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Research Note

Pitch Shifting With the Commercially Available Eventide Eclipse: Intended and Unintended Changes to the Speech Signal

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Purpose: This study details the intended and unintended consequences of pitch shifting with the commercially available Eventide Eclipse.

Method: Ten vocally healthy participants (*M* = 22.0 years; 6 cisgender females, 4 cisgender males) produced a sustained /ɑ/, creating an input signal. This input signal was processed in near real time by the Eventide Eclipse to create an output signal that was either not shifted (0 cents), shifted +100 cents, or shifted −100 cents. Shifts occurred either throughout the entire vocalization or for a 200-ms period after vocal onset.

Results: Input signals were compared to output signals to examine potential changes. Average pitch-shift magnitudes were within 1 cent of the intended pitch shift. Measured pitch-shift length for intended 200-ms shifts was between 5.9% and 21.7% less than expected, based on the portion of shift selected for measurement. The delay between input and output signals was an average of 11.1 ms. Trials shifted +100 cents had a longer delay than trials shifted −100 or 0 cents. The first 2 formants (F1, F2) shifted in the direction of the pitch shift, with F1 shifting 6.5% and F2 shifting 6.0%.

Conclusions: The Eventide Eclipse is an accurate pitch-shifting hardware that can be used to explore voice and vocal motor control. The pitch-shifting algorithm shifts all frequencies, resulting in a subsequent change in F1 and F2 during pitch-shifted trials. Researchers using this device should be mindful of stimuli selection to avoid confusion during data interpretation.

Vocal motor control is often investigated by manipulating an individual's vocal fundamental frequency (f_0) in near real time, thereby changing the perception of its pitch. In order to examine the vocal response to this manipulation, two experimental paradigms are frequently used. In the first type of experimental paradigm, the f_0 is altered after voice onset occurs, thereby auditorily presenting the speaker with a sudden and unexpected change in their pitch. This manipulation, often called a *pitch shift,* typically occurs at a variable point in time after voice onset, and it happens either one time (e.g., Burnett, Senner, & Larson, 1997; Jones & Munhall, 2002; Larson, Burnett, Kiran, & Hain, 2000) or multiple times (Burnett, Freedland, Larson, & Hain, 1998; Hain et al., 2000; H. Liu & Larson, 2007) during a single utterance. Responses to this type of experimental manipulation provide information on an individual's ability to detect errors and send corrective commands to inform the utterances being produced. The mechanism driving these responses is often described as the *feedback* system (Burnett et al., 1997, 1998). The second type of experimental paradigm predictably shifts the f_0 over time (Jones & Keough, 2008; Jones & Munhall, 2000). Responses to this often surreptitious shift in the perception of pitch provide information on the *feedforward* system, which allows an individual to produce fluent f_0 changes by relying on stored motor programs (e.g., Jones & Munhall, 2000; Keough, Hawco, & Jones, 2013; Scheerer, Tumber, & Jones, 2016). This experimental paradigm is hypothesized to slowly change these stored motor programs over time, thereby allowing for evaluation of how an individual updates his or her feedforward system (Guenther, 2006; Guenther, Ghosh, & Tourville, 2006; Jones & Munhall, 2000; Keough et al., 2013; Scheerer et al., 2016).

Experiments that use these two paradigms are typically evaluating one or more of the following aspects: direction, magnitude, or timing of the vocal response. The direction

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of the response may vary between individuals, as individuals may shift f_0 either (a) in the opposite direction of the pitch shift, called an *opposing response*; (b) in the same direction of the pitch shift, called a *following response*; or (c) in no direction, by not shifting f_0, called a *null* or *nonresponse*. Opposing responses may be a compensatory action, that is, a corrective response for an error noted in an individual's own vocal production. The basis for following responses is not as well understood; although some suggest these same-direction responses may result from an individual perceiving the pitch-shifted production as an "external reference" rather than a shift in his or her own voice (Burnett et al., 1997; Hain et al., 2000; H. Liu & Larson, 2007). In addition to the direction of the response, the magnitude, timing, or variability of the response may provide information on aspects such as the stability, reliance, or maturity of the vocal motor control system (Scheerer & Jones, 2012; Scheerer, Liu, & Jones, 2013).

When designing experimental paradigms to examine vocal motor control, both the intended experimental manipulations and the unintended consequences of these manipulations can impact the results. The intended manipulations, set by the experimenter, include the magnitude and duration of the pitch shift. In addition, there can be unintended changes to the speech signal when performing a pitch shift. These include intensity changes accompanying a shift in pitch, formant frequency changes, and the delay time between the vocalization and the auditory presentation of the manipulated speech signal. Therefore, it is essential to have a clear understanding of both the accuracy of the intended experimental manipulations, as well as the presence of any unintended consequences, as both can have significant effects on the interpretation of the data collected.

The intended experimental manipulations of pitch-shift magnitude and pitch-shift length are known to affect the vocal response. Increased pitch-shift magnitude has been shown to result in increased response magnitude and decreased latency (Larson, Burnett, Bauer, Kiran, & Hain, 2001; H. Liu & Larson, 2007), as well as an increased number of following responses (Burnett et al., 1998). With regard to the length of the pitch shift, both the magnitude and the duration of the response have been shown to increase with a longer pitch-shift duration (Burnett et al., 1998; Kiran & Larson, 2001), whereas an increased number of following responses have been noted with a shorter shift duration (Kiran & Larson, 2001). Therefore, the accuracy of the magnitude and length of the pitch shift is necessary for clear interpretation of the vocal response.

The unintended influences that pitch shifting may have on acoustic properties of a speech signal are also important to understand. The first variable to consider is sound pressure level (SPL), as the perception of pitch and loudness have been shown to be correlated (Gramming, Sundberg, Ternström, Leanderson, & Perkins, 1988). Specific to pitch-shift experiments, although the relative SPL level of the pitch shift may not affect the vocal response (Burnett et al., 1998), changes in SPL can elicit a vocal response on their own (Bauer, Mittal, Larson, & Hain, 2006; Hafke, 2009; Heinks-Maldonado & Houde, 2005; Larson, Sun, & Hain, 2007; H. Liu, Zhang, Xu, & Larson, 2007). Larson et al. (2007) noted that different vocal responses in f_0 were present in paradigms in which both f_0 and SPL were manipulated compared to paradigms where solely f_0 was changed (Burnett et al., 1998); changes in SPL can elicit a vocal response on their own (Bauer et al., 2006; Hafke, 2009; Heinks-Maldonado & Houde, 2005; Larson et al., 2007; H. Liu et al., 2007). Larson et al. (2007) noted that different vocal responses in f_0 were present in paradigms in which both f_0 and SPL were manipulated compared to paradigms where solely f_0 was changed. They found that if both f_0 and SPL were increased, the vocal response magnitude was smaller than if only f_0 was increased, whereas the opposite effect was found if both f_0 and SPL were decreased. Furthermore, if f_0 and SPL were shifted in opposite directions, the overall vocal response magnitude decreased, latency increased, and the number of following responses increased. Therefore, although f_0 and SPL levels may be controlled independently, SPL differences may impact the vocal response during a pitch-shift experiment.

The second variable to consider is the potential changes in formant frequencies, which may be related to the method of pitch shifting used. Although a substantial portion of the pitch-shifting literature focuses on sustained vowels, pitch shifting can also be performed at the word or phrase level—where a change in formants could change the perception of the stimuli. One method involves a pitch shift that isolates and only shifts the f_0 (often using a formant frequency correction). However, another popular method involves shifting the entire frequency spectrum. This method is both fast and less computationally intensive, as there is no need to identify and isolate the pitch in real time. In this common scenario, both the f_0 and formant frequencies will be shifted up or down together. As a result, understanding the degree that the shift affects the formants is necessary for later data interpretation. One study found that a 200-cent pitch shift applied to the entire utterance resulted in positive correlations between changes in f_0 and changes in both the first formant (F1) and second formant (F2) frequencies (MacDonald & Munhall, 2012). Similarly, another study noted that during unexpected short duration shifts of 100 cents, F2 changes occurred in addition to changes in f_0 (Eckey & MacDonald, 2015). As F1 and F2 values define an individual's vowel space (Hillenbrand, Getty, Clark, & Wheeler, 1995), a shift in these formant frequencies may result in a perceptual difference between the vocalized and perceived vowel.

Researchers must also consider the potential impact the selected pitch-shifting equipment may have on the results of the experiment. If a researcher chooses to design a custom algorithm to shift pitch, a successful algorithm will need to be accurate, to be natural sounding, and to reduce as much of the unintended consequences of pitch-shifting as possible. Another option is to use a commercially available hardware that already has algorithms designed to shift pitch. All hardware will have an inherent delay, which is required to first process the vocalization and then auditorily present the vocalization to the speaker. Moreover, additional processing time is needed to perform the pitch shift itself, increasing the delay between vocalization and the subsequent auditory presentation of that vocalization. This delay between vocalization and presentation is important to document, as a longer delay has been shown to result in changes such as an increased length of the vocal response (Hain, Burnett, Larson, & Kiran, 2001) and an increased magnitude of the neural response (Behroozmand, Liu, & Larson, 2011). Because of the nature of these experimental designs, a delay will always be present between vocalization and auditory presentation; therefore, it is essential to document the length of the delay in order to understand the potential impact on the vocal response.

Although there are multiple commercially available signal processing programs that could be used to perform pitch shifting, a few devices are popular in current voice and vocal motor control research. Many researchers use Eventide hardware, which shifts the entire frequency spectrum. This full-spectrum shift shifts the values and spacing of all harmonics, thus changing the perception of pitch. However, because the entire spectrum is shifted, it also shifts the associated vowel formants. These include the Eventide Eclipse model (e.g., Behroozmand et al., 2015; Chen, Liu, Jones, Huang, & Liu, 2010; Larson, Altman, Liu, & Hain, 2008; P. Liu, Chen, Jones, Huang, & Liu, 2011) and the earlier Eventide H3000 series (e.g., Burnett et al., 1998; Hain et al., 2000; Jones & Munhall, 2005; Larson et al., 2000; Sivasankar, Bauer, Babu, & Larson, 2005). Another popular hardware used by researchers (e.g., Feng, Xiao, Yan, & Max, 2018; Hawco & Jones, 2010; Jones & Keough, 2008; Mollaei, Shiller, Baum, & Gracco, 2016; Tumber, Scheerer, & Jones, 2014; Zarate & Zatorre, 2008) is the Voice One, made by TC Helicon. The Voice One's pitch-shifting algorithm includes formant correction, thereby avoiding issues related to unintended formant frequency changes during pitch-shifting tasks. Unfortunately, the Voice One has been discontinued and is now considered a "legacy" product of TC Helicon, making both acquiring the hardware and finding support documents difficult. Another piece of hardware of interest used by researchers (e.g., Ning, Loucks, & Shih, 2018; Sturgeon, Hubbard, Schmidt, & Loucks, 2015) is the Eventide H7600, which has algorithms that can also perform a formant-corrected pitch shift. The downside of using these algorithms, however, is that they are time-intensive. Performing a formant-corrected pitch shift requires a minimum of 50 ms between the input and output signals (personal communication, Eclipse helpdesk, March 15, 2017). When using the Eventide H7600, researchers should consider the effect this delay may have on the interpretation of their data. Overall, there are benefits and drawbacks associated with the use of any hardware. None of the aforementioned pieces of hardware are optimized for research but are instead targeted for wider use to allow vocal manipulations.

Vocal motor control studies can provide essential insight into the vocal systems of individuals with both typical and impaired voices. In order to improve the interpretability of the data collected, it is important to detail the intended and unintended results of pitch shifting. Thus, the purpose of this research note is twofold. The first purpose is to present a transparent method of using the commercially available Eventide Eclipse hardware to shift the pitch in near real time. Detailed methodology is presented, allowing researchers who have not conducted these studies to replicate the experimental setup. The second purpose is to clearly delineate all intended and unintended changes that occur during pitch shifting with the Eventide Eclipse hardware. By understanding the intended and unintended changes that occur to the speech signal, informed interpretations can be made concerning the effects of pitch shifting on the vocal system with this commercially available hardware.

Method

Participants

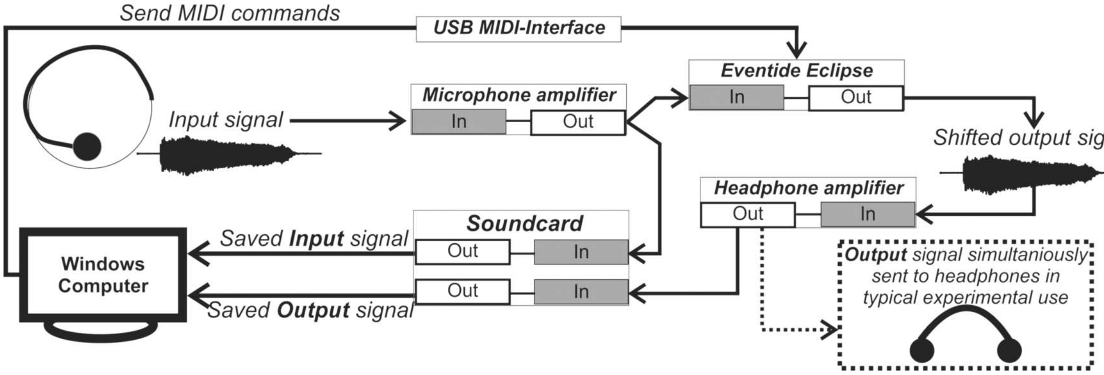
Participants were 10 adults (*M* = 22.0 years, *SD* = 2.7 years; four cisgender males, six cisgender females), all of whom reported no prior history of voice, speech, language, or hearing disorder. Baseline f_0 for each participant was measured from 20 sustained /ɑ/ productions and ranged from 95.7 to 254.3 Hz. All participants completed written consent in compliance with the Boston University Institutional Review Board.

Hardware and Software

Hardware Setup

A schematic of the equipment setup is depicted in Figure 1. An input signal of a sustained /ɑ/ was produced by each participant via a Shure WH20 microphone, sampled at 44.1 kHz with 16-bit resolution, which was then amplified with an RME Quadmic microphone amplifier (Audio AG). The amplified signal was then split and simultaneously sent to two different locations. The first location was the input of the MOTU Ultralite mk3 hybrid soundcard, thereby saving the amplified, but otherwise unaltered, input signal. The second location was the analog I/O input of the Eventide Eclipse hardware. In order to transmit MIDI commands from the computer to the Eventide Eclipse hardware, an M-Audio Uno USB MIDI interface was used. The M-Audio Uno USB MIDI was connected to the MIDI Input on the Eventide Eclipse in order to allow the Eventide Eclipse to receive MIDI messages; as no output messages were sent from the Eventide Eclipse for this study, the MIDI output connection was left unplugged in order to avoid sending any unintended messages. After the MIDI command was received, a pitch shift was then applied with the Eventide Eclipse hardware. The shifted output signal was then sent to a Behringer Xenyx Q02USB headphone amplifier (Music Group), further amplifying the signal to a previously calibrated value relative to the input signal. This final amplified signal was sent to a second input of the MOTU Ultralite mk3 hybrid to be saved.

Figure 1. Schematic of equipment setup and signal flow for a recorded input signal (from a participant) and output signal (shifted by Eventide Eclipse). Indicated by the dotted lines is the place the output signal could be split and simultaneously sent to the participant's headphones during typical experimental use.



Software

The Eventide Eclipse was programmed to accept MIDI system exclusive commands, also known as MIDI SysEx messages (see details in the Eventide Eclipse Settings section below). The experimental scripts and commands were written in MATLAB (MATLAB, 2016). Through MATLAB, a COM server was opened in order to allow communication with a Windows program, MIDI-OX (O'Connell, 2011). MIDI-OX received the SysEx commands from MATLAB and subsequently sent them to control the Eventide Eclipse (see Appendix A). For full details on using SysEx commands to perform key presses with an Eventide device, readers can refer to an Eventide Technical Note (Eventide, 2001).

Frequency Shift Method

The Eventide Eclipse device uses a proprietary algorithm to shift pitch. Briefly, based on the information disclosed in two publically available patents (Agnello, 1983, 1984), the shift in frequency is accomplished by changing the sampling rate. By resampling at a higher sampling rate, the frequencies in the signal are increased; this, however, also decreases the duration of the signal. Inversely, by decreasing the sampling rate, the frequencies are decreased, and the duration of the signal is increased. After resampling the signal, the differences in the time length of the signal need to be rectified. For decreases in pitch, the end of the signal is removed, thereby reducing the length of the signal. For increases in pitch, a portion of the signal must be repeated in order to resolve the timing differences. Details on how selection of a portion of the waveform is sliced and subsequently repeated can be found in Patent No. US4464784A (Agnello, 1984).

Eventide Eclipse Settings

All Eventide Eclipse settings used during this study are provided in Appendix B, both to provide transparency for this study and to allow for replication of these settings by other researchers who may be interested in using this device. Menu items that can be found by selecting the SETUP or LEVEL buttons are typically applied before any digital signal processing. In addition, these encompass what is referred to as "global" changes, meaning they do not change with the programs that are selected further downstream. All user manuals, signal trees, program details, and all other relevant information on this hardware can be found in Eventide Eclipse documents, located on their website (Eventide, 2015).

Trial Types and Data Extraction

There are two trial types in the current experiment, hereafter called *long* and *short trials,* which differed in the manner that pitch was shifted. During both trial types, participants were prompted to produce an /ɑ/ for approximately 3 s; participants were not aware that there were different experimental manipulations being examined. In long trials, the pitch-shift value was set prior to voicing and was held constant for the duration of the trial. Analysis during a long trial was conducted over the entire trial, resulting in an analysis period of approximately 3 s. During short trials, the pitch-shift value was set to 0 cents at voicing onset. Then, at a variable point after voicing onset, the pitch was shifted either +100 cents or −100 cents for a duration of 200 ms, before reverting back to 0 cents. There were two analysis periods defined in the output signal of these short duration trials (see Figure 2). The first analysis portion was the length of the entire pitch shift, defined as starting when the f_0 began deviating from the baseline and as ending when it returned to baseline. The second was the length of the time that the pitch shift was at a steady-state value (see Figure 2). For both the input and output signals, measures of f_0 (Hz), F1 (Hz), F2 (Hz), and SPL (dB) were extracted from each trial in Praat (Boersma & Weenink, 2014). Praat standard settings for pitch and formants[1] were used for this

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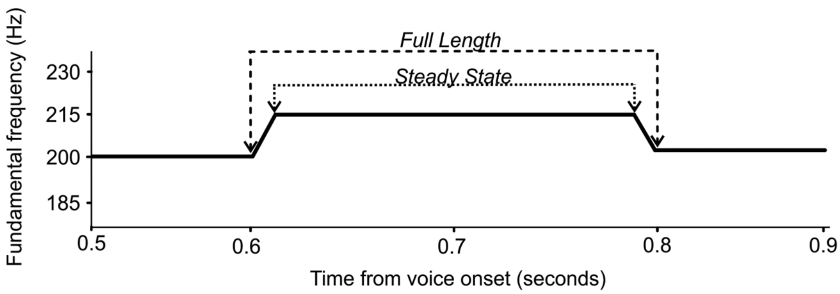
[1] Pitch range (Hz): 75–500, maximum formant (Hz): 5500, number of formants: 5, intensity view range (dB): 50–100.

Figure 2. Schematic of the output signal (solid line) during a +100-cent pitch shift. The full-length (dashed line) and steady-state (dotted line) portions of the pitch shift are indicated.



initial data extraction, and all values were subsequently imported into MATLAB. A custom MATLAB interface was created to display the waveforms and a spectrogram for each trial, with the f_0, F1, and F2 displayed on the spectrogram. If either the f_0, F1, F2, or SPL traces were irregular or did not match the spectrogram via visual inspection, or the average values calculated appeared aberrant, individual trials were examined manually in Praat, allowing for optimization of the pitch and formant settings for the specific trial in question. If a trained experimenter (E. H. M. or A. A. L.) could not obtain a value for a given trial, it was removed from the analysis. Primary reasons for removal included either (a) experimenter error during acquisition, in which the "bypass" button was left on thereby preventing saving of the output signal, or (b) unreliable analysis of the signal due to excessive glottalization or nasalization. The resulting analysis set included 85.1% of the initially acquired trials. All subsequent statistical analyses were conducted in Minitab (Minitab, 2012).

The two intended experimental manipulations examined in this study were pitch-shift magnitude and pitch-shift duration. Intended pitch-shift magnitudes were either 0, +100, or −100 cents, common pitch-shift magnitudes examined in the current literature (e.g., Jones & Munhall, 2000; Larson & Robin, 2016; H. Liu & Larson, 2007). The actual pitch-shift magnitudes in semitones (1 semitone = 100 cents) were determined by comparing the f_0 of the output signal relative to the f_0 of the input signal using Equation 1:

$$39.86 \times \log_{10}\left(\frac{f_0\ \text{output}}{f_0\ \text{input}}\right) \tag{1}$$

Unintended consequences of the experimental manipulation were also examined. *Delay,* defined as the difference in start times of the input and output signals, was visually identified in the waveforms by a trained experimenter. Relative SPL differences between the input and output signals were calculated. Lastly, percent change in formant frequencies for the first and second formants (F1 and F2, respectively) were examined. Of note, for short duration trials, pitch-shift magnitudes, changes in SPL, and changes in formant frequencies were measured during the steady-state portion of the pitch shift.

Results

Pitch-Shift Magnitude Accuracy (Intended)

The accuracy of the pitch shift was defined as the absolute difference between the intended pitch shift and the actual f_0 difference (in cents) between the input and output signals. Average difference from the intended pitch shift to the measured pitch in the output signal was less than 1 cent for all trial types. Trials shifted +100 cents were 0.58 cents (SD = 0.62 cents) away from the intended pitch shift, whereas trials shifted −100 cents were an average of 0.41 cents (SD = 0.43 cents) away from the intended pitch shift. Differences between the intended pitch shift and the measured pitch shift for long and short trials were an average of 0.17 (SD = 0.34 cents) and 0.46 (SD = 0.49 cents), respectively.

Pitch-Shift Duration (Intended)

For short duration trials shifted +100 and −100 cents, the length of the full pitch shift, as well as the steady-state portion of the pitch shift, was measured. Two paired-samples t tests revealed that there were no significant differences in pitch-shift durations between trials that were shifted +100 cents or −100 cents for both measurements of full-length durations and measurements of steady-state portion ($p > .05$). Therefore, the shift directions were collapsed for further analysis. Full-length portions were measured to be an average of 188.2 ms in duration (SD = 37.3 ms), a 5.9% reduction from the 200-ms intended shift duration. The steady-state portion of the shift measured an average of 156.7 ms (SD = 36.4 ms), a 21.7% reduction from the intended shift length.

Delay (Unintended)

The delay between the input and output signals, measured at vocal onset, was calculated for each trial. The average delay between input and output signals for all trials was 11.1 ms (SD = 7.5 ms). Results of a one-way repeated-measures analysis of variance on delay at vocal onset indicated that there was a statistically significant main effect of pitch-shift magnitude (0, +100, −100 cents) at vocal onset. Trials that were not shifted at vocal onset had an average of 10.3-ms (SD = 7.0 ms) delay between output. Trials shifted +100 cents had a 19.4-ms (SD = 9.1 ms) delay, and trials shifted −100 cents had a 10.4-ms

(SD = 5.6 ms) delay.[2] Tukey post hoc analyses indicated that trials shifted +100 cents had significantly longer delays than trials −100 cents ($p < .05$, corrected alpha level of .05). There was no significant difference between trials that were pitch-shifted −100 or trials that were not shifted (0 cents) at vocal onset ($p > .05$).

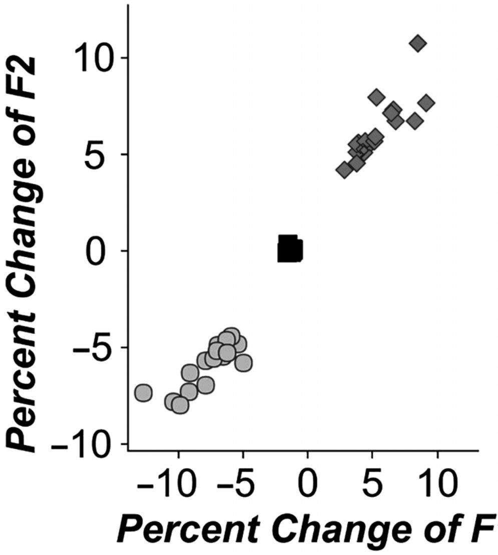
SPL Changes (Unintended)

Potential changes in SPL from input to output were examined. Two paired-samples t tests indicated there were no significant differences found when comparing SPL changes for +100 and −100 cents for either short or long trials. Therefore, the pitch-shift directions were collapsed for further analysis to allow examination of "shifted long trials" and "shifted short trials." A one-way repeated-measures analysis of variance examining the three different trial types (not shifted, shifted long trials, shifted short trials) revealed there was no statistically significant main effect of trial type on changes in SPL ($p > .05$), suggesting that SPL did not significantly change from input to output in the presence of a pitch shift.

Formant Changes (Unintended)

Changes in F1 and F2 were calculated as the percent change in formant values from the input to the output signal. F1 and F2 both shifted in the direction of the pitch shift; that is, they increased for +100-cent pitch shifts and decreased for −100-cent pitch shifts (see Figure 3). To analyze the absolute change in formants regardless of direction, the absolute value of the percent change for both F1 and F2 were calculated, and paired-samples t tests were performed. There were no significant differences in the absolute value of change of either F1 or F2 when comparing trials that were shifted +100 or −100 cents ($p > .05$). Collapsing across both pitch-shift directions, the average absolute value for percent change was 6.5% and 6.0% for F1 and F2, respectively.

Figure 3. Percent change in F1 and F2 in the 0 cent condition (black squares), as compared to the +100 cent (dark gray diamonds) and −100 cent (light gray circles) pitch-shift magnitudes.



Discussion

The Eventide Eclipse is a relatively easy-to-use hardware that researchers can use to perform pitch-shifting experiments. The magnitude of the pitch shift with this hardware was accurate, with average values measuring within 1 cent of the intended pitch shift. The accuracy of the pitch shift was significantly different between long and short trials and between trials shifted +100 and −100 cents. These differences, however, may not be experimentally meaningful for many researchers, as all average values were within 1 cent of the intended pitch target. Pitch-shift duration had variable accuracy in this experiment. On average, trials were 5.7% and 21.6% shorter than the intended duration for the full-length and steady-state portions of the pitch shift, respectively. Therefore, researchers who require more accuracy in pitch-shift length and are interested in using the Eventide Eclipse hardware should examine alternative methods for sending the MIDI commands to this device. Suggestions for additional testing include utilizing different software to create and send SysEx commands, testing digital inputs rather than the analog inputs that were used in the current experiment, and examining different hardware for saving the input and output signals.

Unintended consequences of pitch shifting with the Eventide Eclipse were also examined in this study. Differences in SPL between the input and output signals did not significantly differ among pitch-shift magnitudes of 0, +100, or −100 cents. Therefore, researchers who use the Eventide Eclipse device can be relatively confident that participants' responses are not influenced by unintended changes in SPL caused by the equipment. The same cannot be said for deviation of formant frequencies, as changes in both F1 and F2 followed the direction of the pitch shift. This was not an unexpected finding, as the pitch-shift algorithm used by the Eventide Eclipse shifts all of the frequencies that comprise the signal. Previous work has indicated that when f_0 and formants were shifted in opposite directions, intelligibility was reduced, whereas shifts in the same direction resulted in increased intelligibility (Assmann, Nearey, & Scott, 2002). If researchers are interested in examining changes in f_0 in the context of words or phrases, stimuli selection should carefully consider the result of the shift on F1 and F2 values. Specifically, perception of vowels can be defined in F1 and F2 space (e.g., Hillenbrand et al., 1995; Peterson & Barney, 1952), and therefore, a shift in these values may result in a categorical shift in the perception of the vowel. Although vowels that have similar F1

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[2] As every short trial and half of the long trials were not shifted at vocal onset, there were more analyzable trials not shifted at vocal onset (n = 1,612) than trials shifted −100 cents (n = 150) or +100 cents (n = 148).

and F2 values may be more likely to be confused with each other, previous work has indicated that listeners incorporate additional features, such as duration and formant movement, into their identification of vowels (Neel, 2008). Therefore, as these additional features will not change with the Eventide Eclipse shift, the perceptual magnitude of these shifts cannot be quantified without a careful directed study. Researchers specifically interested in large shifts in f_0 should note, however, that an experimental design resulting in F1 and F2 values not heard in natural speech may have additional perceptual consequences (Assmann & Nearey, 2008; Assmann et al., 2002). Overall, when using the Eventide Eclipse to shift pitch, researchers may want to evaluate the measurable changes in the participants' formant frequencies and how the relevant stimuli are perceived, depending on the research question and design.

The last unintended change that was examined was the delay between the input and output signals. On average, the delay for all trial types was approximately 11 ms. At trial onset, trials that were pitch-shifted +100 cents had a significantly longer delay than trials that were not shifted or were shifted −100 cents. This is a logical finding given the information that can be inferred from Patent No. US4464784A (Agnello, 1984). It is likely that the computational load required to select and repeat a portion of the signal, necessary to rectify timing differences after an increase in pitch, is larger than the computational load required to select and delete a portion of the signal, as needed to rectify timing differences after a decrease in pitch.

Conclusion

The Eventide Eclipse is an accurate pitch shifter that interested researchers can use to examine voice and vocal motor control. The average magnitude of the pitch shift was within 1 cent of the intended pitch shift for all trial types. The accuracy of the duration of the pitch shift was variable. If researchers are interested in explicitly examining the effect pitch-shift length has on the vocal response, further work should focus on optimizing the hardware and software configurations. No SPL differences were noted between trials that were or were not pitch-shifted. This suggests that participants will be unlikely to use SPL differences to detect the presence or absence of a pitch shift. On average, delay times between the input and output signals were approximately 11 ms. Delay times for trials shifted +100 cents were longer than trials shifted 0 or −100 cents, most likely due to the timing correction needed after a pitch shift. Finally, the algorithm used to shift pitch with the Eventide Eclipse shifts all frequencies, thereby resulting in shifted formant frequencies. Researchers should be aware that this shift in formants may change the perception of the produced vowel by some individuals. Overall, this study demonstrates that the Eventide Eclipse hardware provides an accurate method for pitch-shifting vowels, thereby providing a means for examining voice and vocal motor control.

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Appendix A

Sending SysEx Commands From MATLAB to Control the Eventide Eclipse; Relevant Information From Eventide Documentation (Eventide, 2001, 2015)

Below is an outline of information that can be used to control the Eventide Eclipse from MATLAB using SysEx commands. This involves using the software, MIDI-OX, which can be opened via a COM server, that is, hMI = actxserver(’MIDIOX.MOXScript.1’). Each line of a SysEx string has 14 hexidecimal values. In this utilization, values in Positions 1–5 and 14 are the same in each instance of the string, whereas values in Positions 6–13 represent the data. The first value (“F0”) indicates the start of the SysEx command. The second value (“1C”) indicates the Eventide hardware. The third value (“70”) indicates the specific model used. Of note, this value was “70” at the time this article was written; however, this value has the potential to change with future Eventide updates. The fourth value (“01”) is the device ID. This value is set by the user in the settings under SETUP/MIDI; it is important that the user makes sure these two numbers match. The fifth value (“01”) indicates that the subsequent data will be a keypress method. The 14th value (“F7”) indicates the end of the SysEx command.

Values in Positions 6–13 indicate the specific data sent to control the keypresses on the Eventide Eclipse. Below are a few examples of SysEx commands that were used in the current experiment. The values in Positions 6–13 are bolded, and the meaning of each value string is commented following the “%” symbol. As these are keypress commands, if the user examined the front LCD panel of the Eventide Eclipse device as these commands were being sent, the screens would follow the same pattern as if the keys were being manually selected.

```
%Select the user defined pitch shifting program
hMI.SendSysExString (['F0 1C 70 01 01 0F 07 0F 0F 0F 0F 0F 0F F7’ … %select ‘program’ button
                                             ’F0 1C 70 01 01 07 0F 0F 0F 0F 0F 0F 0F F7’ …%select ‘1’ (pitch shifting program*)
                                             ’F0 1C 70 01 01 0F 0F 0F 0F 0F 0F 0E 0F F7’ …%select ‘enter’
                                             ’F0 1C 70 01 01 0F 0F 0F 0F 0F 0F 0F 0B F7’ …%select 4th soft key (loads program)
                                             ’F0 1C 70 01 01 0F 0F 0F 0B 0F 0F 0F 0F F7’]); %select 2nd soft key (pitch option**)
%Set the pitch to shift –100 cents
hMI.SendSysExString (['F0 1C 70 01 01 0F 0F 0F 0F 0E 0F 0F 0F F7’ … %select ‘-‘
                                             ’F0 1C 70 01 01 07 0F 0F 0F 0F 0F 0F 0F F7’ … %select ‘1’
                                             ’F0 1C 70 01 01 0F 0F 0E 0F 0F 0F 0F 0F F7’ … % select ‘0’
                                             ’F0 1C 70 01 01 0F 0F 0E 0F 0F 0F 0F 0F F7’ … % select ‘0’
                                             ’F0 1C 70 01 01 0F 0F 0F 0F 0F 0F 0E 0F F7’]); %select enter
```

*Number of pitch-shifting program was defined by the experimenter. See Appendix B for details. **Selecting the “pitch” option of the pitch-shifting program at this stage allows the pitch to easily be changed during the experiment.

Appendix B

Description of All Eventide Eclipse Settings Used in the Current Study; Relevant Information From Eventide Documentation (Eventide, 2015)

Button on Eventide Eclipse	Menu	Submenu (1)	Submenu (2)	Setting	Notes
General and MIDI settings					
SETUP	DIG-IN	CLOCK	—	44.1 kHz	Sampling rate
	MODES	XFADE	—	0.0 s	Avoids fading transition
	MIDI	CHANNEL	—	omni	Accepts MIDI messages on any channel
		MIDIMODE	PGM CHNG	on	Accepts and obeys program change messages
			NOTE	poly	One channel will accept all the notes
			PRES	channel	MIDI messages will affect all notes on a given channel
			PBEND	0	Sent the pitchbend (i.e., pitch shift) to 0 at this point Note: This study will change pitch shift in PROGRAM rather than during SETUP.
		SYSEX	SYS EXC	1	Setting device ID to 1 for SysEx commands
			SYSXSPD	10	Highest speed the device can transmit MIDI messages
			SEQ OUT	off	Not sending MIDI messages out to another port after receiving them
			CLK OUT	off	Not sending MIDI clock out
LEVEL	IN-GAIN	—	—	0.0 dB	No gain applied by this device
	OUT GAIN	—	—	0.0 dB	No gain applied by this device
	Wet/Dry Mix	—	—	100%	Only the “wet” sound (the shifted output) will be sent out No mixing with the participant’s original input
Program created for pitch shifting (edited from program 162, ST shifter)					
PROGRAM	LEVEL	—	—	0 dB	No gain applied by this device
(*Then key in number of program. This experiment calls this program “1”.)*	PITCH	—	—	0 cents	No initial pitch shift applied during setup Note: This shift is changed during the experiment via MATLAB commands
	DELAY	—	—	0 ms	No intentionally added delay from the device
	FBACK	—	—	0%	Pitch-shift output is not reapplied to the input
	LOWNOTE	—	—	C1	The lowest frequency expected by the system is around 65 Hz
	XFADE	—	—	0 ms	Avoids fading transition