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Speech across the menstrual cycle: A replication and extension study

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Abstract

Whiteside et al. [S.P. Whiteside, A. Hanson, P.E. Cowell, Hormones and temporal components of speech: sex differences and effects of menstrual cyclicity on speech, Neurosci. Lett. 367 (2004) 44–47] documented effects of menstrual cycle phase and sex on voice onset time (VOT) in naturally timed speech using whole words. VOT is a temporal component of speech that plays an important role in production and perception [L.L. Koenig, Laryngeal factors in voiceless consonant production in men, women, and 5-year-olds, J. Speech Lang. Hear. Res. 43 (2000) 1211–1228; A. Löfqvist, L.L. Koenig, R.S. McGowan, Vocal tract aerodynamics in /aCa/ utterances: measurements, Speech Commun. 16 (1995) 49–66; T.M. Nearey, B. Rochet, Effects of place of articulation and vowel context in VOT production and perception for French and English Stops, J. Int. Phon. Assoc. 24 (1994) 1–18; L.M. Rimol, T. Eichele, K. Hugdahl, The effect of voice-onset-time on dichotic listening with consonant–vowel syllables, Neuropsychologia 44 (2006) 191–196; P.G. Simos, R.L. Diehl, J.I. Breier, M.R. Molis, G. Zouridakis, A.C. Papanicolaou, MEG correlates of categorical perception of a voice onset time continuum in humans, Cogn. Brain Res. 7 (1998) 215–219; S.P. Whiteside, J. Marshall, Developmental trends in voice onset time: some evidence for sex differences, Phonetica 58 (2001) 196–210]. The present study was designed to replicate and expand upon Whiteside et al. [S.P. Whiteside, A. Hanson, P.E. Cowell, Hormones and temporal components of speech: sex differences and effects of menstrual cyclicity on speech, Neurosci. Lett. 367 (2004) 44–47] using a speeded syllable repetition paradigm. VOT measurements for 6 English plosives (/p b t d k g/) were obtained from speech samples of 15 women and 20 men (age 20–25 years). Women were tested across two points in the menstrual cycle (Days 2–5: low estrogen and progesterone/low-EP; Days 18–25: high estrogen and progesterone/high-EP) and men were tested once. Results indicated significant interaction between menstrual cycle phase and voicing ($F(1,14) = 8.239$, $P < 0.02$), whereby the voiced plosives (b, g) displayed shorter VOT values and the voiceless plosives (p, k) displayed longer values at the high-EP phase. Thus, the distinction between the voiced and voiceless plosive was enhanced at high-EP. Significant sex effects ($F(1,33) = 10.080$, $P < 0.005$) were seen with women at high-EP but not the low-EP phase having longer VOT values than men for voiceless plosives. Sex differences between the voiced and voiceless plosives were enhanced at the high-EP phase. This study indicates a role for activational ovarian hormones in regulating temporal features of speech in both whole words and speeded syllable repetition.

Keywords: Menstrual cycle; Speech; Voice onset time; Sex differences; Phonetic

A recent study from our laboratory by Whiteside et al. [29] showed effects of menstrual cycle and sex on voice onset time (VOT). VOT is a temporal component of speech that plays an important role in the production and perception of voiced and voiceless plosives [13,15,20,21,25,31]. The results showed that distinction between the voiced and voiceless plosive was enhanced at the high hormonal phase of the menstrual cycle [29]. Sex differences between the voiced and voiceless plosives were also enhanced at the high hormonal phase. This study explored VOT using repetition of sentences at a natural production rate. The sentences were constructed using minimal word pairs (e.g. 'Say pea again'). The study was the first of its kind; exploring hormonal effects on VOT. These findings indicated a role of activational ovarian hormones and organisational sex effects in regulating VOT. Sex differences have earlier been explored and established in the temporal speech parameters. However, the evidence so far had been inconclusive with some studies reporting a significant sex difference in VOT, while others reporting no difference [6,23,26,27,30]. Previous studies exploring sex differences did not focus on hormonal effects, which might be a reason behind the inconclusive findings.

Results reported by Whiteside et al. [29] were consistent with a growing literature on the effects of ovarian hormones on speech and motor behaviour [7–9,11]. Many of these reports were based on the study of speeded speech and motor output [7–9]. Research into activational effects of ovarian hormones

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demonstrated that the high hormonal phase of the menstrual cycle facilitates some behaviours [7–9,16,17,24], whereas the low hormonal phase is known to facilitate some other behaviours [8,10]. In humans, fine motor movements, speech articulation, implicit memory, verbal fluency and perceptual asymmetries are reported to be enhanced at the high hormonal level [7–9,16,24]. Spatial ability is known to be enhanced at the low hormonal level [7,8,10]. Sex differences in spatial and verbal ability have received much attention. However, limited evidence is available in the human speech domain, regarding the activational effects of ovarian hormones on specific behavioural elements involved in the organisation and co-ordination of speech production. Therefore, the current study aimed to replicate the VOT effects as a function of menstrual cyclicity and sex, and expand the scope using speech samples obtained from a speeded syllable repetition task. These data form part of a larger scale research project designed to examine hormones, speech and related behaviours.

Participants were 15 women (mean age 22.51 ± 0.56 years) and 20 men (mean age 23.00 ± 0.37 years) recruited from University of Sheffield student population. All were right handed, native English speakers, with no known history of neurological, speech, language or hearing difficulties. Women had regular menstrual cycles between 28 and 30 days (mean 28.60 ± 0.32 days), were not using oral contraceptives and had not been pregnant or lactating for at least 1 year prior to the study. Written informed consent was obtained from each participant. The research protocol was approved by the Department of Human Communication Sciences Research Ethics Committee, University of Sheffield.

Test sessions included an initial interview to collect demographic information, family, hormonal, medical and educational history. Baseline testing for manual laterality and IQ (women 118.66 ± 1.66; men 122.05 ± 1.66) was conducted for all participants. This was followed by the single syllable repetition task. Testing for speech took place across two sessions for each female participant corresponding to two phases of the menstrual cycle. The menstrual phase was defined as Days 2–5: low estrogen and progesterone/low-EP (mean 3.66 ± 0.33 days). The midluteal phase was defined as Days 18–25: high estrogen and progesterone/high-EP (mean 21.16 ± 0.94 days). The midluteal phase was confirmed by counting backwards from the onset of the next menstrual cycle. All women were tested within 14 days counting backward (mean 10.33 ± 0.61 days). Males were tested once for all behavioural tests.

For women the same speech tasks were repeated at low-EP and high-EP phase. In the case of women, administration of the first test session was counterbalanced, such that nine participants started the testing during menstrual phase, and the other six started testing during the midluteal phase. The speech task consisted of speeded repetition of a single syllable. In English, the plosives /p/ and /k/ are 'voiceless', and the plosives /b/ and /g/ are 'voiced'. These plosives combined with a vowel sound yielded the syllables /pa/, /ka/, /ba/ and /ga/. Syllables /ta/ and /da/ were not used in this study as they did not show significant differences in the Whiteside et al. study [29]. Participants were required to repeat each syllable 10 times as quickly and as accurately as possible. This gave a potential total of 40 speech samples per subject (10 repetitions × 4 syllables) and 2000 speech samples for all 35 subjects (1200 speech samples for females, 600 for each phase of the menstrual cycle and 800 for the 20 males). Speech data were recorded onto a digital recorder (Marantz Portable Professional Solid State Recorder, Model PMD670) using a sampling rate of 44100 Hz. Audio files were then transferred onto Adobe® Audition™ (version 1.5) for speech analysis (file type PCM.wav file, stereo 16 bit). Sound pressure waveforms and spectrograms were generated using these speech files. VOT measurements were made from the sound pressure waveforms by measuring the distance between the release of the plosive and the onset of voicing (identified by the first visible of a quasi-periodic cycle). All VOT measurements were made in milliseconds. In cases where measures of VOT needed validation, spectrograms were used. In some cases where both the waveforms and spectrograms were used for validation, VOT measurements were taken from the same data source (i.e. sound pressure waveform or spectrogram). In cases where VOT was unclear due to distortion or background noise, the speech samples were excluded from analysis. Because of the nested repeated measures design of the study, any distorted single data trial resulted in the loss of an entire case. Five subjects from the original data set of 20 were therefore excluded on this basis. Inter-rater reliability for VOT measurements was computed for eight subjects (six females and two males). A Pearson's product moment correlation was used to calculate the level of inter-rater reliability, which indicated a high level of reliability in the VOT measurements ($r = 0.995$, $P < 0.001$).

Mean ± standard error of mean for the VOT values (in ms) for syllables /pa/ /ka/ /ba/ and /ga/ are presented in Table 1 as a function of sex and menstrual cycle phase. The voiced–voiceless contrast [29] was also analysed. This was done by taking the difference between the mean VOT values of the 'voiceless' bilabial plosive /p/ and its 'voiced' cognate /b/, and the 'voiceless' velar plosive /k/ and its 'voiced' cognate /g/. Measurements were expressed in milliseconds (Fig. 1).

Effects of menstrual cycle phase on VOT were analysed using a $2 \times 2 \times 2$ ANOVA where Phase (low-EP and high-EP), Place of articulation (bilabial, velar) and Voicing (voiced, voiceless) were repeated measures. Significant effects of Place ($F(1,14) = 76.322$, $P < 0.001$) and Voicing ($F(1,14) = 163.717$, $P < 0.001$) were observed. Order of magnitude for plosives was $b < g < p < k$ (Table 1). Phase was not significant ($F(1,14) = 0.065$, $P > 0.05$), but there was a significant Phase and Voicing interaction ($F(1,14) = 8.239$, $P < 0.02$). VOT for voiced plosives (b, g), was shorter at the high-EP phase, and

Table 1
Means and standard errors for VOT (in ms) by single syllables (/pa/ /ka/ /ba/ /ga/) for sex and low (low-EP) and high (high-EP) estrogen and progesterone data samples

Single syllables	Low-EP phase	High-EP phase	Males
/pa/	40.80 ± 3.48	44.31 ± 3.88	40.18 ± 2.04
/ka/	56.38 ± 2.61	57.77 ± 2.66	52.31 ± 2.03
/ba/	14.27 ± 1.10	10.87 ± 0.80	15.63 ± 1.08
/ga/	26.38 ± 1.59	23.34 ± 1.66	30.04 ± 1.78