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Self-Contained In-The-Ear Device To Deliver Altered Auditory Feedback: Applications For Stuttering

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Abstract

The design and operating characteristics of the first self-contained in-the-ear device to deliver altered auditory feedback is described for applications with those who stutter. The device incorporates a microdigital signal processor core that reproduces the high fidelity of unaided listening and auditory self-monitoring while at the same time delivering altered auditory feedback. Delayed auditory feedback and frequency-altered feedback signals in combination or isolation can be generated to the user in a cosmetically appealing custom in-the-canal and completely in-the-canal design. Programming of the device is achieved through a personal computer, interface, and fitting software. Researchers and clinicians interested in evaluating persons who stutter outside laboratory settings in a natural environment and persons who stutter looking for an alternative or adjunct to traditional therapy options are ideal candidates for this technology. In both instances an inconspicuous ear level alternative to traditional body worn devices with external microphones and earphones is offered.

Key words: digital signal processor, delayed auditory feedback, frequency altered feedback, stuttering.

Self-Contained In-The-Ear Device To Deliver Altered Auditory Feedback: Applications For Stuttering

The application of altered auditory feedback in an attempt to improve speech communication with those suffering from speech and language communication disorders has been ongoing for decades. Delayed auditory feedback (DAF) has been widely utilized with a diversity of disorders including aphasia,[7] dysarthria,[14] dyspraxia,[22] Parkinson's disease,[11] and vocal tremor.[24] The most popular application of altered auditory feedback in the field of communication sciences and disorders has, however, been with stuttering.

Manifestations of the altered auditory feedback known to inhibit stuttering include DAF, auditory masking or masked auditory feedback (MAF), frequency-altered feedback (FAF), and reverberation. DAF and FAF have been shown to be more effective in inhibiting stuttering frequency than MAF.[16,18] Although Howell et al.[16] reported FAF to be more effective than DAF in inhibiting stuttering, others have reported DAF and FAF to be equally effective.[18, 25] Traditionally these forms of altered auditory feedback have been generated by electronic signal processing devices, however, passive mechanical devices may produce altered auditory feedback effects as well.[29] The mean in which altered auditory feedback inhibits stuttering remains undetermined.

Positive findings have led to the suggestion of developing a wearable prosthetic device employing altered auditory feedback as an adjunct or alternative to current stuttering therapy.[4, 19] Almost all behavioral stuttering therapies from the 1800s to the present day have used slow speech rate in some form as a therapeutic strategy.[30] That is, those who stutter are trained to reduce speech rate via specific articulatory/vocal targets. Unfortunately, while speech may be more fluent following stuttering therapy it is typically unnatural sounding[20] and generalization of these "motoric strategies" from the therapy room to situations of daily living is difficult and relapse is common.[6] For these individuals, a therapeutic approach using a prosthetic device may be more beneficial. This reasoning is fivefold: First, the inhibition of stuttering under altered auditory feedback is achieved virtually spontaneously with no conscious effort similar to that observed with choral or shadowed speech.[2] Second, altered auditory feedback inhibits individuals with mild and severe stuttering without a sacrifice in perceived speech naturalness.[31] Third, stuttering inhibition occurs during both the production of conversational speech and oral reading.[5] Fourth, a significant reduction in stuttering frequency can be achieved with monaural feedback regardless of ear relative to nonaltered feedback.[27] Finally, the robust effects of altered auditory feedback occur outside the laboratory environment (i.e., public speaking in front of various audience sizes[3] and speaking on the telephone to strangers[32]).

It has been our opinion that any prosthetic device must meet two criteria. First, it should be "acoustically invisible."[4, 28] In other words, the device should reproduce the high fidelity of unaided listening and auditory self-monitoring while at the same time delivering optimal altered feedback. Optimal altered feedback has been operationally defined as those parameters that maximize stuttering reduction while at the same time are minimally distorted (i.e., sounding as close to nonaltered feedback).[4, 28] Delays as short as 50 ms[21] and alterations in frequency as little as plus/minus one-quarter of an octave have proven to be maximally effective.[15, 28] Second, and almost certainly the most important criterion, a prosthetic device should be cosmetically appealing. In this case, cosmetically appealing is defined as an inconspicuous self-contained ear level device. The use of altered auditory feedback as a therapy tool has been used in the past, however, devices have not been self-contained at ear level.[10, 12, 13, 23, 26] Simply put, technology has been limited to notoriously conspicuous devices that are body worn incorporating additional head worn pieces for signal delivery.

We recently developed the first self-contained ear-level device for application with those who stutter. The most salient feature of the new device is its inconspicuous nature and clean digital signal reproduction. This device employs DAF and FAF. What follows herein is a report of its design and operating characteristics.

Microdigital Signal Processor (DSP) Device Core

The TOCCATA™ Digital Processor System is the micro digital signal processor (DSP) core of the self-contained ear-level device. The flexibility of the TOCCATA™ allows for the implementation of DAF and FAF algorithms, while meeting the constraints of low-power consumption, high fidelity, and small size. The chipset incorporates a 16-bit general-purpose software-programmable Harvard architecture DSP (RCore); a Weighted Overlap-Add (WOLA) filter bank coprocessor and a power-saving input/output controller for analysis filtering, gain application and synthesis filtering; and a low noise14-bit analog to digital (A/D) and a 14-bit digital to analog (D/A) converter for high fidelity sound production. The performance operating characteristics and architecture of the TOCCATA™ micro DSP core are presented in Table 1 and Fig. 1, respectively.

Device Construction

The ear-level device to inhibit stuttering was constructed in both an in-the-canal (ITC) and completely-in-the-canal (CIC) custom made shell design (see Fig. 2). Figure 3 illustrates the ITC model *in situ.* The shells were generated from an ear impression and fabricated by a standard light-curable acrylic shell mold material (Audalite™). In addition to the DSP core described above, both models incorporate an electret condenser microphone (Knowles TM4546 and Knowles EM4346 for the CIC and ITC model, respectively) and a Class D amplified magnetic receiver (Knowles ES3207). Both models utilize multiple channels, automatic gain control input, adaptive feedback suppression, dual time constants, microphone noise suppression, and a noise attenuation algorithm. The ITC model includes a volume control while the CIC model implements wide dynamic range compression without volume control. Size 312 and 10 zinc-air batteries power the ITC and CIC model, respectively.

PC Interface

Programming for communication between computers and the device is established through a hardware interface. This can be achieved via a serial RS-232C cable to the serial (COM) port (e.g., AudioPro, Micro-DSP or Hi-Pro™, Madsen Electronics) or by USB connection via a hearing aid programming interface PC Card (e.g., Microcard, Micro-Tech). Linkage to the PC is achieved between the device and the interface with a standard CS44 programming 9-pole D-range male/female cable.

Fitting Software

A Microsoft® Windows® based operating system (i.e., Windows® 95, Windows® 98, or later) fitting software was designed to work as a complete selection, fitting, and programming tool for the stuttering inhibition device. It was designed to be simple, easy, and comprehensive for future application in clinical settings. The minimum computer system requirements include Intel® Pentium® Processor 166 MHz, 16 MB RAM, and 20 MB of free disk space.

The fitting software allows access to system information, interface connection status, and fitting parameters. The fitting parameters include FAF (i.e., plus/minus shift to 2000 Hz in 500 Hz increments), DAF (i.e., 0-128 ms), linear gain control (i.e., four 5 dB step size increments), and independent eight band 20 dB gain controls (with center frequencies of 250, 750, 1250, 2000, 3000, 4000, 5250, and 7000 Hz). The software allows for customized programming of DAF and FAF alone or in combination. Figure 4 illustrates the user interface of the fitting software.

Electroacoustic Performance Characteristics

With respect to electroacoustic performance,[1] the following is characteristic of both ITC and CIC models: The frequency range limit of the devices is 200-8000 Hz with a flat *in situ* response. The high frequency average (i.e., 1000, 1600, and 2500) full-on gain is typically 10-20 dB. Total harmonic distortion is les than 1%. Maximum saturated sound pressure output is approximately 105 dB SPL with a high frequency average of 95-100 dB SPL. Equivalent input noise is less than 24 dB. Typical coupler frequency responses for both models are shown in Fig. 5.

The frequency altering capabilities of the devices are illustrated in Fig. 6 for the CIC model. A synthetic vowel [æ] was generated[8] and played in sound field to each device while coupler responses were recorded. Three recordings were made with each device: no alteration, maximum frequency shift up, and maximum frequency shift down (as described above). What are evident in Fig. 6 are clear shifts of the formant frequencies during frequency alterations relative to the nonaltered frequency response. Essentially identical results are achieved with the ITC model as well.

Discussion

The present research and clinical application of an inconspicuous self-contained ear-level device to inhibit stuttering is obvious: researchers and/or clinicians interested in evaluating persons who stutter outside laboratory settings in a natural environment and persons who stutter looking for an alternative or adjunct to traditional therapy options are ideal candidates. The appeal of the device can be supported both practically and empirically.

First, on a practical level, these devices free researchers from the reliance on generating altered auditory feedback via devices that are not *in situ* (e.g., racks of electronic signal processing equipment). For the person who stutters, the device has clear cosmetic appeal in the in-the-ear self-contained construction. This is an advantage to previously reported devices that are cumbersome requiring ear phones and or additional exterior microphones.[10, 12, 13, 23, 26] Second, on an empirical level, the robust effects of DAF and FAF observed in laboratory and controlled situations of daily living suggest that the device should have some therapeutic success. There is previous research that suggests a wearable, albeit not ear level device, delivering altered auditory feedback can maintain long-term inhibition of stuttering.[9] The "Edinburgh masker" was reported to be effective in inhibiting stuttering in 89% of 195 persons who stutter. In a follow-up of 62 of these persons, 82% were found to have benefit with six months use and some up to three years postfitting. Clearly, further investigation is warranted with an in-the-ear device. There is some preliminary evidence, however, from a single case study that supports success for the present device following more than 100 hours of use.[17]

The device is not without its difficulties. First, there may be problems for the user listening to other signals in their environment that will be altered by the device's DAF or FAF processing. This may result in conversational distraction in the case of conversational speech generated by others and/or inattention to familiar environmental stimuli. Of course, this is less of a problem with monaural versus binaural fitting. At any rate, this may be alleviated in the future with voice activation capabilities and further refinements in noise suppression capacity. Long-term efficacy studies with this self-contained ear level device are also warranted with those that stutter. Application of the device with others suffering from other speech communication disorders (e.g., aphasia, dysarthria, dyspraxia, Parkinson’s Disease, and vocal tremor) should be explored in addition.

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Table 1

Typical Performance Characteristic As A Function Of Operating Parameter For The TOCCATA™ DSP Core Of The Self-Contained Ear-Level Device To Inhibit Stuttering.

Parameter	Typical Performance
Operation Voltage	1.2 V
Current Consumption[a]	1 mA
Input/Output Sampling Rate	32 kHz
Frequency Response	200-7000 Hz
THD+N (@ -5dB re: Digital Full Scale)	<1%
Programmable Analog Preamplifier Gain	18, 22, 28 dB
Programmable Digital Gain	42 dB
Programmable Analog Output Attenuation	12, 18, 24, 30 dB
Equivalent Input Noise	<24 dB

Note: [a]algorithm dependant.

Figure Captions

Figure 1. Architecture of the TOCCATA™ micro DSP core for the self-contained ear-level device to inhibit stuttering.

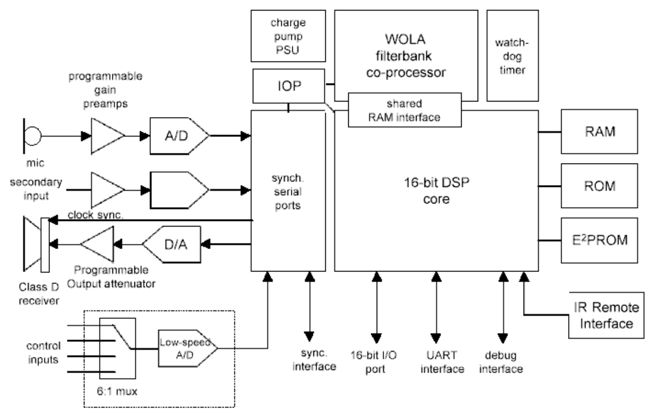
Figure 2. ITC (top) and CIC (bottom) self-contained ear-level device models to inhibit stuttering beside an American dime.

Figure 3. ITC self-contained ear-level device models to inhibit stuttering *in situ* with an adult male.

Figure 4. The user interface of the Microsoft® Windows® based operating system fitting software for the self-contained ear-level device to inhibit stuttering.

Figure 5. Typical frequency responses of the ITC and CIC device models to inhibit stuttering. Responses were measured in HA1 and CIC couplers for the ITC and CIC models, respectively.

Figure 6. Coupler responses with the CIC device model illustrating frequency alterations in response to a synthetic vowel [æ] generated and delivered to the device in sound field.



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watch-dog timer
programmable gain preamps
IOP
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mic
A/D
RAM
secondary input
synch. serial ports
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ROM
clock sync.
D/A
E²PROM
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sync. interface
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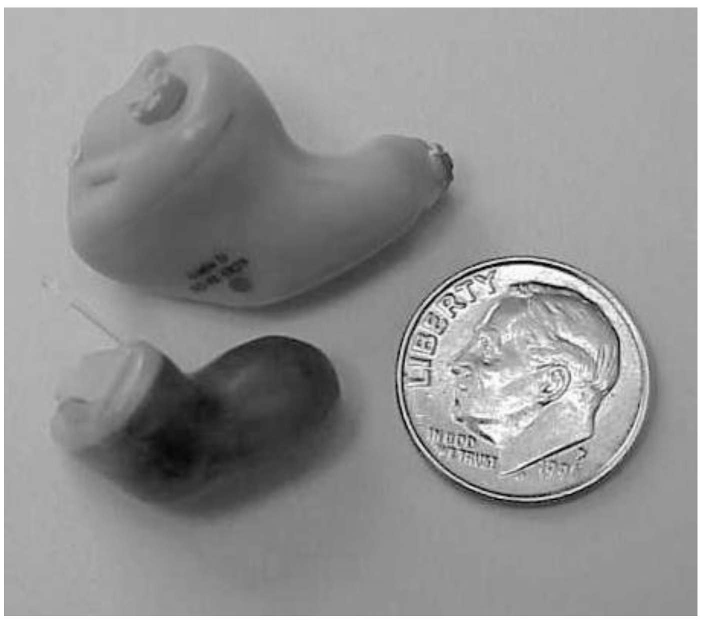
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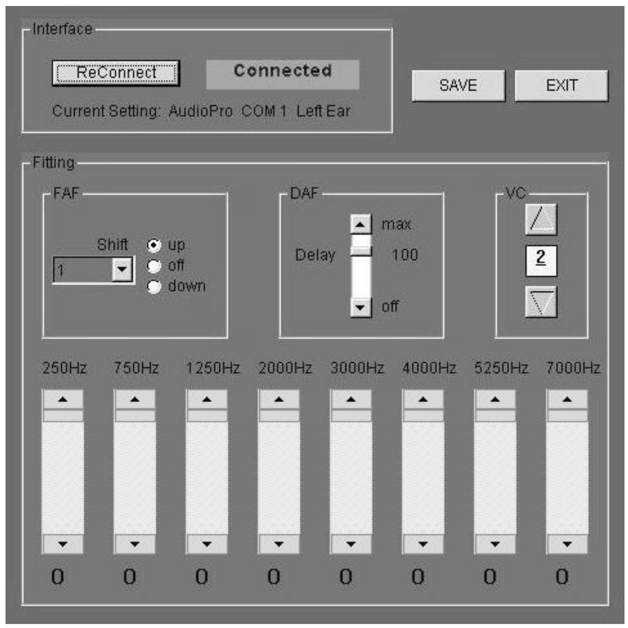

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Fitting
FAF
Shift
1
up
off
down
DAF
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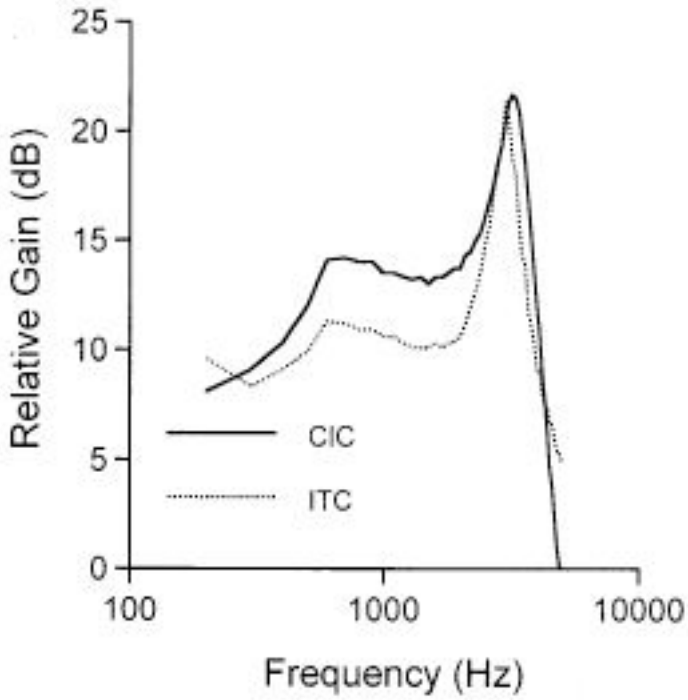
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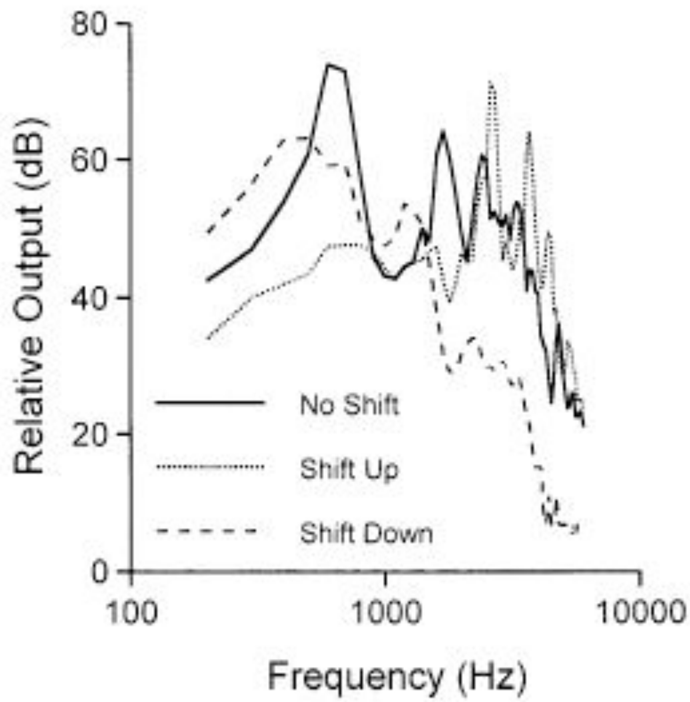

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0
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1000
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Frequency (Hz)
No Shift
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Shift Down