Give a Little Whistle: A Neglected Characteristic of Australian English Productions of /s/

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Abstract

This acoustic-phonetic study examined the presence of whistle in Australian English (AusE) adult and child productions of /s/. We report on whistle identification based on visual and auditory analysis, and we consider how the presence of whistle can impact kurtosis (M_4), a lesser-studied spectral measure known to correlate with whistle presence. Results of linear mixed models indicated that tokens with whistle characteristics had higher kurtosis (M_4) values compared to tokens without whistle, with no differences found for age or gender groups. Whistled tokens in rounded vowel contexts had lower M_4 values compared to whistled tokens in non-rounded vowel contexts.

Index Terms: fricatives, kurtosis, whistle, Australian English, vowel contexts, gender, children's speech

1. Introduction

Whistled fricatives are characterised by the simultaneous occurrence of a whistling component along with frication during production. Fricatives are characterised by a continuous noise source resulting from constriction in the vocal tract [1]. The fricatives /s, z, ʃ/ can be produced with whistle [1, 2, 3], although this is perhaps more common for the voiceless alveolar fricative /s/, which has phonemic variations in languages like Xitsonga and Changana [4, 5] and non-phonemic variations in language like English and French [6, 7]. /s/ is produced with a narrow constriction, formed by raising the tongue blade to the alveolar ridge, resulting in turbulent airflow (frication) which is channelled through the deep, narrow groove on the tongue dorsum and amplified by the lower teeth obstacle [8, 9, 10]. The frication noise is characterised by aperiodic energy concentrated at high frequencies above 4kHz [9]. Fricative spectral shapes are based on the shape and size of the cavity in front of the constriction [11]. Alveolar fricatives have long front cavities (in comparison to labiodental or dental fricatives), which result in clearly defined spectral shapes [11].

There may be subtle differences in articulatory configurations in productions of non-whistled and whistled /s/. Articulatory configurations for productions of English /s/ have been shown to vary between speakers and in different vowel contexts [3]. Although we do not know the articulatory configurations of non-phonemic whistled fricatives, [12] suggests that a raised tongue tip can produce "edge tone" whistled fricatives. The "edge tone" model is one of the proposed mechanisms for how whistles are produced when an unstable jet of air strikes an obstacle [1, 12]. For whistled fricatives, the tongue constriction channels the jet of air, and the teeth are the obstacle (or edge) [1, 12]. The turbulent air oscillates around the teeth and couples with the resonances of the cavity between the tongue constriction and teeth, resulting in a whistled fricative [1, 4, 12, 13]. Small changes in articulatory configuration will affect the front cavity resonances [6, 9], which can be measured with spectral moments analysis.

Spectral moments analysis allows us to examine the distribution of energy in the fricative [14]. Four spectral moments are calculated from the distribution; the mean energy (M_1), also referred to as centre of gravity (COG), variance (M_2), skewness (M_3) and kurtosis (M_4); only M_4 shall be analysed here. Kurtosis (M_4) is a measure of the peakiness of the spectrum (i.e., the distribution) [15]. A clearly defined spectrum with higher peaks will have a positive kurtosis (i.e., higher M_4 values), while a less defined spectrum without clear peaks will have a negative kurtosis (i.e., lower M_4 values) [11]. Kurtosis is rarely reported in analyses of spectral moments of fricatives, with many studies providing data on a limited number of spectral moments, or in some cases only the first spectral moment, COG [7, 15]. However, kurtosis may be a useful metric for identifying whistle presence in fricatives [16].

Although whistling is thought to be relatively common in fricative production [13], non-phonemic whistled fricatives are rarely reported in fricative analysis studies. One recent study conducted an exploratory analysis on the proportion of whistled /s/ and /z/ in whispered and voiced speech produced by adult female Portuguese speakers [2]. The corpus consisted of sustained fricatives and fricatives in onset, medial and coda position. Whistled tokens were identified by the presence of a spectral peak between 9 and 13kHz. [2] reported a high proportion of whistled tokens in their dataset – 402 whistled /s/ tokens (219 voiced, 183 whispered) compared to 166 non-whistled /s/ tokens (69 voiced, 97 whispered), and 154 whistled /z/ tokens compared to 113 non-whistled /z/. Another recent study reported on the ultra-high frequency whistled [ʂ], characterised by a COG above 10kHz, in southern Chilean Spanish [16]. [16] reported that non-phonemic whistled [ʂ] comprised 9% of their corpus, with female speakers more likely to produce this phone compared to male speakers. Lower socioeconomic status was associated with increased use of whistled [ʂ], indicative of a sociophonetic function [16].

The spectra of whistled fricatives (phonemic and non-phonemic) are described to have high-amplitude and narrow-bandwidth peaks [1, 5]. However, extracting and interpreting spectral slices for individual whistled fricative tokens in a corpus can be a time-consuming process, and it may not be necessary to inspect spectra to confirm the auditory percept of a whistled fricative. For instance, the Changana phonemic whistled fricative /sv/ is described to have a dark horizontal band below 5000Hz on the spectrogram [5]. It may also be possible to identify non-phonemic whistled /s/ based on audible whistling and spectrographic cues such as this. Kurtosis has been suggested as a key measure for distinguishing between /s/ and the ultra-high frequency whistled [s̗] in Chilean Spanish, with higher values observed for the whistled variant [16]. Kurtosis values may also reflect differences in tongue posture in /s/ productions [17]. In [17], English /s/ was reported to have higher M_4 values compared to Japanese /s/, with the difference proposed to stem from slight variations in articulatory configurations between English /s/ (more apical) and Japanese /s/ (more laminal) productions.

[6, 7] suggest that non-phonemic whistled fricatives occur more frequently in rounded vowel contexts. In [6], a single adult French-speaking male participant produced a whistled /s/ in the context of /usu/, and the spectra was observed to have a high-amplitude, narrow-bandwidth peak at 8.2kHz. [7] reported that kurtosis varied across speakers, and it was suggested that this variance may be partially due to whistled fricatives occurring in rounded contexts. Kurtosis was reported to be higher in whistled /s/ tokens produced by a male adolescent participant in their study [7]. The number of whistled fricatives produced by this single participant was not reported, and it is unclear if other participants also produced whistled fricatives.

The main research question of this paper is whether the presence of non-phonemic whistle in the English voiceless alveolar fricative /s/ is associated with high kurtosis (M_4) values. It was hypothesised that kurtosis (M_4) would be higher in tokens with visual and auditory features of whistle presence, compared to tokens without these features. Two studies have observed non-phonemic whistled /s/ tokens produced by an adolescent [7] and an adult speaker [6]. Gender differences have been observed for some spectral moments (M_1-M_3) of /s/ produced by Australian-English speaking children [18]. In the present study we analysed tokens produced by adult and child speakers to determine whether non-phonemic whistled /s/ differs across age groups and whether females produce more whistled /s/ tokens compared to male speakers, as observed for the ultra-high frequency [s̗] in Chilean Spanish [16]. The second exploratory research question of this paper is whether M_4 values in whistle tokens are moderated by vowel context. As previous observations of non-phonemic whistled /s/ have noted the impact of vowel rounding [6, 7], we predict that M_4 values of whistle tokens would be higher in the more rounded vowel context (/ɔ/), compared to the unrounded contexts (/ɪ, æ, ɐ/). Kurtosis may reflect variability in fricative production, highlighting the importance of this spectral measure.

2. Method

2.1. Participants

Participants were Australian English-speaking adults and children. A total of 36 adults between the ages of 18-40 (M_{age}= 24; F = 25, M = 10, Gender Unspecified = 1) and 19 children between the ages of 4 years – 5 years;11 months (M_{age} = 57 months; F = 10, M = 9) participated. Participants were recruited in Sydney and were reimbursed with either course credit (where applicable) or a $30 voucher (per session). Adult participants were recruited through Macquarie University undergraduate units and via Macquarie University channels. Child participants were recruited from local childcare centres and via advertisements. All adult participants had completed their schooling in Australia and at least one parent/caregiver of child participants had completed all schooling in Australia. Participants had no history of speech disorders or hearing impairment. Four adults were excluded due to incomplete questionnaires, history of speech intervention, or non-binary gender identification. Child participant's hearing was screened using the Sound Scouts iPad application [19] and only those who obtained a 'Pass' result were included in this study (4 children were excluded on this basis). 15 child participants were included in this study (M_{age}= 57.5 months; F = 7, M = 8). This production study was conducted within the context of a larger PhD project.

2.2. Stimuli

The target items consisted of four CVC words, with the voiceless alveolar fricative /s/ in onset position, followed by a short monophthong: (two front unrounded vowels /ɪ, æ/; one central unrounded vowel /ɐ/; one back rounded vowel /ɔ/) (*sip*, *sap*, *suck* and *sock*). Although the target items were not specifically selected to examine vowel rounding effects, /ɔ/ (*sock*) is likely to be more rounded in AusE than the other vowels [20], providing an opportunity to explore this feature. Four additional CVC target words with the voiceless alveolar stop /t/ in onset position were also elicited; these are not analysed in the current study. The target words were produced in utterance final position in the carrier phrase "A happy X". In addition to the target items, 7 non-target CVC words were used for practice trials.

2.3. Procedure

The study was conducted in a child-friendly, acoustically attenuated lab in the presence of the first author, with caregivers of child participants able to observe from a connected room. Participants were seated at a desk in front of a computer screen on which the experiment was presented, using a customised Praat script controlled by the experimenter. Recordings were made with a Neumann TL103 condenser microphone at a sampling rate of 44.1kHz. The microphone was mounted on an articulated microphone boom and positioned approximately 20cm from the participant's mouth. Prior to the production task, the experimenter showed participants images of each target word while modelling the target word, and the participant was asked to repeat the word. Participants were informed that they would be prompted with the correct word if required during the task. Auditory instructions and stimuli prompts to be used in the experiment were produced by a 30-year-old female Australian English-speaker in a child-directed manner and recorded in an acoustically attenuated lab at a sampling rate of 44.1kHz. Stimuli prompts were the natural /s/ productions of this speaker.

The visual stimulus for each trial consisted of a sad cartoon panda on the left side of the screen and the image of the target item on the right side of the screen. A short introduction to the experiment familiarised participants with the carrier phrase "A happy X". An audio recording informed the participant that they could help make the panda smile by saying the name of the objects next to the panda. On each practice trial, the participant saw the visual stimulus and heard an auditory prompt, e.g., "Make the panda happy! Say, a happy pig", and participants would repeat the phrase "A happy X". On each test trial, the visual stimulus was paired with the auditory prompt "Make the panda happy!", and participants produced the carrier phrase and target word. If the participant could not remember the target word or produced the target word in isolation, an auditory stimulus prompt would be played, e.g., "Say, a happy sip". Once the participant produced the carrier phrase and target word, the image of the sad panda would change to an image of a happy panda at the end of each trial. Adult and child participants completed the same task, differing only in the number of trials. We retrospectively analysed the stimuli prompts, which revealed a slight whistle in the *sip* context. Of the total 403 *sip* tokens, 19 tokens were produced after hearing the prompt; of these, 3 tokens were produced with whistle, all by children.

Child participants completed 6 blocks of trials which contained the 8 target words in a pseudo-randomised order, for a total of 48 tokens (8 words x 6 repetitions) per child participant; 24 of these were /s/-target words. Adult participants completed 10 blocks of trials, for a total of 80 tokens (8 words x 10 repetitions) per adult participant; 40 of these were /s/-target words.

2.4. Analysis

Audio files and corresponding text files were processed using the BAS web services pipeline to generate phoneme aligned TextGrids [21]. Using Praat [22], boundaries for the /s/ phoneme were individually inspected and corrected when these did not align with the phoneme onset and offset. The /s/ onset boundary was placed at the start of strong frication and the /s/ offset boundary was placed at the end of strong frication on the spectrogram. The spectrogram view range was increased to 16kHz when coding for whistle presence to ensure that this characteristic was identified consistently across adult and child tokens.

Each token was inspected to determine whether whistle was present or absent. Whistle presence was indicated by an audible whistle during part of the fricative and the presence of a strong band of energy in the spectrogram. Measurements obtained included measures of duration, intensity, spectral peak and the four spectral moments (M_1-M_4). Spectral measures were obtained by processing audio files and corresponding TextGrids with a customised Praat script [23]. This script was originally adapted from DiCanio [24] with adjustments for some of the formulas, including window spacing and bin calculations, and subsequently updated to include the revised calculation methods in version 4.0 of the DiCanio script [25]. Potential effects of co-articulatory voicing on spectral measures [26] were reduced by high-pass filtering target sounds at 300Hz within the Praat script. Spectral measures were calculated using time averaging of windows, as recommended by Shadle [13]. Each sound had a trim of 25% for both onset and offset, i.e., the central 50% of each sound domain was used for spectral measure calculations. Ten rectangular windows with a 5ms size were spaced evenly across this sound domain. The focus here is on kurtosis (M_4), as it may be sensitive to the presence of whistle [6, 7, 16].

There were 35 tokens excluded from analyses (e.g., for noise, mispronunciations, pauses, etc.). The analysis was conducted on a total of 1605 tokens (Adults = 1272, Children = 333).

2.5. Statistical Analysis

The analysis reported here assesses the effect of speaker age, gender, whistle presence and vowel context on the dependent variable, kurtosis (M_4). Linear Mixed Effects Regression (LMER) analysis of kurtosis was conducted in R Studio [27] using the lme4 package [28]. Degrees of freedom for t-tests were estimated with Satterthwaite's method using the lmerTest package [29]. The fixed effects in the model were group (i.e., Adults vs Children), gender (i.e., Female vs Male), whistle presence (i.e., Absent vs Present in token), vowel context (i.e., /æ/ vs /ɪ, ɐ, ɔ/; *sap* vs *sip*, *suck, sock*) and fricative duration. The model included an interaction term for group and gender, and an interaction term for whistle presence and vowel context. The random effects structure included intercepts for participants.

3. Results

A total of 180 tokens were identified to have whistle present (Adults = 116, Children = 64). Whistle tokens were produced by 62% of the participants (19 Adults, 10 Children). Table 1 provides the total number of tokens with and without whistle in the analysis, by group and gender. The number of tokens with whistle presence was roughly equivalent across vowel contexts (/ɪ/ = 11%, /æ/ = 12%, /ɐ/ = 10%, /ɔ/ = 12%).

Table 1. *Tokens with and without whistle*

Group	Gender	Whistle Absent	Whistle Present	% with Whistle
Adults	Female	781	92	11%
Adults	Male	375	24	6%
Children	Female	128	32	20%
Children	Male	141	32	18%
Total =		1425	180	11%

Adult speakers had a mean kurtosis (M_4) value of 3.6 (Female M=3.7, SD=5.7; Male M= 3.6, SD=2.9), and child speakers had a mean M_4 value of 2.98 (Female M=4.61, SD=9.68; Male M=1.48, SD=2.13). Figure 1 provides the kurtosis (M_4) values by whistle presence and vowel context, averaged over group and gender, and the mean M_4 value represented with purple circles. Some tokens that were labelled as 'Whistle Absent' during acoustic coding have relatively high M_4 values between 10 – 20. Although these 'Whistle Absent' tokens did not have an audible whistle or clear bands of energy in the spectrogram, the high M_4 values may indicate that these tokens were produced with a similar mechanism as those produced with audible/visible whistle characteristics.

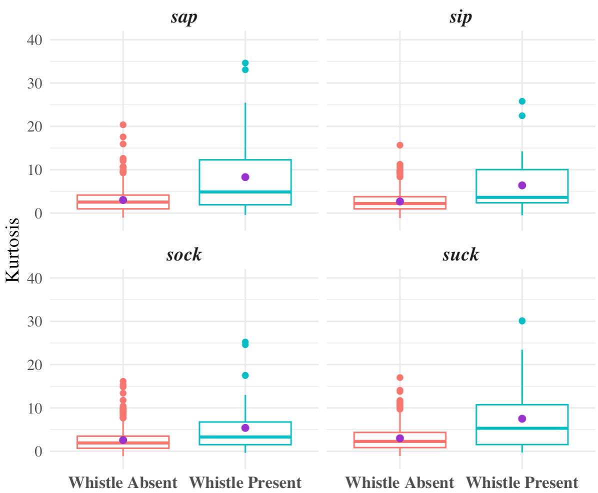

Figure 1: *Kurtosis (M_4) by whistle presence & vowel context.*

The analysis of speaker age, gender, whistle presence and vowel context on kurtosis (M_4) found a significant interaction between whistle presence and vowel context (β = -4.1, SE= 0.955, t(1554)= -4.27, p < 0.001). *Post hoc* comparisons were run using the emmeans package [30] in R, with Tukey HSD corrections to *p*-values for multiple comparisons. Our first research question asked whether whistle in /s/ tokens would predict higher M_4 values, and research question 2 asked whether this was moderated by vowel rounding. In support of our prediction for research question 1, pairwise comparisons indicated that M_4 values were significantly higher in tokens with whistle present, compared to tokens without whistle present (all vowel contexts $p < 0.001$). In contrast to the prediction for research question 2, whistles in *sock* tokens have a significantly lower M_4 compared to the M_4 values of whistle tokens in other vowel contexts ($p < 0.05$). This interaction may indicate that in the /ɔ/ vowel context, there are other (perhaps more prominent) cues to whistle, such as the other spectral moments (M_1, M_2, M_3) or other acoustic measures. There were no other significant simple effects or interactions, indicating there is no evidence that M_4 values differ based on group or gender for this dataset.

Two example spectrograms are provided here, both with a view range of 16kHz, to illustrate the range of whistle characteristics. Figure 2 is an example of a female adult's token with whistle present and a strong band of energy visible around 8kHz. This token had an audible whistle during the fricative and a high M_4 value of 85.

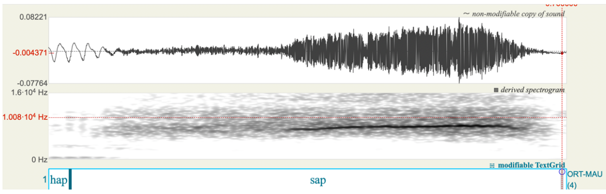

Figure 2: *Whistle presence in female adult's token.*

Figure 3 is an example of a female child's token with whistle present and a strong band of energy visible between 8-10kHz. This token had an audible whistle during the fricative and a M_4 value of 21.

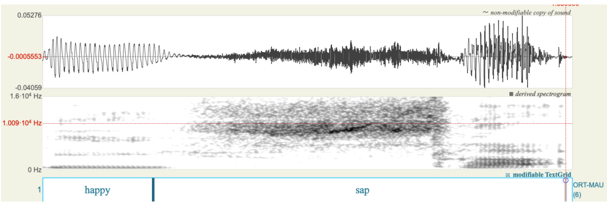

Figure 3: *Whistle presence in female child's token.*

4. Discussion

This study aimed to investigate whether the presence of whistle in /s/ productions is associated with higher kurtosis (M_4). Consistent with previous observations of non-phonemic whistled /s/ [6, 7], this study has provided evidence that high M_4 values may be indicative of /s/ produced with whistle characteristics. The LMER analysis indicated that whistled /s/ tokens had higher M_4 values, compared to non-whistled /s/ tokens, across all vowel contexts. Some non-whistled /s/ tokens were observed to have relatively high M_4 values, which may indicate that these tokens were produced with a similar articulatory configuration to whistled /s/ tokens. Some studies have observed whistled /s/ in rounded contexts [6, 7], while this study has observed whistled /s/ in both unrounded vowel contexts (i.e., /ɪ, æ, ɐ/) and rounded contexts (i.e., /ɔ/). There was a significant interaction of M_4 values and vowel context; contrary to our expectations, M_4 values in whistled tokens in the *sock* context were lower compared to M_4 values of whistle tokens in the *suck*, *sap* and *sip* contexts. This is despite high kurtosis being previously reported, and confirmed here, as being associated with whistled fricatives, and suggestions that whistling may be more common in the context of rounded vowels [6, 7]. It is possible that the lower M_4 values seen here in the /ɔ/ context for whistle tokens may reflect the backness of the vowel, which is produced with a more retracted tongue position [20] compared to the front and central vowels (/ɪ, æ, ɐ/). Future research should examine whistling in fricatives in a greater range of vowel contexts, both rounded and unrounded.

The total proportion of whistled /s/ tokens in this study was comparable to the proportion of whistled [ʂ̩] in Chilean Spanish [16]. Whistled /s/ was relatively common in both age groups, with children observed to have a higher proportion of whistled /s/ compared to adults. Female adults were observed to have a higher proportion of whistled /s/ compared to male adults, as was also reported for Chilean Spanish speakers [16]. However, there were insufficient tokens in this data set for a logistic regression analysis to assess the significance of the observed age and gender differences. Future research should examine whether these age and gender differences are observed in larger corpora of Australian English and in spontaneous, conversational speech.

There was a lower proportion of whistled /s/ observed in this study compared to the proportion of whistled /s/ reported to occur in whispered and voiced speech of female Portuguese speakers [2]. This may reflect differences in elicitation methods, as this study did not elicit whispered speech, and /s/ was only elicited in onset position, while [2] elicited /s/ in onset, medial and final position in whispered and voiced speech, as well as eliciting sustained /s/ tokens. Further research is required to determine whether whistled /s/ occurs in medial and final position to the same or greater extent than /s/ in onset position. The higher proportion of whistled /s/ for Portuguese speakers may also reflect a subtle difference in the production of /s/ by English and Portuguese speakers.

Kurtosis is infrequently reported in studies on fricatives, perhaps due to the perception that kurtosis does not capture sociophonetic features [15]. However, this may be a misperception, as kurtosis is a key measure for identifying non-phonemic whistled [ʂ̩] in Chilean Spanish, which is associated with female speech [16]. This study has demonstrated that kurtosis is also an important measure for identifying non-phonemic whistled fricatives in Australian English. Further research is required to determine whether sociophonetic factors are associated with English non-phonemic whistled /s/. The neglect of kurtosis may need to be reconsidered when describing typical fricative production by children and adults. Whistled /s/ was relatively common in both age groups and kurtosis appears sensitive to this phenomenon, which suggests it may be a useful metric for capturing variability in fricative production. Analysing kurtosis may be a more time-efficient method for identifying whistle presence in fricatives, compared to extracting and interpreting individual spectral slices. Future studies of fricative production would benefit from identifying whistled tokens and including kurtosis in analyses of spectral moments, as it may improve our knowledge of sociophonetic variation in English.

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