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Hormones and temporal components of speech: sex differences and effects of menstrual cyclicity on speech

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Abstract

Voice onset time (VOT) is a salient acoustic parameter of speech which signals the “voiced” and “voiceless” status of plosives in English (e.g. the initial sound in ‘bat’ vs. the initial sound in ‘pat’). As a micro-temporal acoustic parameter, VOT may be sensitive to changes in hormones which may affect the neuromuscular systems involved in speech production. This study adopted a novel approach by investigating the effects of menstrual cycle phase and sex on VOT. VOT data representing the 6 plosives of English (/p b t d k g/) were examined for 7 women (age 20-23 years) at two phases of the menstrual cycle (day 18-25: High Estrogen and Progesterone; day 2-5: Low Estrogen and Progesterone). Results indicated that menstrual cycle phase had a significant interaction with the identity of the plosive (F (5,30) = 5.869, $P < .002$). Menstrual cycle phase also had significant effects on the contrasts between cognate voiced and voiceless plosives (F (1, 6) = 11.444, $P < .02$); samples from the high hormone phase displayed an enhanced voiced/voiceless contrast. Subsequently, VOT data samples from the two phases of the menstrual cycle were compared with those from 5 men in order to explore sex differences at different phases of the menstrual cycle. Low hormone phase samples displayed no significant sex differences for either VOT values (F (1,10) = 2.085, $P > .05$), or the contrast between voiced and voiceless cognates (F (1,10) = .407, $P > .05$). In contrast, the high hormone phase VOT samples displayed significant plosive by sex interactions (F (5,50) = 4.442, $P < .005$). In addition, significant sex differences were found for the contrasts between cognate voiced and voiceless plosives (F (1,10) = 5.019, $P < .05$); the women displayed a more marked voiced/voiceless contrast. The findings suggest that ovarian hormones play some role in shaping some temporal components of speech.

Keywords: menstrual cycle, voice onset time, sex differences, speech, young adults, development

Research has shown that many sex differences in language that were once explained by testosterone-mediated effects alone are now believed to be the result of active differentiation in both sexes, i.e., masculinisation in males and feminisation in females [4]. Ovarian estrogen is known to affect the organisation of many neurobehavioural systems in both humans and non-human species [1,3,13]. Fluctuations of ovarian estrogen are known to affect a number of activational parameters at the neuroanatomical, neurofunctional and behavioural levels [7,15,18]. In humans, performance on various tests of cognition and behaviour has been shown to alter systematically as a function of hormonal changes across the menstrual cycle. These include reports of motor and perceptual skills [8,19] and functional laterality in perception [17]. Overall, the literature indicates that certain abilities are positively affected, and others negatively affected, at particular phases of the menstrual cycle that correspond to high levels of circulating ovarian estrogen [14] and in some cases, also to progesterone [9]. However, much remains unclear about the organisation and co-ordination of speech production systems as a function of activation by ovarian hormones across the menstrual cycle.

The emergence of speaker sex differences during puberty in the frequency characteristics of speech and the voice is well established [11], and is largely explained by sexual dimorphism of the larynx [10] and supralaryngeal vocal tract [5] due to the rises in hormone levels during puberty. Although there have been some attempts to investigate sex differences in the temporal domain of speech in adults, these findings are less well established [6,16], and little or no attention has been paid to the influence of hormones on the temporal components of speech. Furthermore, while there is some evidence for the developmental emergence of sex differences in the temporal speech domain, this area remains to be fully explored in light of the rises in hormone levels during puberty for both males and females [22]. One temporal component of speech is voice onset time (VOT), a parameter which plays a crucial role in the perception and production of voiced and voiceless stop consonants (e.g. bat vs. pat, cap vs gap) [12,20].

We report on a study which examined the VOT patterns of six stop consonants of English in 7 women aged 20-23 years at two phases of the menstrual cycle (day 18-25: High Hormones - Estrogen and Progesterone; day 2-5: Low Hormones - Estrogen and Progesterone). Seven

women (mean age 21;8) and five men (mean age 22;3) participated in the study. All participants were native speakers of English with no known speech, language or hearing problems. All women participants fulfilled the following criteria: i) they were not taking oral contraceptives, either at the time of the study, or for at least one year prior to the study; ii) they had not been pregnant or lactating in the year prior to the study; iii) they had regular menstrual cycles of between 25-35 days (mean 30.71 days S.D 2.87); and iv) they were not taking any hormonally based medication. All subjects completed the vocabulary and matrix subtest of the Wechsler Abbreviated Scale of Intelligence [21] to control for individual variations in IQ; the men had an average IQ of 117.8, and the women an average IQ of 117.7.

Speech samples were collected from the women on two separate occasions to encompass naturally fluctuating levels of hormones during the menstrual cycle; once between days 2-5 (mean day 4.6, SD 0.53) when estrogen and progesterone levels were low (menstrual - low EP-phase), and once between days 18-25 (mean day 21.14, SD 2.73) when estrogen and progesterone levels were high (midluteal - high EP-phase). Day one of the cycle is defined by the onset of menstruation. Date of testing for the midluteal phase was confirmed by checking the date of onset for the next menstrual period. All participants were tested within sixteen days counting backward from the onset of the next cycle (mean 10 days, SD 5.42). Three participants were tested first during the low-EP phase, whilst the other four had their first test session during the high-EP phase to counterbalance any possible learning effects. Young men display diurnal variations in testosterone, with the highest and lowest levels occurring in the morning and late afternoon, respectively [2]. Speech samples were therefore collected from the men during a single session between 2.30pm and 5pm to control for diurnal variations in male testosterone levels.

In English, the plosives /p t k/ are classed as "voiceless", and /b d g/, their respective "voiced" cognates. Speech samples representing all six plosives were therefore collected as follows. Each subject produced five repetitions of all plosive consonants (/p b t d k g/) in a syllable initial position in a target word within the frame "Say _____ again". The target words used were *pea, bee, tea, Dee, key, ghee, purred, bird, turn, Dearne, curl, girl, part, Bart, tart,*

dart, card, and *guard*. This gave a possible total of 90 speech samples (5 repetitions x 18 target words) for each subject, and an overall total of 1710 samples for all 12 subjects (1260 samples for the 7 women (630 for each phase of the menstrual cycle), and 450 for the 5 men). The phrases and target plosives were elicited using a verbal repetition task.

The speech data were recorded in a quiet room. Data were recorded directly onto a DAT (Digital Audio Tape) recorder (Sony, model TCD-D3). Subsequently, speech samples from each subject were digitized onto a Kay Elemetrics Computerized Lab (CSL) model 4300 using a sampling rate of 16 kHz. From this digital information, sound pressure waveforms and wideband (146 Hz) FFT spectrograms were generated and displayed. VOT measurements were made directly from the spectrograms by measuring the distance between the release of the plosive and the onset of voicing (marked by the first visible sign of low frequency periodic acoustic activity in the spectrograms). The point of closure release was taken as the transient burst of the plosive's release. In the cases where measures of VOT needed validation, sound pressure waveforms were used. In the cases where both the speech waveform and the spectrogram were referred to for validation, the VOT measurement was taken from the same data source. In the cases where VOT was unclear (e.g. plosives being released with affrication or the presence of background noise), the speech sample was discarded. All VOT measurements were taken in milliseconds. To ensure consistency in the VOT measurements, a test of inter-rater reliability was carried out. The inter-reliability measures were conducted by randomly selecting one subject for reanalysis by a second rater. A Pearson’s product-moment correlation was used to calculate the level of inter-rater reliability. A significant correlation coefficient (r = 0.99, P < 0.0001) demonstrated that there was a high level of inter-rater reliability.

In addition, the effects of estrogen and sex on the contrast between the "voiced" and "voiceless" plosives was examined for each place of articulation (bilabial, alveolar, velar). This was done by calculating the mean differences between the VOT values of the "voiceless" bilabial plosive /p/ and its "voiced" cognate /b/, the "voiceless" alveolar plosive /t/ and its "voiced" cognate /d/, and the "voiceless" velar plosive /k/ and its "voiced" cognate /g/. The

voiced-voiceless contrast was calculated by subtracting the "voiced" VOT values from the "voiceless" VOT values for all three places of articulation.

Mean VOT values for low and high estrogen menstrual phase data samples are illustrated in Fig. 1 (a) by plosive, and mean values for the voiced-voiceless contrast for low-EP and high-EP menstrual phase samples are displayed in Fig. 1 (b) by place of articulation. Effects of menstrual cycle phase on VOT by plosive and the voiced-voiceless contrast by place of articulation were tested using 2 two-factor ANOVA where phase (low-EP and high-EP) and plosive (b, d, g, p, t, k) were repeated measures. There were significant plosive effects (F (5, 30) = 360.216, P < .0001), and the order of magnitude for VOT values by plosive was as follows: b < d < g <p <t < k. Multiple comparisons with Bonferroni adjustment revealed significant differences (P < .05) for all between plosive comparisons except for t and k. These results are totally in line with previously published data, and represent the VOT patterns of voiced and voiceless plosives of English for all three places of articulation [12,16,22]. Results also indicated that there were no significant menstrual cycle phase effects on VOT overall (F (1, 6) = .314, P > .05). There was, however, a significant interaction between menstrual cycle phase and plosive (F (5, 30) = 5.869, P < .002), whereby the voiced plosives (b, d, g) displayed shorter VOT values for the high-EP phase, and the voiceless plosives p and k displayed longer values for the high-EP phase (see Fig. 1(a)). The voiced-voiceless contrast displayed no significant effects for either place of articulation (F (2,12) = 3.208, P > .05) or place of articulation by menstrual cycle phase interaction effects (F (2,12) = 3.433, P > .05). There were however, significant menstrual cycle phase effects for the voiced-voiceless contrast (F (1, 6) = 11.444, P < .02); high-EP phase samples displayed an increased voiced-voiceless contrast across all places of articulation, and post-hoc paired t-tests with Bonferroni adjustment (significant at P =.017) revealed that this was significant for the bilabial place of articulation (t_6 = 6.131, P = .001) (see Fig 1(b)).

Subsequently, VOT data samples representing the two phases of the menstrual cycle were compared with those from the 5 men in order to explore the nature and extent of sex differences at different phases of the menstrual cycle. Four mixed design ANOVAs with plosive (b, d, g, p, t, k) as the repeated measure, and sex as the between subjects measure were used

to test for sex differences for the low-EP, and high-EP phase VOT samples, and the voiced-voiceless contrast data. For the low-EP phase, the following results were found. There were significant plosive effects (F (5, 50) = 419.638, P < .0001), and the order of magnitude for VOT values by plosive was as follows: b < d < g <p < k < t. Multiple comparisons with Bonferroni adjustment revealed significant differences (P < .05) for all between plosive comparisons except for t and k. In addition, the low estrogen phase samples displayed no significant sex differences (F (1,10) = 2.085, P > .05),or significant plosive by sex interactions (F (5,50) = 1.051, P > .05) for the low estrogen phase VOT samples. The contrast between voiced and voiceless cognates for low-EP phase samples displayed significant place of articulation effects (F (2, 20)=7.903, P < .005), but no significant sex differences (F (1,10) = .407, P > .05), or significant place of articulation by sex interactions (F (2, 20) = .705, P > .05). The following results were found for the high-EP phase VOT samples. Firstly, as for the low-EP phase samples, there were significant plosive effects (F (5, 50) = 452.221, P < .0001), and the order of magnitude for VOT values by plosive was as follows: b < d < g <p < k < t. Multiple comparisons with Bonferroni adjustment revealed significant differences (P < .05) for all between plosive comparisons except for t and k. Secondly, although the women displayed significantly longer VOT values than the men, these trends did not reach significance (F (1,10) = 2.871, P > .05). There were, however, significant sex by plosive interactions (F (5, 50) = 4.442, P < .005) which were characterized by the women having longer VOT values for the plosives p, b, and k (see Fig. 1(a)). The contrast between voiced and voiceless cognates displayed significant place of articulation effects (F (2, 20) = 5.081, P < .02), and significant sex differences (F (1,10) = 5.019, P < .05); the women displayed greater voiced/voiceless contrasts for all three places of articulation, and post-hoc independent t-tests with Bonferroni adjustment for multiple comparisons reached significance for the velar place of articulation (t_{10} = 2.843, P = .017 - see Fig 1(b)). Place of articulation by sex interactions were not significant (F (2,20) = 1.4, P > .05).

The results suggest that hormonal cyclicity has a significant effect on at least one temporal component of speech; voice onset time. High-EP phase VOT samples appear to display shorter values for the voiced plosives, and longer values for the voiceless plosives (see Fig 1(a)). The

net effect of this is that the High-EP phase samples display an increased distinction between the voiced and voiceless cognates (p/b, t/d, k/g); a pattern which will result in enhancing the intelligibility and clarity of phonetic structures in speech output. In addition, sex differences in VOT values appear to be enhanced during the high-EP phase, thus paralleling some of the effects of menstrual cycle phase on VOT of voiceless plosives. However, whether the menstrual cycle effects reported here are due to cyclical changes in the peripheral tissue systems involved in speech production, or effects on the central nervous system, or indeed both sets of factors, requires further investigation. Menstrual cycle phase is a factor that has not been considered in the study of VOT patterns in adults, which may explain why reports of sex differences in the VOT patterns of adults have been inconsistent; studies have reported both a presence and absence of significant sex differences [see 22 for a summary of these trends]. However, the results of this study are consistent with the notion that the rise of hormones around puberty may, in part, be responsible for the developmental emergence of sex differences that have been observed in the VOT patterns of children aged between 10 and 11 years (mean age 10;7 years) [22], and may therefore explain the presence of significant sex differences in the VOT patterns of adults [e.g. 16, and as summarized in 22].

In summary, the results suggest that hormones play some role in shaping the VOT patterns of speech. Both menstrual cycle phase and sex appear to affect this temporal component of speech; high and low estrogen samples display similar patterns to sex differences observed for high-EP phase samples, therefore suggesting that estrogen may have the effect of enhancing sex differences in speech. In addition, samples from the high-EP phase appear to display greater voiced-voiceless contrasts which will contribute to enhanced speech intelligibility. However, a factor that should not be overlooked is that the data were contrasted between the menstrual and midluteal phases when both estrogen and progesterone were at low and high levels, respectively. Therefore, further investigation is required to determine the precise role of these ovarian hormones on VOT and other speech parameters, and their effect on sex differences in motor speech output.

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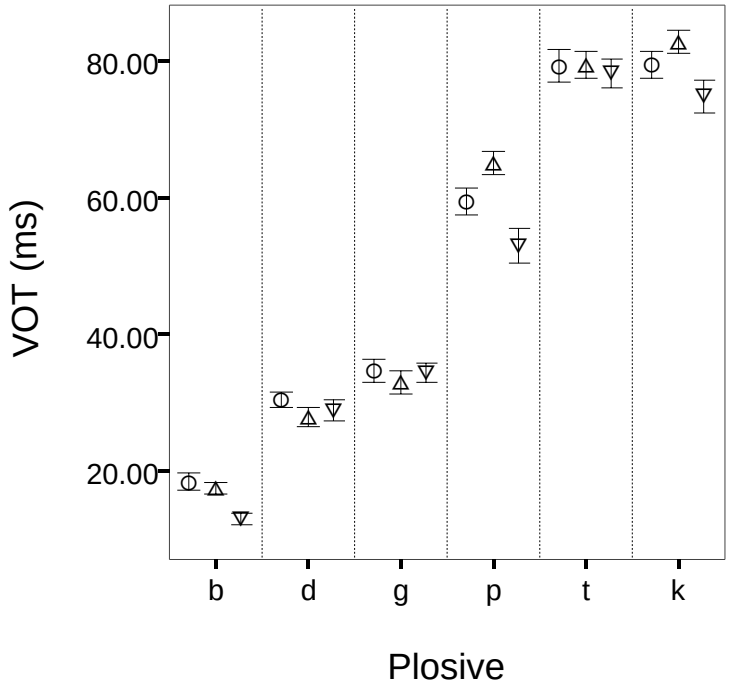

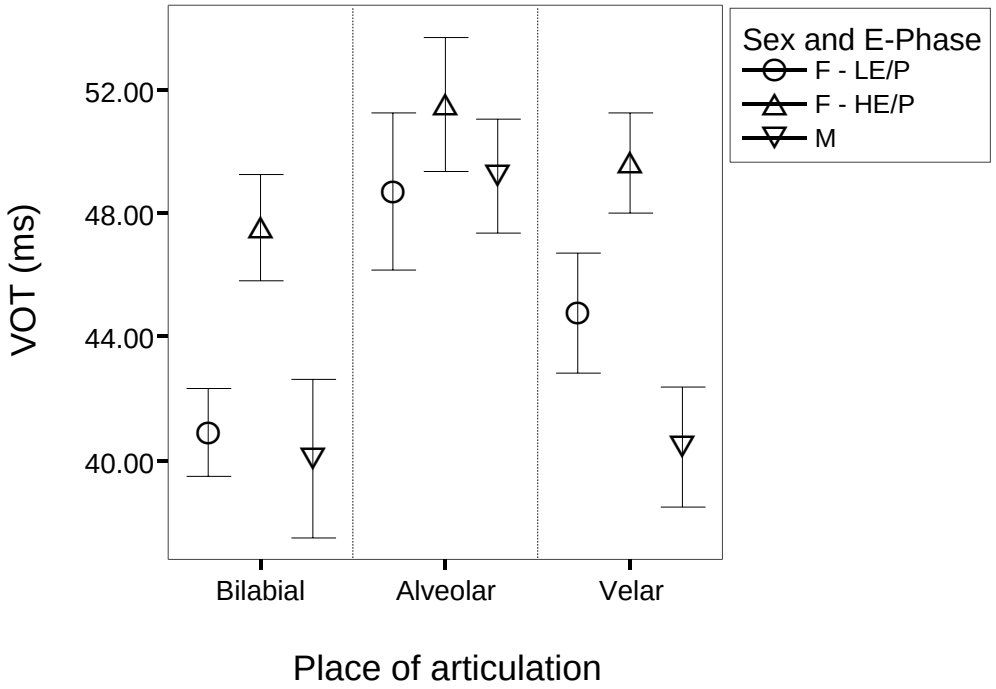

(a) (b)

Fig. 1. Mean values for: (a) VOT (in ms) by plosive (b d g p t k) for sex and low (LE/P) and high (HE/P) estrogen/progesterone data samples, (b) voiced/voiceless contrasts (in ms) by place of articulation for sex and low (LE/P) and high (HE/P) estrogen/progesterone data samples. Error bars represent ± 1.0 SE of the mean.