglu, Kalinowski, & Guntupalli, 2004; Snyder, Hough, et al., 2009).

1.4 Exposure to speech feedback over various sensory modalities enhances the production of fluent speech

Any number of speech feedback stimuli (e.g., metronomic pacing, auditory masking and sidetones, second speech signals) employing various methodologies (i.e., synchronous and asynchronous stimuli, internal- and external generation) are documented to enhance the production of fluent speech in those who stutter (Bloodstein & Bernstein Ratner, 2008); moreover, this fluency enhancing speech feedback phenomenon also remains effective across a variety of sensory modalities, including audition, vision, and tactition (Bloodstein & Bernstein Ratner, 2008; Kuniszyk-Jozkowiak & Adamczyk, 1989; Kuniszyk-Jozkowiak, Smolka, & Adamczyk, 1996, 1997; Snyder, Blanchet, Waddell, & Ivy, 2009; Snyder, Hough, et al., 2009).

The most widely-documented sensory modality used in the fluency enhancing speech feedback phenomenon is the auditory pathway, including auditory masking and side-tones (Barr & Carmel, 1969; Kalinowski, Armson, Roland-Mieszkowski, Stuart, & Gracco, 1993; Maraist & Hutton, 1957; May & Hackwood, 1968), DAF (Andrews, et al., 1983), FAF (Hargrave, Kalinowski, Stuart, Armson, & Jones, 1994; Howell, El-Yaniv, & Powell, 1987), and ACS (Bloodstein & Bernstein Ratner, 2008).

Fluency enhancing speech feedback has also been documented to be effective via the visual pathway. One documented example used speech-contingent flashing lights to enhance fluency in those who stutter (Kuniszyk-Jozkowiak & Adamczyk, 1989; Kuniszyk-Jozkowiak, et al., 1996, 1997). A few years later, researchers documented a more efficient fluency-enhancing visual speech feedback methodology in the form of an externally-generated synchronous visual second speech signal, and named it visual choral speech (Kalinowski, et al., 2000). This latter finding was seminal in that it suggests fluency-enhancement via speech feedback of a SSS is not solely an auditory phenomenon (such as DAF, FAF, or ACS), but rather a multi-sensory phenomenon (Kalinowski, et al., 2000). The hypothesis that fluency-enhancement via a SSS functions as a multi-sensory phenomenon led to a study documenting that exposure to self-generated synchronous and asynchronous visual SSSs (i.e., speaking with a mirror or delayed visual feedback) likewise enhances the production of fluent speech in those who stutter (Snyder, Hough, et al., 2009).

Research also suggests that externally-generated digital vibrotactile speech feedback (sensed by the speakers' middle fingers) also enhances fluency in those who stutter (Kuniszyk-Jozkowiak & Adamczyk, 1989; Kuniszyk-Jozkowiak, et al., 1996, 1997). The methodology employed by these studies measured the effects of synchronous, echo (i.e., delayed), and reverberated (i.e., prolonged) visual, auditory and/or tactile speech feedback on stuttering frequency and articulatory rate. Tactile feedback was presented at 230 Hz, with a 0.05 mm maximum amplitude of oscillation, to the participants' middle fingers. Data collected from these studies revealed that externally-generated digital vibrotactile speech feedback served as an effective fluency enhancer, regardless of experimental presentation (i.e., synchronous, echo, or reverberation; (Kuniszyk-Jozkowiak & Adamczyk, 1989; Kuniszyk-Jozkowiak, et al., 1996, 1997). This finding led to the hypothesis, and subsequent documentation, that exposure to self-generated synchronous self-generated digital vibrotactile feedback resulted in the production of enhanced fluent speech in those who stutter (Snyder, Blanchet, et al., 2009). Self-generated synchronous digital vibrotactile feedback was approximated by the speaker tactilely sensing their own vibrating thyroid cartilage by placing their thumb and index finger on either side of the thyroid notch while speaking. Results revealed that this methodology enhanced the production of fluent speech similar to that found via other methods and sensory modalities (Snyder, Blanchet, et al., 2009).

1.5 The role of sensory modality in the fluency enhancing speech feedback phenomenon

Data clearly reveal that any number of synchronous or asynchronous speech feedback stimuli, generated internally or externally, and sensed by a variety of sensory modalities, is sufficient to enhance the production of fluency speech in those who stutter. While there is substantial research examining the role of the content embedded within speech feedback stimuli, there has been little research attention focusing on the role sensory modality relative to the enhanced fluency phenomenon. Therefore, the purpose of the present study was to investigate the role of sensory modality in the fluency enhancement phenomenon, and to document any differential effects that it may have in the enhancement of fluent speech production. In order to test the effects of sensory modality on the fluency enhancing speech feedback phenomenon, we measured the effects of a single form of speech feedback stimulus, presented over a combination of productive and sensory modalities, on overt stuttering frequency. Specifically, syllabic gestural priming, as approximated by opening and closing manual gestures, was the speech feedback stimulus employed in this study; this stimulus was presented to research participants via production (only), simultaneous production and perception, and perception (only).

2. Method

2.1 Participants

Eight adults diagnosed with persistent stuttering (6 males and 2 females, mean age = 30.75 years, SD = 9.3 years) participated in this study. Participants reported either normal or corrected vision, right-hand dominance, and no other diagnosed speech, language, hearing or attention disorders. While all participants had a history of speech therapy, none were currently enrolled. All participants, at a minimum, had graduated from high school.

2.2 Task and Stimuli

Measuring the effects of visual speech feedback requires specially designed speaking and reading tasks. These tasks require that participants' eye gaze remain focused on the visual speech feedback, thereby disallowing focused eye gaze on another speaker, written text, or text scrolling across a monitor. Consequently, the principal speaking task and stimuli employed in this study modified a methodology used in previous visual speech feedback research (Kalinowski, et al., 2000; Snyder, Hough, et al., 2009). In the control and experimental speaking conditions, participants were asked to recite a speaking passage aloud. Each passage, consisting of approximately 300 syllables, was divided into 10-15 word phrases, and was printed on large cue cards. For all speaking conditions, participants were seated at a table with the cue cards, and instructed to silently read and memorize a phrase of "comfortable length" (ranging from 3 to 7 words). Participants were then instructed to look up and away from the cue card and recite the phrase they had just silently read and memorized.

This procedure was used in all speaking conditions (including the control condition), thereby balancing potential confounding variables, such as silent rehearsal (Bloodstein & Bernstein Ratner, 2008). Demonstrations and practice trials were allowed for every speaking condition until participants reported feeling comfortable with each speaking task; however, alternate reading passages were used during demonstrations and practice trials to avoid potential "practice effects," which have been documented to affect stuttering frequency (Bloodstein & Bernstein Ratner, 2008). Participants were instructed to speak at their natural rate of speech and not to use any speaking techniques that could control or reduce stuttering. Speaking conditions and passages were counterbalanced using a Latin square.

During select experimental speaking conditions, each participant was given a hand puppet (representing a monkey with a functional mouth and jaw) and instructed to produce opening and closing manual gestures (i.e., mimicking speech) immediately preceding, and thereby initiating, speech production. In essence, participants produced syllabic gestural priming (SGP) by manually mimicking oral opening and closing frames (MacNeilage, 1998) with the hand puppet to coincide with speech gesture initiation and syllabic production.

Specifically, participants were instructed to produce manual hand puppet gestures (performed with the right hand) such that the puppet was initiating an opening and closing frame (MacNeilage, 1998) coinciding with each syllable produced by the participants. Manual hand puppet syllabic gesturing continued concurrently with the participants' speech until the phrase was completed. Special instructions were given to manually initiate gestural opening-frames (MacNeilage, 1998) immediately before every syllable produced within the memorized text; participants were specifically instructed to "let the puppet initiate each syllable, and let your mouth follow along." Participants were instructed to "speak naturally" and perform this speaking task with a "natural rhythm and cadence of speech," and were given a demonstration and practice trials until natural sounding speech output was achieved.

2.3 Control and Experimental Speaking Conditions

A "no syllabic gestural priming" (NSGP) speaking condition served as the control condition. A second speaking condition consisted of participants producing self-generated manual syllabic gestural primes outside of their own visual field (beneath the large stimulus cue cards), creating the self-generated syllabic gestural priming without visual feedback (SG-SGPO). For this condition, participants were instructed to first initiate a manual opening frame via hand puppet gestures (i.e., self-generated manual syllabic gestural prime) prior to each syllable; this speaking condition provided self-generated manual gesturing without visual priming or feedback.

A third speaking condition tested fluency enhancement via self-generated manual syllabic gestural primes inside the participants' visual field (SG-SGPI), thus providing visual feedback of the syllabic gestural priming. For this condition, participants were instructed to first initiate a manual opening frame via hand puppet gestures (i.e., self-generated manual syllabic gestural prime) prior to each syllable, and also to use the visual speech feedback of the puppet's lips, mouth, and jaw movement to initiate speech production.

During the fourth speaking condition, the experimenter provided externally-generated manual hand puppet gestures (i.e., syllabic gestural primes) that served as visual speech feedback for the participants (EG-SGPI). In this condition, participants were instructed to wait for the experimenter to begin manually producing an opening frame via hand puppet gesturing, and then to follow the syllabic movement of the puppet's lips, mouth, and jaw to initiate speech production of the memorized phrase.

2.4 Data Collection and Reliability Analysis

All conditions were video recorded using a Sony Hi-8mm video camera (model #CCD-TRV75), and a Radio Shack lapel microphone (model #33-3003) that was attached at approximately 0^0 altitude, and -180^0 azimuth. Given that stuttering is often behaviorally defined as the production of three percent or greater stuttered syllables during speech (Bloodstein & Bernstein Ratner, 2008; Starkweather, 1987; Van Riper, 1982), only those participants demonstrating three percent or greater stuttering frequency in the control speaking condition were included in this study. Moments of overt stuttering were operationally defined as whole- and part-word repetitions, sound or syllable prolongations, or inaudible postural fixations (i.e., "blocking") (Bloodstein & Bernstein Ratner, 2008). Stuttered syllables were counted from the first 300 syllables of each speaking condition by the primary author of the study. Intrajudge syllable-by-syllable agreement for 25% of the data, as indexed by Cohen's *kappa* (Cohen, 1960) was .90. A trained research assistant, blind to the purpose of the study, randomly selected and independently analyzed 25% of the data, revealing an interjudge syllable-by-syllable agreement of .84, a value that represents excellent agreement (Fleiss, 1981).

3. Results

The distributions of stuttering frequency as a function of visual feedback speaking condition are presented in Figure 1. Stuttered syllables were counted from the first 300 syllables of each speaking condition. The mean values of stuttering frequency were 47.88 stuttered syllables (SE = 13.30) for the NSGP speaking condition, 23.75 stuttered syllables (SE = 10.64) for the SG-SGPO speaking condition, 12 stuttered syllables (SE = 7.75) for the SG-SGPI speaking condition, and 19.88 stuttered syllables (SE = 9.22) for the EG-SGPI speaking condition.

Insert Figure 1 about here

As shown in Figure 1, there was an approximate 50% reduction of mean stuttered syllables with SG-SGPO, a 75% reduction of mean stuttered syllables with SG-SGPI, and a 58% reduction of mean stuttered syllables with EG-SGPI. Due to the relatively small sample used in this study (i.e., fewer than 20 participants), a square root transformation was performed on the data prior to analysis, resulting in a more symmetrical (transformed) distribution (Jones, Onslow, Packman, & Gebski, 2006). A one-factor repeated measure analysis of variance (ANOVA) was conducted to investigate differences in the occurrence of stuttered syllables as a function of speaking condition, and revealed a main effect of syllabic gestural priming on stuttering frequency [$F(3,21) = 15.588$, Greenhouse-Geisser $p = .000$, $\eta_p 2 = .690$]. Post-hoc orthogonal single df comparisons revealed significant differences in stuttering frequency between the NSGP and each of the three experimental speaking conditions ($p < .0001$). The orthogonal single df contrasting the SG-SGPI speaking condition against the SG-SGPO and EG-SGPI conditions resulted in a statistical trend towards significance ($p = .0764$). Lastly, a single df comparison revealed that the difference between the SGPO and EGPI conditions was nonsignificant ($p = .5314$). Thus, all three experimental speaking conditions reduced stuttering frequency to a statistically significant degree; no single experimental speaking condition was significantly more effective than the other two.

4. Discussion

4.1 Syllabic Gestural Priming Enhances Fluency

Results of the present study revealed that all three syllabic gestural priming speaking conditions served as effective fluency enhancers in these adults who stutter. Why these experimental speaking conditions resulted in fluency enhancement in those who stutter is beyond the scope of this manuscript. However, a number of existing theoretical models attempt to account for enhancement of fluent speech in those who stutter, including the engagement of mirror neuron networks (Kalinowski & Saltuklaroglu, 2003a, 2003b), the EXPLAN model (Howell, 2002; Howell & Au-Yeung, 2002), and the dual premotor systems hypothesis (Alm, 2004, 2005; Snyder, 2004; Snyder, Hough, et al., 2009).

4.2 The role of sensory modality relative to fluency enhancing speech feedback

Data from this study suggest that the act of producing syllabic gestural primes enhances fluency. Moreover, perceiving syllabic gestural primes via the visual sensory modality likewise enhances fluency. Interestingly, the combination of endogenous motor production and (visual) sensory perception of syllabic gestural priming resulted in a trend toward statistical significance in fluency enhancement, when compared to either endogenous or exogenous syllabic gestural priming alone. This finding suggests that there may be an additive effect of simultaneous motor production and sensory perception of syllabic gestural primes relative to efficacy of enhancing fluent speech in those who stutter. In other words, any one sensory modality may not be significantly different than any others, relative to the enhanced fluency phenomenon. Furthermore, these data suggest that the content of the speech feedback plays a larger role in fluency enhancement than the sensory modality in which it was perceived. However, these data could be also interpreted as suggesting that using multiple modalities of speech feedback input may be more effective and efficient at stimulating the production of enhanced fluency than using any one sensory modality. Clearly, further research is needed to test and clarify these assumptions.

4.3 Ancillary Observations: The "stuttering" block at a central neural level

A particularly interesting ancillary finding was consistently observed during data collection. In essence, any moments of "stuttering" occurring in the SG-SGPO and SG-SGPI experimental speaking conditions appeared to affect gestural initiation at the level of the mouth (i.e., initiation of the speech gesture) and at the hand (i.e., initiation of the manual syllabic gestural prime); this behavior was noted to be both reliable and uniform among all the participants.

In other words, failures in "fluency" were observed to simultaneously occur at the manual and oral levels. For example, when stuttered speech manifested itself as a sound or syllable prolongation, the manual syllabic priming gestures ceased and the hand position appeared to become fixed (or frozen) in an open position until cessation of the stuttering moment. Similarly, when stuttered speech resembled that of a (facial) postural fixation (i.e., a "block" or failure to initiate the speech gesture), a similar (manual) postural fixation was also found to occur with the hand position fixed in the closed (i.e., uninitiated) frame position. Interestingly, a related observations relative to manual and speech dysfluencies are recently reported (Saltuklaroglu, et al., 2008). Consequently, these data could be interpreted to support the notion that stuttering is not solely a disorder of speech, but rather a more generalized motor disturbance, perhaps unique to expressive communication (Snyder, 2006).

Although the cause of this simultaneous manual and oral dysfluency is unknown, we hypothesize that these amalgamated failures in the production of fluent gestural movements (or gestural initiation of speech and manual movement) share common processes occurring at the central neurological level (Fox, et al., 2000; Salmelin, et al., 1998; Snyder, 2004). Data may support such a hypothesis, as previous research has suggested a shared neural circuitry between programming of hand and speech gestures (Rizzolatti & Arbib, 1998, 1999; Rizzolatti, et al., 1996). Moreover, the data also document a "blurred" cerebral regional functional boundary of hand and mouth motor representations within the stuttering population (Fox, et al., 2000; Salmelin, et al., 1998).

4.4 Implications & Future Directions

Direct clinical application of this research may be limited, as the methodology employed only provided fluency enhancement in the presence of the speech feedback; moreover, some clients may feel that enhanced fluency via this methodology would likely receive greater social consequence than the stuttered speech in which it replaces. However, this was not the purpose of the present study. To wit, the present findings provide useful insights relative to the role of sensory modality within fluency enhancing speech feedback. Specifically, results suggest that the sensory modality used in fluency enhancing speech feedback is of lesser importance than the content of the speech feedback itself; while the visual sensory modality was not shown to be more effective than proprioception at instigating the production of enhanced fluency in those who stutter, data does suggest that a combination of production and perception (or the simultaneous use of multiple modalities) may provide more efficient fluency enhancement relative to any one modality alone. In addition, observations from this study suggest that the act of stuttering can simultaneously occur at both the manual and oral levels. Consequently, concepts such as syllabic gestural priming (e.g., an exogenous rhythmic gestural initiator) and the simultaneous use of sensory modalities within speech feedback may be integrated into treatments, such as improvements to existing (or entirely new applications of) behavioral and prosthetic stuttering management strategies.

Clearly, further research is both necessary and warranted. A larger, and perhaps more homogeneous, sample would provide greater statistical power, thus providing better statistical resolution between post hoc comparisons of control and experimental speaking conditions. Furthermore, alternate study methodologies could be designed to test different aspects of sensory perception within the enhanced fluency phenomenon. Specifically, a study using a single (or similar) speech feedback stimulus (such as an initiatory burst) over the visual, tactile, and auditory sensory modalities would provide useful data relative to the nature of stuttering and the optimization of prosthetic stuttering management devices.

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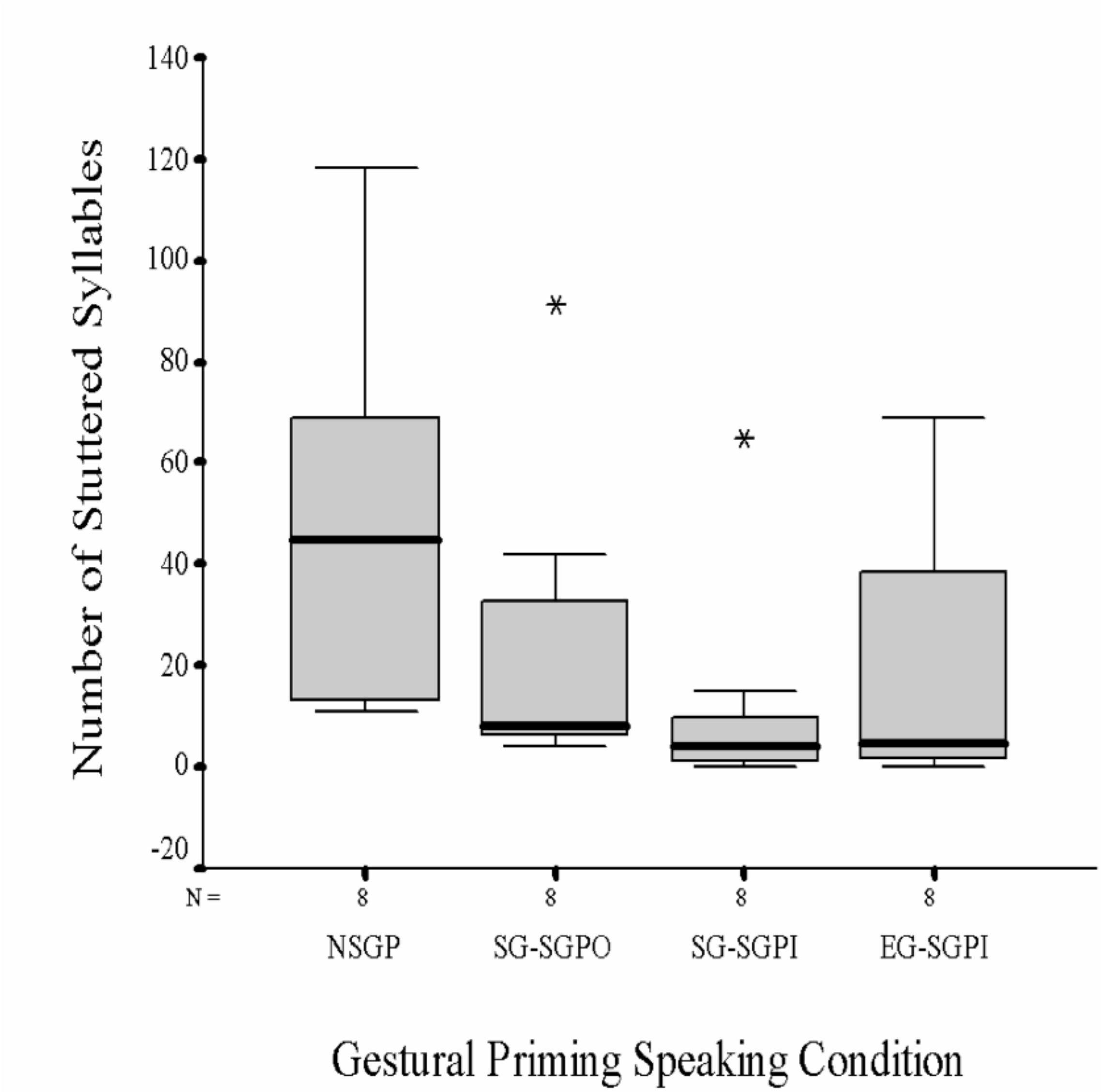

Figure 1. Minimum/maximum, inter-quartile range, and median values for the No Syllabic Gestural Priming (NSGP), Self-Generated Syllabic Gestural Priming Outside of the Visual Field (SG-SGPO), Self-Generated Syllabic Gestural Priming Inside of the Visual Field (SG-SGPI), and Externally-Generated Syllabic Gestural Priming Inside the Visual Field (EG-SGPI) speaking conditions. Asterisks represent statistical outliers.