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The effects of self-generated synchronous and asynchronous visual speech feedback on overt stuttering frequency

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Abstract

Purpose: Relatively recent research documents that visual choral speech, which represents an externally generated form of synchronous visual speech feedback, significantly enhanced fluency in those who stutter. As a consequence, it was hypothesized that self-generated synchronous and asynchronous visual speech feedback would likewise enhance fluency. Therefore, the purpose of this study was to investigate the effects of self-generated visual feedback (i.e., synchronous speech feedback with a mirror and asynchronous speech feedback via delayed visual feedback) on overt stuttering frequency in those who stutter.

Method: Eight people who stutter (4 males, 4 females), ranging from 18 to 42 years of age participated in this study. Due to the nature of visual speech feedback, the speaking task required that participants recite memorized phrases in control and experimental speaking conditions so that visual attention could be focused on the speech feedback, rather than a written passage. During experimental conditions, participants recited memorized phrases while simultaneously focusing on the movement of their lips, mouth, and jaw within their own synchronous (i.e., mirror) and asynchronous (i.e., delayed video signal) visual speech feedback.

Results: Results indicated that the self-generated visual feedback speaking conditions significantly decreased stuttering frequency (Greenhouse–Geisser $p = .000$); post hoc orthogonal comparisons revealed no significant differences in stuttering frequency reduction between the synchronous and asynchronous visual feedback speaking conditions ($p = .2554$).

Conclusions: These data suggest that synchronous and asynchronous self-generated visual speech feedback is associated with significant reductions in overt stuttering frequency. Study results were discussed relative to existing theoretical models of fluency-enhancement via speech feedback, such as the engagement of mirror neuron networks, the EXPLAN model, and the Dual Premotor

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System Hypothesis. Further research in the area of self-generated visual speech feedback, as well as theoretical constructs accounting for how exposure to a multi-sensory speech feedback enhances fluency, is warranted.

Learning outcomes: : Readers will be able to (1) discuss the multi-sensory nature of fluency-enhancing speech feedback, (2) compare and contrast synchronous and asynchronous self-generated and externally generated visual speech feedback, and (3) compare and contrast self-generated and externally generated visual speech feedback.

1. Introduction

Stuttering is generally considered to be a speech disorder that emerges between 2 and 4 years of age, affects approximately 1% of the global population, and is characterized by part- and whole-word repetitions, prolongations, and inaudible postural fixations during speech production (Bloodstein & Bernstein-Ratner, 2008). While approximately 5% of all children exhibit stuttered speaking behaviors at some point during their speech and language development, approximately 80% of children demonstrating stuttering behaviors spontaneously recover from the stuttering phenomenon (Yairi & Ambrose, 2005); the remaining 20% of children demonstrating stuttered speaking behaviors continue to exhibit stuttering into adulthood (Yairi & Ambrose, 2005). Substantial evidence indicates that the etiology of the stuttering phenomenon has a genetic and/or neurological genesis, with the possibility of environmental factors contributing to the development of the pathology as well (Yairi & Ambrose, 2005).

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). One such example is 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 (Bloodstein & Bernstein-Ratner, 2008). Moreover, fluency-enhancement via the metronome effect remains significant at both normal and fast speech rates (Hanna & Morris, 1977). Although Stager, Denman, and Ludlow (1997) reported that metronome-timed speech resulted in increased subglottal pressure rise time, as well as decreased vowel intensity and peak pressure, it remains unclear whether these changes in speech production are the cause or result of the subsequent fluency-enhancement.

Other forms of fluency-enhancing speech feedback include exposure to auditory masking noise and white noise (Bloodstein & Bernstein-Ratner, 2008). A number of studies document significant reductions in overt stuttering frequency in the presence of auditory masking noise (Cherry & Sayers, 1956; Shane, 1955). Significant fluency-enhancement via auditory masking noise is documented to occur with exposure to both low (<500 Hz) and high (>500 Hz) 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) has been documented to enhance fluency in those who stutter (Maraist & Hutton, 1957). In other words, although 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).

Finally, research suggested fluency-enhancement via exposure to speech feedback of a second speech signal (Guntupalli, Kalinowski, Saltuklaroglu, & Nanjundeswaran, 2005; Kalinowski & Dayalu, 2002; Kalinowski, Stuart, Rastatter, Snyder, & Dayalu, 2000). 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). A variety of methodologies employ the use of synchronous and asynchronous SSSs through various sensory modalities. Specific examples of the SSS include delayed auditory feedback (DAF; Andrews et al., 1983), frequency altered feedback (FAF; Hargrave, Kalinowski, Stuart, Armson, & Jones, 1994; Howel, El-Yaniv, & Powell, 1987), auditory choral speech (ACS; Bloodstein & Bernstein-Ratner, 2008) and visual choral speech (VCS; Kalinowski et al., 2000). Relatively synchronous SSSs that are documented to significantly enhance fluency include methodologies such as FAF, ACS and VCS, as the primary and second speech signals are in relative unison. Asynchronous forms of a SSS include DAF, with data revealing that delays from 50 ms to over 250 ms are sufficient to significantly enhance fluency in those who stutter (Kalinowski, Stuart, Sark, & Armson, 1996). Although fluency-enhancement via exposure to any number of SSSs is widely documented, a single prevailing paradigm accounting for how and why exposure to a SSS enhances fluency has not emerged (Bloodstein & Bernstein-Ratner, 2008).

Research has revealed remarkable data regarding fluency-enhancement via visual speech feedback. Visual feedback, in the form of speech-contingent flashing lights, was documented to enhance fluency in those who stutter (Kuniszyk-Jozkowiak, Smolka, & Adamczyk, 1996, 1997). A few years later, Kalinowski et al. (2000) documented a more efficient fluency-enhancing visual speech feedback methodology in the form of an externally generated synchronous visual second speech signal (i.e., visual choral speech). 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 speculation that fluency-enhancement via a SSS functions as a multi-sensory phenomenon lead to the hypothesis that exposure to self-generated synchronous and asynchronous visual SSSs would likewise enhance fluency in those who stutter.

Therefore, the purpose of the present study is twofold: first, to report preliminary data on fluency-enhancement secondary to exposure to synchronous and asynchronous self-generated visual SSSs. Second, to report any differential effects on fluency-enhancement as a result of exposure to synchronous and asynchronous self-generated visual SSSs. For the purposes of this study, synchronous self-generated visual speech feedback will be presented by the use of a mirror; asynchronous self-generated visual speech feedback will be presented by the use of a delayed visual feedback apparatus.

2. Methods

2.1. Participants

Eight adults who stutter (4 males, 4 females), ranging from 18 to 42 years of age (median age = 26, mean age = 30.14, S.D. = 10.21), participated in this study. Participants reported either normal or corrected vision, and no other diagnosed speech, language, hearing, or attention disorders. Although all participants had a history of speech therapy, only one was currently enrolled. All participants, at a minimum, had graduated from high school.

2.2. Task and stimuli

Measuring the effects of visual SSS speech feedback requires specially designed speaking and reading tasks. These tasks require that participants' eye gaze remain focused on the visual SSS 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).

During each speaking condition, participants read passages taken from junior high school science textbooks, all of which have been used in previous research (Kalinowski et al., 2000). Each passage, consisting of approximately 300 syllables, was divided into phrases consisting of 10–15 words, and printed on large double-sided cue cards. Participants sat at a table (approximately 75 cm in height), and were instructed to silently read and memorize a ‘‘phrase of comfortable length’’ (generally ranging from 5 to 7 words). Participants were then instructed to look up from the cue card, direct their eye gaze in to the visual SSS speech feedback, and recite the phrase they had just silently read and memorized.

Although this task required participants to silently rehearse each phrase, the same procedure was used for all speaking conditions, thereby controlling for any differential effects of silent rehearsal on stuttering frequency. Practice trials, using an unrelated reading passage, were allowed in all speaking conditions until participants reported feeling comfortable with each speaking condition. Participants were instructed to speak at a normal rate, and not to use any speaking techniques that could alter, control, or reduce stuttering. Both the speaking conditions and passages were counterbalanced using a Latin Square.

2.3. Apparatus and procedure

A ‘‘no visual feedback’’ (NVF) speaking condition served as the control condition for the study. During this condition, participants were instructed to read and silently memorize a phrase of comfortable length from the cue card, and then to look up (away from the cue card) and initiate speech.

A vertically positioned mirror (24 cm high × 33 cm wide, placed approximately 46 cm from the face of participant) positioned at eye level was used to create synchronous self-generated visual feedback (SVF) for the second speaking condition. During this experimental condition, participants were instructed to read and silently memorize a phrase of comfortable length from the cue card, and then to ''look at your reflection and follow the movement from your lips, mouth, tongue, and jaw to initiate and maintain speech.''

A third speaking condition tested fluency-enhancement via asynchronous self-generated visual feedback. The AVF was generated by using a 3Com HomeConnect universal serial bus netcam (model #0776) connected to a Winbook XL2 laptop computer. This netcam was positioned approximately 61 cm from the participant, where it was mounted slightly above eye level, and aimed at the participants' lips, mouth and jaw. The participants' AVF was displayed on the laptop computer's monitor, which was no more than 46 cm from the participant and positioned at eye level. The laptop computer (Winbook XL2) ran Microsoft's Windows 98 (Version 4.10.1998) and was configured with 128 megabytes of random access memory and a 300-MHz Pentium II processor. The laptop computer was equipped with a 14-in. active matrix liquid crystal display configured to 800 by 600 pixels resolution. The use of this hardware and software configuration provided a noticeable and reliable visual delay.

The AVF speaking condition followed a nearly identical protocol as the SVF condition, with the exception that participants were instructed to look at their image (displayed on the laptop's monitor), and pause for the asynchronous (delayed) visual feedback to become temporarily synchronous with the participants' head position. Once the asynchronous (delayed) visual image ''caught up'' with the participants' head movement, thereby providing participants with direct visual access to their lips, mouth and jaw displayed on the laptop monitor, they were instructed to ''look at your image on the screen and follow the movement from your lips, mouth, tongue, and jaw to initiate and maintain speech.''

Although the methodology described above successfully provided asynchronous visual feedback, the precise delay time of the visual feedback was initially unknown. Consequently, a specialized protocol was developed to precisely quantify the visual delay created by the methodology in the present study. This protocol involved the netcam and laptop computer configured to the previously described study specifications, a strobe light (RS#41-3048), and a stand-alone digital video camera (Sony #DSR-PD100). This protocol was designed to quantify the visual delay by allowing the stand-alone digital video camera to capture a single strobe flash directly from the strobe light, as well as the image of the strobe flash, which was captured by the netcam and displayed on the laptop's LCD monitor. As such, the video captured by the stand-alone digital video camera contained both the original strobe flash and the image of the strobe flash rendered on the laptop computer. Consequently, the video captured by the stand-alone video camera was used to quantify the latency period between the original strobe flash and the rendered strobe flash displayed on the laptop computer's monitor.

This video signal was digitized using Broadway Pro (version 5.10.9) into an .avi video file (at 75 megabytes-per-minute) at 30 frames per second, and analyzed with Ulead's Video Editor (version 6.0). The individual video frames from the original strobe flash and the rendered image of the strobe flash displayed the laptop computer's monitor were identified. The difference between frames was calculated, and then divided by 30, thereby providing the latency period between the original strobe flash and the rendered strobe flash in seconds. This process was iterated five times and averaged to generate an average visual delay of 0.36 s (S.D. = .054 s), which estimated the visual delay provided by the study's AVF protocol.

No other asynchronous (i.e., delayed) visual feedback time delay settings were employed in this preliminary study. During the experimental speaking conditions, participants perceived either synchronous or asynchronous visual speech feedback; no forms of altered auditory speech feedback were introduced during any speaking condition. All participants were video recorded using a Hi-8mm video camera (Sony #CCD-TRV75), and a lapel microphone (RS #33-3003) that was attached no more than 15 cm from their mouth with an approximate orientation of 0° azimuth and -180° altitude.

2.4. Data collection and analysis

Given that stuttering is often behaviorally defined as the production of three percent or greater stuttered syllables during speech production (Bloodstein & Bernstein-Ratner, 2008; Starkweather, 1987; Van Riper, 1982), only those participants demonstrating 3% or greater stuttering frequency in the control speaking condition were included in this study. For the purposes of this study, moments of overt stuttering were operationally defined as whole- and part-word

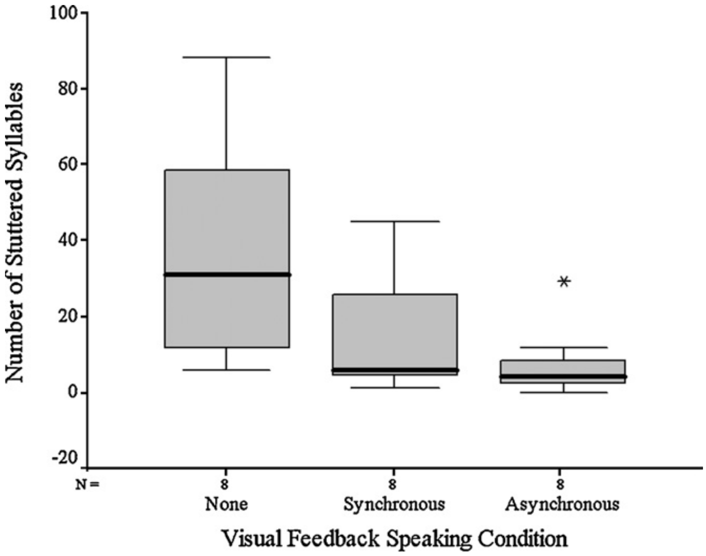

Fig. 1. The minimum, maximum, inter-quartile range, and median values as a function of the no visual feedback (NVF), synchronous visual feedback (SVF), and asynchronous visual feedback (ASV) speaking conditions. The asterisk in the ASV speaking condition denotes an outlier.

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 .94. A trained stuttering 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 .83, 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 Fig. 1. Specifically, the mean stuttering frequency was 37.13 stuttered syllables (S.E. = 10.55) for the NVF speaking condition, 14.88 stuttered syllables (S.E. = 6.41) for the SVF speaking condition, and 7.38 stuttered syllables (S.E. = 3.33) for the AVF speaking condition.

As shown in Fig. 1, approximately 60% and 80% reductions of stuttered syllables occurred in the SVF and AVF speaking conditions, respectively. Due to the relatively small sample used in this study (i.e., <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 visual feedback. The results of this analysis revealed a main effect of visual speech feedback [$F(2,14) = 21.334$, Greenhouse–Geisser $p = .000$, $\eta_p^2 = .753$]. Post hoc orthogonal single df comparisons revealed a significant difference between the no visual feedback and the two visual feedback speaking conditions ($p = .0003$); however, no significant difference was found between the synchronous and asynchronous visual feedback speaking conditions ($p = .2554$). In other words, these data reveal that study participants spoke significantly more fluently with the use of self-generated visual feedback; however, there were no statistically significant differences noted in the stuttering frequency between the two experimental speaking conditions.

4. Discussion

Results of this study suggest that exposure to self-generated synchronous and asynchronous visual SSS speech feedback significantly enhances fluency in those who stuttering. These data differ from those obtained in previous research in that this methodology utilized a self-generated visual SSS rather than an externally generated visual second speech signal, such as visual choral speech (Kalinowski et al., 2000). Moreover, data obtained from this study indicate that self-generated visual SSS speech feedback, in both its synchronous and asynchronous forms, significantly enhances fluency.

4.1. Existing explanations of fluency-enhancement via self-generated visual speech feedback

What might account for the fluency-enhancement via the perception of self-generated SSS speech feedback? Unfortunately, there is no single prevailing stuttering research paradigm that can account for these data. As a consequence, a handful of competing theoretical perspectives on stuttering have created models that are capable of integrating these data into their existing paradigms (with varying degrees of scientific relevance). Accordingly, this discussion will limit interpreting these data to select recent perspectives, such as the engagement of mirror neuron networks (Kalinowski & Saltuklaroglu, 2003a,b), the EXPLAN model (Howell, 2002), and a novel application of the dual premotor systems hypothesis (Alm, 2004, 2005; Snyder, 2004).

4.2. Speech feedback and mirror neuron networks

Stuttering research documents any number of speech feedback methodologies that are capable of enhancing fluent speech in those who stutter (Bloodstein & Bernstein-Ratner, 2008). However, some stuttering researchers cite research documenting that choral speech is unique in that it produces ‘‘true fluency,’’ which is operationally defined as speech that is effortless, natural sounding, and stable over time and environment (Dayalu & Kalinowski, 2002). Subsequently, those speech feedback conditions resembling auditory choral speech—thereby emulating its effect—are classified as ‘‘second speech signals’’ (Kalinowski & Dayalu, 2002). Examples of speech feedback conditions that are thought to emulate choral speech include delayed auditory feedback, frequency altered feedback and visual choral speech. Research suggests that the sensory perception of a SSS may activate mirror neuron networks embedded within the central nervous system (CNS) (Kalinowski & Saltuklaroglu, 2003b). In essence, exposure to a SSS activates (speech related) mirror neuron networks, which are hypothesized to innervate fluent speech production (Kalinowski & Saltuklaroglu, 2003a; Saltuklaroglu, Kalinowski, & Guntupalli, 2004). Consequently, this perspective would suggest that exposure to SSSs (including a synchronous or asynchronous self-generated visual SSS), regardless of the sensory modality in which it was perceived, influences the CNS to activate mirror neuron networks that would innervate fluent speech production.

4.3. Speech feedback and the EXPLAN model

An alternate explanation for fluency-enhancement via exposure to self-generated visual SSS speech feedback can be found in the EXPLAN model. The EXPLAN model is unique in that it addresses linguistic structure and processing relative to fluency-enhancement. In essence, the EXPLAN model suggests that failures in speech fluency result from dyssynchrony between cognitive-linguistic formulation of a speech plan (PLAN) and the motor execution (EX) of the linguistic plan (Howell, 2002, 2004; Howell & Sackin, 2002). Moments of stuttering are theorized to occur when the plan is not fully formed in time for (fluent) motor execution (Howell, 2002, 2004; Howell & Sackin, 2002). From this perspective, altered speech feedback is hypothesized to enhance fluency by offering a second source of rhythm, which is theorized to affect the global or local speech rate relative to (speech) motor execution. These alterations (i.e., reductions) in either global or local speech rate allow for increased time relative to cognitive-linguistic speech planning, thereby enhancing fluent speech production. Consequently, the EXPLAN model would suggest that the perception of speech feedback actively influences the peripheral nervous system (PNS), resulting in a (global or local) reduced rate of speech, thereby allowing more time for cognitive-linguistic formulation, which allows for speech motor execution of fully formed cognitive-linguistic speech plans (Howell, 2002, 2004; Howell & Sackin, 2002).

4.4. Speech feedback and the dual premotor systems hypothesis

A novel explanation for these data may be found in Goldberg and Bloom's (1990) Dual Premotor System Hypothesis (DPSH), which differentiates the roles of medial and lateral premotor systems (Goldberg, 1985, 1992). The DPSH identifies a medial premotor system, which is believed to be responsible for initiating self-generated (speech) motor plans (Goldberg & Bloom, 1990; MacNeilage, 1998). The DPSH also provides evidence for a lateral premotor system (Goldberg & Bloom, 1990), which utilizes a multitude of multi-sensory afferent connections (Pandya, 1987) to activate externally generated (speech) motor plans (Schubotz, Yves von Cramon, & Lohmann, 2003). We hypothesize (as have other stuttering researchers) that the concept of activating an alternate (e.g., lateral) premotor system during speech production may be an essential component relative to fluency-enhancement via speech feedback (Alm, 2004, 2005; Snyder, 2004).

Although novel, the invocation of a dual premotor hypothesis relative to stuttering and fluency-enhancement is neither new nor frequently cited (Alm, 2004, 2005; Caruso, 1991; Molt, 1999; Snyder, 2004). Existing research suggests that sensory input engages the lateral premotor cortex (Schubotz et al., 2003). Further research into this phenomenon documents that (lateral) premotor engagement can be stimulated via modality-dependent (i.e., bottom-up) or property-dependent (i.e., top-down) perceptual attention (Schubotz et al., 2003). Modality-dependent (i.e., bottom-up) premotor engagement is driven by the sensory modality of the stimulus, such as auditory or visual speech feedback. Property-dependent (i.e., top-down) premotor engagement is driven by the stimulus characteristics (e.g., rhythmic cues or speech gestures embedded within the speech feedback). Accordingly, data suggest that the perception of speech feedback (regardless of the sensory modality in which it was perceived) can likewise induce activations within the premotor fields for speech-related processing in the CNS (Schubotz et al., 2003).

If a second speech signal does represent a unique form of speech feedback, then it is hypothesized that the engagement of an alternate (i.e., lateral) premotor system, via the perception of externally generated speech gestures embedded within a SSS, activates (fluent) speech related CNS processing. Accordingly, we hypothesize a link between the perception of externally generated speech gestures and production of (enhanced fluency) speech gestures by the cross-pollination of the motor theory and the dual premotor systems hypothesis (Goldberg, 1985, 1992; Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967; Liberman & Mattingly, 1985; Liberman & Whalen, 2000). In essence, exposure to a sensory modality (i.e., bottom-up) containing property-dependent (i.e., top-down) gestural cues utilizes an alternate (i.e., lateral) premotor system to innervate fluent speech production.

4.5. Idiosyncrasies of visual speech feedback

Various idiosyncrasies relative to the study and clinical use of visual speech feedback should be noted. For example, extensive pilot testing revealed that fluency-enhancement via self-generated visual feedback required active perceptual attention on the speech-related oral movements within the visual second speech signal; this phenomenon was also observed during the collection of these data. However, once participants actively attended to the visual SSS, fluency-enhancement appeared to be immediate. As a result, carry-over fluency-enhancement as a function of exposure to self-generated visual speech feedback may be limited, a finding that would be consistent with fluency-enhancement via an exposure to an auditory second speech signal (Bloodstein & Bernstein-Ratner, 2008; Starkweather, 1987). Additionally, as diversions of eye gaze are common secondary stuttering behaviors (Bloodstein & Bernstein-Ratner, 2008; Starkweather, 1987; Van Riper, 1982), clinical or prosthetic use of self-generated visual feedback in some clients may be limited until such secondary stuttering behaviors are controlled.

In addition, some participants reported that successful use of the self-generated visual speech feedback was not as "automatic" as their past experiences with auditory self-generated speech feedback; however, these participants required only 3–5 min of practice to gain proficiency at consciously using the oral movements within the visual speech feedback to enhance fluent speech. That is, once participants successfully learned to isolate and extract the pertinent (speech) gesture information from within the visual speech feedback, fluency-enhancement apparently became straightforward. This ad hoc finding may be in congruence with predictions made by property-dependent (top-down) premotor engagement (Schubotz et al., 2003); if this is indeed the case, then this observation could be in congruence with the CNS's involvement in fluency-enhancement, as suggested by the engagement of mirror neuron networks or the DPSH relative to stuttering.

Alternatively, this experiential learning curve reported by some participants may also suggest that self-generated visual speech feedback is not passively affecting speech processing in the CNS to enhance fluent speech production at all. Instead, exposure to self-generated visual speech feedback may be actively influencing the PNS, resulting in either global or local changes in speech rate, thereby allowing additional time for linguistic formulation to occur, resulting in the (fluent) speech motor execution of fully formed speech plans (Howell, 2002, 2004; Howell & Sackin, 2002). Further research is needed to infer if the exposure to self-generated visual speech feedback appears to enhance fluency passively (such as the passive activation of the CNS via the engagement of mirror neuron networks or the DPSH), or actively (such as the active engagement of the PNS resulting in changes in either global or local speech rate).

4.6. Technological and methodological limitations

The methodology employed in this study did have technological limitations. One potential limitation of this study was the dissimilar visual signal-to-noise ratio, as research participants were asked to focus on a mirror (synchronous) and a laptop monitor (asynchronous), which measured 40.6 cm (diagonal) and 35.6 cm (diagonal) respectively. Another potential limitation may be that the two speaking conditions, utilizing a mirror and a laptop display, share little commonality. Future investigators might attempt to create an improved hardware configuration allowing for the synchronous and asynchronous speaking conditions that has the flexibility to amplify the visual signal-to-noise ratio, as well introducing an additional speaking condition consisting of a motionless picture of the participants' lips, mouth and jaw.

Future investigators might also consider employing the use of a more sophisticated and powerful visual processing apparatus that has the ability to precisely quantifying a variety of differential visual delays within asynchronous speaking conditions. Finally, future investigators should consider increasing the number of participants, thereby increasing the study's statistical power such that the relationship between synchronous and asynchronous visual speech feedback may be documented with greater accuracy and precision.

4.7. Summary and conclusions

Data from this study reveal that self-generated visual feedback, in either its synchronous or asynchronous forms, significantly enhanced fluency in those who stuttering. Accounting for this phenomenon is difficult in that competing theories on fluency-enhancement, such as the engagement of mirror neuron networks (Kalinowski & Saltuklaroglu, 2003a,b), the EXPLAN model (Howell, 2002), and the DPSH (Alm, 2004, 2005; Snyder, 2004), appear to have theoretical frameworks that are potentially capable to integrate these data into their models of stuttering and fluency-enhancement. Clearly, further research is needed to clarify the nature of stuttering, speech feedback and fluency-enhancement.

Appendix A. Continuing education

1. The most efficient and immediate form of fluency-enhancement in those who stutter utilizes:
   a. psychological therapy.
   b. behavioral therapy.
   c. speech feedback.
   d. both a and b.
   e. none of the above.
2. Various forms of speech feedback in the form of a second speech signal could include:
   a. delayed auditory feedback.
   b. frequency altered feedback.
   c. auditory choral speech.
   d. delayed visual feedback.
   e. all of the above.
3. Visual feedback that requires the speaker to pause until the feedback ‘‘catches up’’ to his or her head movement is referred to as:
   a. synchronous.
   b. asynchronous.
   c. dyssynchronous.
   d. both a and b.
   e. none of the above.
4. Which of the following were are associated with enhanced fluency in those who stutter?
   a. visual choral speech.

  b. synchronous self-generated visual feedback.
  c. asynchronous self-generated visual feedback.
  d. all of the above.
  e. none of the above.

5. What is known to be the reason why asynchronous visual feedback enhances fluency in those who stutter?
   a. asynchronous visual speech feedback is sufficiently distracting to the person who stutters, thus enhancing fluency.
   b. asynchronous visual speech feedback sufficiently slowed the speakers' articulatory rate, thus enhancing fluency.
   c. asynchronous visual speech feedback sufficiently prolonged the speakers' syllabic production, thus enhancing fluency.
   d. exact mechanism that associates asynchronous visual speech feedback and enhanced fluency in those who stutter remains unknown.

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