MEASURING THE EFFECTS OF PROSTHETIC TACTILE PACING ON OVERT STUTTERING FREQUENCY IN ADULTS WHO STUTTER

by
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ABSTRACT

While the cause has been historically enigmatic, persistent stuttering exhibits distinct behavioral, neural and genetic characteristics. Throughout many years, a variety of motoric treatments have attempted to ameliorate overt stuttering behaviors; however, most therapeutic options provide unstable, effortful, and/or unnatural sounding results with high relapse rates. Conversely, research documents natural sounding speech coupled with stable and effortless reductions in overt stuttering frequency when a person who stutters is exposed to speech feedback of a second speech signal (i.e. choral speech). The most prolific clinical use of this technology is a prosthetically introduced auditory second speech signal; yet its current application has several technological and environmental limitations, and may not be tolerated well by users. Conversely, the tactile modality may be more comfortable relative to prosthetic implementation and thus better suited for activities of daily living. Prosthetic tactile speech feedback, in the form of a tactile second speech signal, is still a young technology and is currently in development. However, an immediate and inexpensive alternative to real-time speech feedback of a tactile second speech signal may be vibrotactile pacing administered through a smartphone application.

Thirteen adults with persistent stuttering participated in this study, which included data collection sessions once a week for four weeks over videoconference. Participants read three ~300 syllable, junior high passages under three different speaking conditions, including a control, a deactivated phone, and a activated smartphone application; moments of overt stuttering were counted by the primary investigator as well as a trained research assistant. The results of this study demonstrate a main effect of the tactile pacing smartphone application on overt stuttering frequency. Bonferroni post hoc analysis reveals significant differences between the control speaking condition and the vibrotactile smartphone application ($p=.000$) as well as between the deactivated smartphone and the vibrotactile smartphone application ($p=.033$). Based on these data, an inexpensive tactile pacing smartphone application, such as the StutterLess application used in this study, might be an inexpensive and beneficial prosthetic treatment option.

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TABLE OF ACRONYMS

PS	Persistent Stuttering
SLD	Stuttering Like Disfluencies
PWS	People Who Stutter
QoL	Quality of Life
CWS	Children Who Stutter
SLP	Speech Language Pathologist
ADL	Activities of Daily Living
AAF	Altered Auditory Feedback
SSS	Second Speech Signal
DAF	Delayed Auditory Feedback
FAF	Frequency Altered Feedback
OASES	Overall Assessment of the Speaker's Experience of Stuttering
RM-ANOVA	Repeated Measure Analysis of Variance

INTRODUCTION

Researchers typically cite persistent stuttering (PS) as a life-long speech disorder characterized by 3% or more stuttered syllables (i.e. speech blocks, whole word and partial word repetitions, prolongations, or postural fixations of sounds and/or syllables) during speech production (Bloodstein & Ratner, 2008). Stuttering like disfluencies (SLDs) typically emerge between 3 and 5 years of age in approximately 5% of children. Although data suggest that approximately 80% of children exhibiting SLDs spontaneously recover regardless of treatment (Yairi & Ambrose, 1999; Yairi, Ambrose, Paden & Throneburg, 1996), the remaining 20% will demonstrate PS throughout their lifetime (Bloodstein & Ratner, 2008; Van Brosel, 2014).

Coupled with overt stuttering behaviors, people who stutter (PWS) exhibit distinctly irregular neural activation patterns (Fox, 2000; Giraud, 2008; Chang, Kenney, Loucks & Ludlow, 2009; Kell, Neumann, von Kriegstein, Posenenske, von Gudenberg, Euler & Giraud, 2009; Ingham, Grafton, Bothe & Ingham, 2012). Abnormal activations within the cortico-basal-ganglia-thalamo-corticol (CBGTC) loop, which has demonstrated a significant role in motor preparation (Bohland, Bullock, & Guenther, 2010), have shown a positive correlation with the frequency and severity of stuttering behaviors (Braun, Varga, Stager, Schulz, Selbie, Maisog & Ludlow, 1997; Chang et al., 2009; Fox, 2000; Giraud, 2008; Ingham et al., 2012; Kell et al., 2009; Vanhoutte, Santens, Cosyns, van Mierlo, Batens, Corthals & Borsel, 2015; Vanhouttte et al., 2016). Atypical neural activation patterns associated with PS include hypo-activity in left-lateralized activations; hyperactivity in the cerebrum, cerebellum and right hemisphere

(De Nil, Kroll, Lafaille, & Houle, 2003; Fox, Ingham, Ingham, Hirsch, Downs, Martin & Lancaster, 1996; Watkins, Smith, Davis, & Howell, 2007; Xuan, Meng, Yang, Zhu, Wang, Yan & Yu, 2012; Brown, Ingham, Ingham, Laird, & Fox, 2005; Foundas, Corey, Angeles, Bollich, Crabtree-Hartman & Heilman, 2003; Fox, 2000; Sowman, Crain, Harrison, & Johnson, 2012); decreased cerebral glucose uptake (Wu et al., 1995); and significantly increased dopaminergic activity (Wu et al., 1997). These neurological abnormalities manifest themselves in compensatory behavioral moments of stuttering as a means to overcome a 'block at the central level' that is experienced by those who stutter (Guntupali, Kalinowski, & Saltuklaroglu, 2006; Snyder, Waddell, & Blanchet, 2016). Therefore, enhanced fluency is associated with gross changes in neural processing (Vanhoutte, et al., 2015; Vanhoutte et al., 2016; Wu et al. 97; Alm, 2004; Salmelin, Schnitzler, Schmitz, Jancke, Witte & Freund, 1998; Watkins et al., 2007; Chang et al., 2009).

In addition to behavioral and neurological characteristics, research documents a genetic component of stuttering (Ambrose, Cox & Yairi, 1997). Research has repeatedly reported this genetic link in twins with PS (Felsenfeld, Kirk, Zhu, Statham, Neale & Martin, 2000; Dworzynski, Remington, Rijsdijk, Howell & Plomin, 2007; Fagnani, Fibiger, Skytthe & Hjelmborg, 2011; Bloodstein, 1961; Ooki, 2005) as well as in families (Viswanath, Lee & Chakraborty, 2004; Kidd, Kidd & Records, 1978; Seider et al., 1983; Cox, Seider & Kidd, 1984). Kang et al. (2010) confirmed the presence of genetic features, as they documented a polygenetic basis for PS. While it is unlikely that all families and populations share the same genetic markers (Alm and Risberg, 2007), links causal to stuttering have been discovered on chromosomes 12 (Riaz, Steinberg, Ahmad, Pluzhnikov, Riazuddin, Cox & Drayna, 2005), 3q (Raza, Riazuddin & Drayna, 2010), 16q (Raza, Amjad, Riazuddin & Drayna, 2012), 2p, 3p (Raza, Gertz, Mundorff, Lukong, Kuster, Schaffer & Drayna, 2013), and 10 (Domingues, Olivera, Oliveira, Juste, Andrade, Giacheti & Drayna, 2014) in specific populations within the stuttering community (Kang et al., 2010; Lee, Kang, Drayna & Kornfeld, 2011; Raza, Mattera, Morell, Sainz, Rahn, Gutierrez & Drayna, 2015; Riaz et al., 2005; Shugart, Mundorff, Kilshaw, Doheny, Doan, Wanyee & Drayna, 2004; Suresh, Ambrose, Roe, Pluzhnikov, Wittke-Thompson & Cox, 2006; Wittke-Thompson, Ambrose, Yairi, Roe, Cook & Cox, 2007). An underlying connection between these different polygenetic mutations was unidentified until results from Raza et al.'s (2015) study documented a genetic mechanism that unifies each of these mutations to intracellular trafficking through *Adaptor Related Protein Complex 4 Epsilon 1 Subunit (AP4E1)*. Accordingly, researchers hypothesize that any new links discovered in the future will also be attributed to deficits in this genetic process.

While a complete understanding of the etiology and nature of PS remains elusive, research documents a number of negative consequences when living with stuttering, including social, personal, professional, and quality of life (QoL), beginning in childhood and extending throughout adulthood. Children who stutter (CWS) were more likely to be socially rejected, more likely to be perceived negatively, less likely to be popular, and less likely to be nominated as a 'leader' compared to fluent peers (Davis S., Howell P., Cooke F., 2007). In one study CWS were six times more likely to have a social anxiety disorder, seven times more likely to have a subclinical generalized anxiety disorder, and four times more likely to have any anxiety disorder (Iverach, Jones, McLellan, Lyneham, Menzies, Onslow, 2016). Adolescents who stutter (Blood & Blood, 2004) and CWS (Mooney & Smith, 1995) are also more susceptible to bullying.

Data documents that Speech-Language Pathologists (SLPs) (Lass, Ruscello, Pannbacker, Schmitt & Everly-Myers, 1989; Silverman, 1982; Turnbaugh, Guitar & Hoffman, 1979; Woods & Williams, 1971; Yairi & Williams, 1970), teachers (Crowe & Walton, 1981; Lass, Ruscello, Schmitt, Pannbacker, Orlando, Dean & Bradshaw, 1992; Woods & Williams, 1976; Yeakle & Cooper, 1986), college students (Betz, Blood & Blood, 2008), parents (Crowe & Cooper, 1977; Woods & Williams, 1976), school age children (Franck, Jackson, Pimentel, & Greenwood, 2003; Hartford & Leahy, 2007) and protective service workers (Li, Arnold & Beste-Guldborg, 2016) hold negative stereotypes of PWS (i.e. quiet, reticent, guarded, avoiding, nervous, and afraid). Due to stereotyping and stereotype threats (i.e. when a person feels fear of conforming to the predetermined stereotype that has been ascribed to him or her) PWS may not reach their full potential (Steele & Aronson, 1995) or experience negative professional assessment and overall decreased QoL (Schmader, Johns & Forbes, 2008; Sekaquaptewa & Thompson, 2003).

The fundamental attribution error is the natural tendency of a person to perceive others' behaviors as negative or awkward and attribute them to their psychological character even when environmental involvement is known (Jones & Harris, 1967); accordingly, the fundamental attribution error can be extended to account for the misattribution of stuttering to psychological anxiety, unfriendliness, and shyness. This incorrect assumption has led to discrimination and negative stigmas (Boyle, 2013). PWS have reported that the negative perception of their speech has led to erroneous assessments within a professional setting, affected their ability to get a job, as well as hindered the advancement of their career (Hurst & Cooper, 1983; Klein & Hood, 2004; Williams, 2006). Due to unfounded perceptions of stuttering, adults who stutter experience a significant negative impact on their lives, which in turn decreases their QoL (Craig, Blumgart & Tran, 2009; Dorsey & Guenther, 2000; Franck et al., 2003; Hawton, Green, Dickens, Richards, Taylor, Edwards & Campbell, 2011; Hughes, Gabel, Irani, & Schlagheck, 2010; McGee, Kalinowski & Stuart, 1996; McKinnon, Hess & Landry, 1986; Yaruss, 2010) and creates a feeling of social isolation (Allport, 1985). Further, adults with PS were found to be at an increased risk of poor emotional performance in vitality, social functioning, emotional functioning, and mental health status (Craig et al., 2009).

Given the documented negative impacts relative to the QoL of PWS, a wide variety of stuttering treatments, most commonly psychological or behavioral (Bloodstein & Ratner, 2008), have been designed to reduce overt stuttering frequency and improve QoL. While peer reviewed data from behavioral, suggest overall treatment efficacy (Blomgren, 2010; Bloodstein & Ratner, 2008), an exhaustive review of therapeutic approaches over the course of decades found that although these approaches are often diametrically opposed in both theoretical basis and implementation method, yet data suggest that all treatment options yield similar results (Bloodstein & Ratner, 2008; Guntupalli et al., 2006; Dayalu & Kalinowski, 2002). Moreover, these approaches often do not produce long-term amelioration, particularly relative to real world application in ADL (Yaruss, Scott, Quesal, Reeves, Lawrence, Molt, Kluetz, Caruso, McClure &

Lewis, 2002; Stewart & Richardson, 2004; Blomgren, Roy, Callister & Merrill, 2005; Blomgren, 2010).

When considering the often unstable (Bloodstein, 1995; Kalinowski & Saltuklaroglu, 2004; Stewart & Richardson, 2004; Yaruss et al., 2002), effortful (Dayalu & Kalinowski, 2002; O'Brian, Onslow, Cream & Packman, 2003; Perkins, 1983; Webster, 1980), unnatural sounding (Armson & Kalinowski, 1994; Dayalu & Kalinowski, 2002; Kalinowski, Noble, Armson, & Stuart, 1994; McClean, Kroll & Loftus, 1990; Metz, Schiavetti & Sacco, 1990; Story, Alfonso & Harris, 1996; Onslow et al., 1992) results with high relapse rates (Saltuklaroglu & Kalinowski, 2005), a need for better treatment options is clear. Often overlooked, early examples of exogenous (non-behavioral) treatment strategies, such as metronomic pacing, rhythmicitiy, and syllabification, provided promising results (Bloodstein & Ratner, 2008; Brayton & Conture, 1978; Hutchinson & Navarre, 1977; Perkins, Bell, Johnson & Stocks, 1979). More recent implementations of exogenous treatment strategies include prosthetic stuttering management (Kalinowski et al., 2004) and pharmaceutical stuttering management (Kalinowski et al., 2004). Given the significant genetic components of stuttering, current research is targeting pharmaceutical intervention, such as dopaminergic antagonists (Wu et al., 1997), and prosthetics that utilize altered auditory feedback (AAF) through a second speech signal (SSS) (Kalinowski et al., 2004). While pharmaceuticals have documented some success in certain cases of PS, the side effects and risks associated with many drugs in current use (i.e. weight gain, dry mouth, fatigue, tardive dyskinesia, galactorrhea, sexual dysfunction, amenorrhea, and dysphoria) have prevented mainstream implementation, especially with children and those with a lower degree of stuttering severity (Bothe, Davidow, Bramlett, Franic, & Ingham, 2006; G.A. Maguire et al., 2000).

On the contrary, utilizing a SSS via AAF (in the forms of delayed auditory feedback (DAF) and frequency altered feedback (FAF)) is suggested to be the most effective treatment approach to PS (Armson & Stuart, 1998; Hargrave, Kalinowski, Stuart, Armson, & Jones, 1994; Howell, Sackin & Williams, 1999; Kalinowski, Stuart, Wamsley & Rastatter, 1999; Macleod, Kalinowski, Stuart, & Armson, 1995; Sparks, Grant, Millay, Walker-Batson & Hynan, 2002; Stuart, Kalinowski, Rastatter, Saltuklaroglu & Dayalu, 2004; Van Borsel, Reunes & Van den Bergh, 2003). A SSS is the speech feedback of a second linguistically similar and simultaneous speech signal relative to the originally spoken speech signal (Andrews, Howie, Dozsa & Guitar, 1982; Kalinowski et al., 2000; Snyder et al., 2009a; Snyder et al., 2009b). Research has demonstrated that SSSs are effective whether it be implemented via the auditory, visual, or tactile sensory modality. (Hargrave et al., 1994; Snyder et al., 2009a; Snyder et al., 2009b; Kalinowski et al., 2000; Snyder et al., 2016) However, commercially available applications of SSSs relative to fluency enhancement are currently limited to AAF. Given optimal environmental circumstances, this method produces an excellent reduction of overt stuttering frequency with minimal client discomfort (Armson & Stuart, 1998; Armson, Foote, Witt, Kalinowski & Stuart, 1997; Hargrave et al., 1994; Howell et al., 1999; Ingham, Moglia, Frank, Ingham, & Cordes, 1997; Kalinowski et al., 1993; Kalinowski et al., 1996; Kalinowski et al., 1999; Macleod et al., 1995; Sparks et al., 2002; Stuart et al., 1996; Stuart et al., 1997; Stuart et al., 2004; Van Borsel et al., 2003). However, in loud environments, the signal to noise ratio creates a challenging environment for PWS; therefore real-world application is problematic (Lincoln, Packman & Onslow, 2006).

Appreciating the natural challenges and limitations of prosthetically introduced AAF SSSs, researchers have studied the prosthetic use of tactile SSSs as a better and more comfortable means to enhance fluency in those who stutter (Snyder et al., 2009). Self-generated tactile speech feedback has been shown to significantly decrease stuttering behaviors (Waddell, Goggans & Snyder, 2012). In furthering this research paradigm, tactile speech feedback researchers have demonstrated that using an accelerometer, rather than a microphone, to capture the speakers' primary SSS provides comparable fluency enhancement; as a result, accelerometer based prosthetic tactile speech feedback devices are functionally immune from the signal to noise challenges inherent in auditory speech feedback methodologies (Waddell et al., 2012). Accordingly, tactile speech feedback fluency enhancement holds promise relative to the effective reduction of overt stuttering behaviors; however, prosthetic tactile speech feedback is still a young technology and currently in development, and is thus not commercially available. However, fluency enhancement as a function of tactile stimulation may be approximated with ubiquitous handheld smartphone devices, all of which are equipped with tactile stimulators (Hwang, Song, Gim, 2015). One such example may be the infusion of a known exogenous fluency enhancing methodology, in the form of pacing (Bloodstein & Ratner, 2008), with tactile stimulation provided by modern smartphones. Accordingly, researchers and entrepreneurs from StutterLess LLC (Carter & Weaver, Limited Liability Company 1104961, 2016) have developed an inexpensive smartphone application that provides pacing via rhythmic tactile stimulation.

Although this unconventional approach has yet been examined, the promise of an inexpensive and tactile pacing smartphone application has the potential of providing a novel stuttering treatment alternative.

METHODS

Participants and study design

Thirteen adults with PS (range= 23-69 years; mean= 38.38; SD=14.06), four self-identified females and nine self-identified males, participated in this study. Participants reported English proficiency and no additional diagnosed attention, speech, hearing or language disorders. As some researchers qualify PS as a function of frequency, three percent or more stuttered syllables during the control speaking condition served as inclusion criteria for this study; for the purposes of this study, primary overt stuttering behaviors were defined as gestural prolongations, repetitions, and inaudible gestural fixations. Participants also completed the Overall Assessment of the Speaker's Experience of Stuttering (OASES) (Yaruss & Quesal, 2006). Each participant verbally acknowledged an understanding of this study as well as informed consent prior to the first session.

Protocol

This study, which aimed to measure the effects of tactile pacing delivered by a smartphone application on overt stuttering frequency, was comprised over four weeks. Data was collected at the initial interview and at the end of each week thereafter. All data was collected over videoconference.

During the initial session, participants provided informed consent prior to participating in this study. Each participant then completed the OASES, as a baseline self-reported measure. Stuttering impact scores were calculated for individual sections of the survey as well as a total impact score based upon each participant's answers. Eight participants received overall impact ratings of Mild-to-Moderate, four received Moderate ratings, and one received a Moderate-to-Severe rating. For participant demographic information, see Table 1.

During each data collection session, participants were instructed to read a different passage aloud under three different speaking conditions. All of the passages used in this study have been used in previous research (Snyder et al., 2009); the first 300 syllables were used in data analysis. Latin Squares were used to balance both the reading passages and order of speaking conditions. Participants were asked to refrain from using any fluency enhancing techniques learned in therapy or self-taught compensatory strategies. Individuals were also instructed to use the StutterLess application no less than five times each day while participating in this research.

Table 1

	Gender:	Age:
Participant 1	F	30
Participant 2	M	32
Participant 3	M	24
Participant 4	F	23
Participant 5	M	34
Participant 6	F	55
Participant 7	M	69
Participant 8	M	50
Participant 9	M	43
Participant 10	M	23
Participant 11	M	37
Participant 12	F	43
Participant 13	M	36

Table 1: Distribution of age and gender

Apparatus

During this study, participants were provided with a tactile pacing smartphone application for either iOS or Android mobile device platform. The mobile application, StutterLess, was offered to participants in a pre-released stage of software development via a third-party application, Ionic View Version e30ae3ef (Drifty, 2017), which allows software developers to test and share their applications across different platforms. This application utilizes a smartphone to provide speech-related prosthetic tactile pacing. Upon opening the application, participants were instructed to gently touch the screen of their mobile device each time they initiated speech, thereby activating the metronomic tactile pacing. Upon sensing the vibrations, participants were instructed to pair speech initiation with the tactile signal. Participants were asked to maintain their natural speed and prosody of speech. When the application is activated, touching the screen delivers pulsating tactile vibrations through the phone's tactile stimulators. Frequency of metronomic tactile pacing can be adjusted from every 0.6 seconds to one second. Participants were instructed to find their optimal frequency of which they were most comfortable; each participant reported setting the tactile frequency at 0.6 seconds.

Control and experiment speaking conditions

Three speaking conditions were used in this study. During the control speaking condition, individuals were instructed to read passages aloud without the use of any fluency enhancing techniques with phones turned off and out of reach. For the next speaking condition, participants were instructed to speak without using any fluency enhancing techniques and touch their inactive phone in the same manner in which they would use the application. In the final speaking condition, participants were asked to refrain from using any fluency enhancing techniques while touching their active smartphone running the StutterLess application.

Data collection and reliability analysis

Each data collection session was held over videoconferencing (Skype version 8.16.0.4). The sessions were recorded using the software application Telestream ScreenFlow Version 6.2 (28271), which recorded audio and video using the laptop's internal camera and microphone. Stuttered syllables were counted from the first 300 syllables of each passage. Intrajudge and interjudge reliability compared the analysis of 10% of randomly chosen speech samples with the original analysis of the data. Relative to stuttering frequency, an intrajudge syllable-by-syllable agreement was > 0.94, with an interjudge syllable-by-syllable agreement of > 0.89, as indexed by Cohen's kappa (Cohen, 1960). Kappa values exceeding 0.75 suggest an excellent agreement beyond chance (Fleiss, 1981)

RESULTS

Stuttering Frequency and Data Transformation

Using the raw data, the mean frequency of stuttered syllables for the control speaking condition was 20.46 (SD=17.16). For the condition in which participants lightly touched their inactive phone, the mean frequency of stuttered syllables was 18.04 (SD=16.19). For the experimental condition testing the smartphone application, the mean frequency of stuttered syllables was 15.00 (SD=13.46). Within the small sample size of this study, overt stuttering frequency varied greatly between participants. To normalize the data distribution, a square root transformation was performed (Onslow et al., 2006).

The effects of smartphone application on stuttering frequency with time as a covariant

Given the possibility that time served as a covariant in this dataset, a repeated measure analysis of variance (RM-ANOVA) of tactile pacing speaking condition on overt stuttering frequency, including time (i.e. progression of sessions over 4 weeks) as a covariant was performed [$F(2,68)=2.215$, Greenhouse-Geisser $p=.117$, $\eta^2=.061$]; the interaction between the tactile pacing speaking condition by time was [$F(2,68)=0.121$ Greenhouse-Geisser $p=.1886$, $\eta^2=.004$]. With data suggesting that time was not functioning as a covariate, a univariate analysis relative to the tactile smartphone application and time was performed and revealed no interaction [$F(1,46)=0.261$, $p=0.612$, $\eta^2=.006$], thereby confirming that time did not serve as a covariate in this dataset. Accordingly, the RM-ANOVA was re-run without time as a covariate as a means to enhance the power of these data to detect a main effect of tactile speech feedback speaking condition. See Table 2 for averages of stuttering frequency as a function of time.

Table 2

Week	Control	Deactivated Smartphone	Smartphone with Tactile Pacing Application
Initial Evaluation	Mean=21.23, SD=16.58	Mean=19.08, SD=14.65	Mean=16.38, SD=16.72
End of Week 1	Mean=20.15, SD=16.53	Mean=18.23, SD=19.01	Mean=16.00, SD=14.62
End of Week 2	Mean=20.46, SD=18.10	Mean=18.38, SD=16.67	Mean=13.85, SD=8.95
End of Week 3	Mean=19.78, SD=20.37	Mean=15.78, SD=15.86	Mean= 13.22, SD=13.94

Table 2: Mean overt stuttering frequency by condition over time

The effects of smartphone application on stuttering frequency without time as a covariant

The previous measure was then repeated, excluding time as a covariant, as a means to improve the power of the study. This RM-ANOVA revealed significant main effect of the smartphone application on overt stuttering frequency [$F(2,70)=13.112$, Greenhouse-Geisser $p=.000$, $\eta^2=.273$]. The interaction between stuttering frequency as a function of speaking condition by participant yielded [$F(2,70)=1.569$, Greenhouse-Geisser $p=.075$, $\eta^2=.350$]. See figure 1 for a distribution of overt stuttering frequency for each speaking condition, collapsed over time, for each participant. These data reveal that eight out of thirteen participants saw reductions in overt stuttering frequency while using the tactile pacing smartphone application.

Figure 1

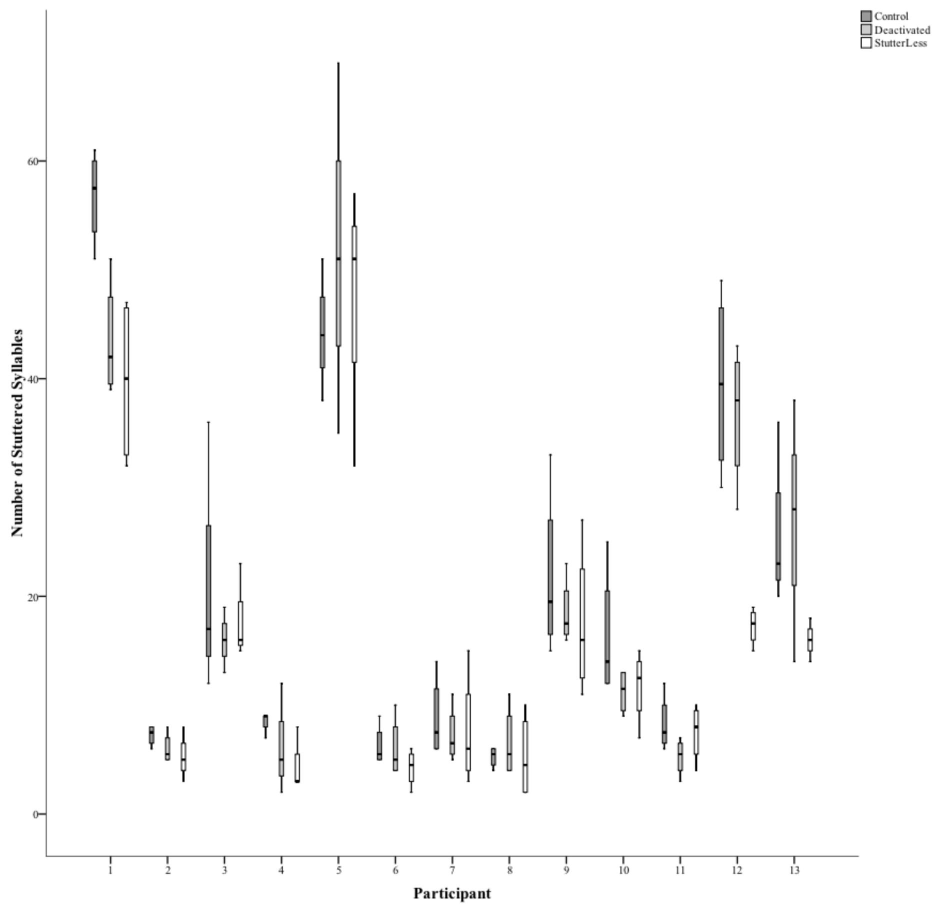

Figure 1: Distribution of overt stuttering frequency for each speaking condition, collapsed over time, for each participant

Post-hoc of speaking condition

Bonferroni post-hoc comparisons demonstrate that the control speaking condition is significantly different from the tactile pacing smartphone application ($p=.000$) and the deactivated smartphone speaking condition is significantly different from the tactile pacing smartphone application ($p=.033$). However, the control and deactivated phone speaking conditions are not significantly different from each other ($p=.071$).

Self-Reported Stuttering Severity

As trending data suggests participants may have responded to the tactile smartphone application differently, analyses were performed if an ideal client for the tactile pacing smartphone application could be identified with the available data. The hypothesis that participants with a higher level of self-reported severity, based upon the OASES, would respond best to the application was unsupported [$F(1,46)=.436$, $p=0.536$, $\eta^{2}=0.009$]. See Table 3 for OASES severity by participant. Interestingly, an apparent inverse relationship between overt stuttering frequency and OASES severity was observed (Figure 2).

Table 3

Participant	OASES – Section 1: General Information	OASES – Section 2: Personal Reactions	OASES – Section 3: Communication in Daily Situations	OASES – Section 4: Quality of Life	OASES – Total Severity Score
Participant 1	Moderate	Moderate	Moderate	Moderate	Mild-to-Moderate
Participant 2	Mild-to-Moderate	Moderate	Moderate	Mild-to-Moderate	Mild-to-Moderate
Participant 3	Moderate	Moderate	Moderate	Mild	Mild-to-Moderate
Participant 4	Moderate	Moderate	Moderate	Mild-to-Moderate	Mild-to-Moderate
Participant 5	Mild-to-Moderate	Moderate	Mild-to-Moderate	Moderate	Mild-to-Moderate
Participant 6	Mild-to-Moderate	Moderate	Mild-to-Moderate	Mild-to-Moderate	Mild-to-Moderate
Participant 7	Moderate-to-Severe	Severe	Moderate	Moderate	Moderate-to-Severe
Participant 8	Mild-to-Moderate	Moderate	Moderate-to-Moderate	Moderate	Mild-to-Moderate
Participant 9	Moderate-to-Severe	Severe	Moderate	Moderate-to-Severe	Moderate
Participant 10	Moderate	Moderate	Moderate	Mild	Mild-to-Moderate
Participant 11	Moderate-to-Severe	Moderate-to-Severe	Moderate	Mild	Moderate
Participant 12	Moderate	Moderate-to-Severe	Moderate	Moderate	Moderate
Participant 13	Mild-to-Moderate	Moderate-to-Severe	Moderate-to-Severe	Moderate	Moderate

Table 3: Section 1, 2, 3, and 4 are comprised of general information, personal reactions to stuttering, communication in daily situations, and quality of life respectively.

Figure 2

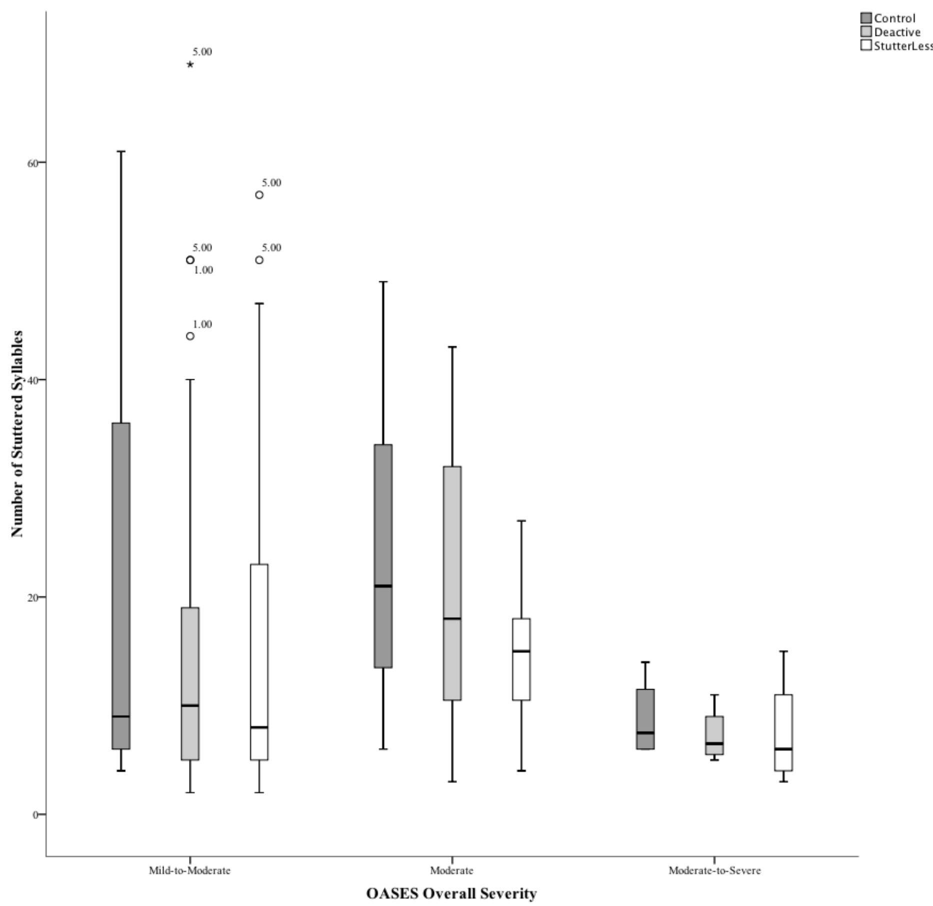

Figure 2: Overt Stuttering Frequency as a function of Self-Reported Stuttering Severity

DISCUSSION

Data suggests that the StutterLess smartphone application provided reductions in overt stuttering frequency for a majority of its users. Additionally, data suggests that the resulting fluency enhancement was relatively stable and did not adapt over time. Considering the inexpensive and globally accessible nature of a multiplatform smartphone application, the StutterLess application may be a worthwhile option for those who stutter to explore.

While the StutterLess tactile pacing smartphone application provided a significant reduction in overt stuttering frequency, these data suggest that fluency enhancement from tactile pacing may not be as powerful or efficient as methodologies using the SSS (Kalinowski et al., 2004). One explanation for the profound fluency enhancement associated with exposure of a SSS may be found in the mirror neuron systems hypothesis (MNSH) (Snyder et al., 2016; Snyder & Jones, 2017). When a person with PS is exposed to a SSS, it is hypothesized that mirror neurons are activated as the exogenous motoric gestures (i.e. speech) of another person are immediately mapped for endogenous imitation, thereby allowing the person with PS to fluently initiate speech gestures (Snyder et al., 2016). Data from recent studies suggest that activation of mirror neurons results in significantly effective, effortless, stable, and natural sounding fluent speech, which suggests that the compensatory nature of overt stuttering behaviors are neurologically bypassed via the activation of mirror neuron systems (Snyder et al., 2016). As this study likely did not result in the activation of mirror neurons, it is expected that the resulting fluency enhancement will not be as robust.

While data documents that the StutterLess smartphone application provides reductions in overt stuttering frequency, the efficacy of fluency enhancement varied significantly between participants. Initial analysis of these data was unable to account for this variation, as self-reported severity scores (OASES) within this study were unable to successfully predict the efficacy or efficiency of subsequent fluency enhancement. However, initial genetic data suggests differential treatment results as a function of polygenetic subtypes of stuttering (Drayna, 2017). As a result, researchers may consider including genetic data as a covariant in future studies. Additionally, a larger sample size of participants, with a balance of overt stuttering severity, will likely provide greater power to detect differences within the dataset. Clinically, the application may be utilized as a therapeutic supplement, perhaps as a means of priming targeted speech-motor therapy behaviors. The application also seems to have a viable future for intermittent use to mediate disfluencies in specifically difficult speaking circumstances or environments. Examples include talking on the telephone, conference calls, ordering at a drive through, during presentations and other professional or social situations.

Finally, the combination of an inexpensive smartphone application reduces the financial barrier of entry for its users; additionally, participants in this study reported no accompanying health or comfort issues when using the StutterLess tactile pacing smartphone application. While resulting fluency enhancement varied by participant, and while the accompanying fluency enhancement was not as powerful or robust as that of a SSS, tactile pacing was still found to be effective for the majority of its users, while entirely avoiding the documented challenges associated with an auditory SSS (Bothe, Finn & Bramlett, 2007; Gallop & Runyan, 2012; Pollard, Ellis, Finan & Ramig, 2009).

LIMITATIONS

The small sample size may have impacted the power and external validity of this study; additionally, longer reading passages may provide a better sample of overt stuttering behaviors. Additionally, participants in this study varied greatly relative to overt stuttering severity; accordingly, future research may balance overt stuttering severity within the participant group. This study utilized videoconferencing as a means of increasing participant recruitment. However, online data collection over videoconference was accompanied by additional complications, such as the quality of Internet conductivity and signal interruptions. Additionally, should this study be replicated, additional surveys and measures on client speech effort and client speech naturalness may be beneficial relative to the overall effectiveness of prosthetic tactile pacing administered through a smartphone application. Finally, future studies may consider incorporating a conversational speech sample in addition to reading passages, as a means to better represent the effects of the technology on overt stuttering frequency and QoL.

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