Effects of Speaking Rate on Breathing and Voice Behavior

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Summary: Objectives. The objective of this study was to investigate the effects of speaking rate (habitual and fast) and speech task (reading and spontaneous speech) on seven dependent variables: Breath group size (in syllables), Breath group duration (in seconds), Lung volume at breath group initiation, Lung volume at breath group termination, Lung volume excursion for each breath group (in % vital capacity), Lung volume excursion per syllable (in % vital capacity) and mean speaking Fundamental frequency (f_O).
Methods. Ten women and seven men were included as subjects. Lung volume and breathing behaviors were measured by respiratory inductance plethysmography and f_O was measured from audio recordings by the Praat software. Statistical significance was tested by analysis of variance.
Results. For both reading and spontaneous speech, the group increased mean breath group size and breath group duration significantly in the fast speaking rate condition. The group significantly decreased lung volume excursion per syllable in fast speech. Females also showed a significant increase of f_O in fast speech. The lung volume levels for initiation and termination of breath groups, as well as lung volume excursions in % vital capacity, showed great individual variations and no significant effects of rate. Significant effects of speech task were found for breath group size and lung volume excursion per syllable, where reading induced more syllables produced per breath group and less % VC spend per syllable as compared to spontaneous speech. Interaction effects showed that the increases in breath group size and breath group duration associated with fast rate were significantly larger in reading than in spontaneous speech.
Conclusion. Our data from 17 vocally untrained, healthy subjects showed great individual variations but still significant group effects regarding increased speaking rate, where the subjects seemed to spend less air per syllable and inhaled less often as a consequence of greater breath group sizes in fast speech. Subjects showed greater changes in breath group patterns as a consequence of fast speech in reading than in spontaneous speech, indicating that effects of speaking rate are dependent on the speech task.
Key Words: Speech tempo— Speaking rate— Lung volume— Speech breathing— Voice therapy— Respiratory Inductance Plethysmography.

INTRODUCTION

Speaking rate seems to be a parameter of relevance to voice function. It has been suggested that a fast habitual speaking rate is associated with increased risk of developing functional voice disorders due to vocally traumatic behaviors such as hyperfunctional voice use or glottal attacks[1] and clinical experiences from voice therapy suggest that voice quality and pitch can change with a change in speaking rate.[1,2] However, the relation between speaking rate and voice is not fully understood.

One possible hypothesis regarding the physiological coupling between speaking rate and voice is that a fast rate involves higher articulatory demands, leading to increased laryngeal tension.[1] Previous research has found increases in both speaking fundamental frequency (f_O) and sound pressure level (SPL) of repeated sentences or syllables with increased speaking rate, findings that might be explained by a general increase in muscle tone during fast speech.[1,2]

Another possible coupling between speaking rate and voice is that speaking rate affects speech breathing behavior in terms of e.g. breath group size and speaking lung volumes. If that is the case, those changes in breathing pattern might affect glottal airflow and compression. Previous research has found that phonation at low lung volume levels induces a lower transglottal airflow and a more hyperfunctional type of phonation.[3-5] A mechanical linkage between lung volume and the voice source in terms of a tracheal pull has been described as a possible explanation to such phonatory effects.[3,5-7] Furthermore, speaking lung volume has been shown to affect fundamental frequency (f_O) and sound pressure level (SPL), showing that speaking at higher lung volume levels is associated with increased speaking f_O and SPL.[4,5,7,8] This might be a result of the increased subglottal pressure (P_s) associated with the elastic recoil forces of the system at high lung volume levels in untrained voice users.[7,8]

Grosjean & Collins[9] investigated the speech breathing effects of increased speaking rate in a reading task. Their results showed that participants increased breath group size measured in words when they increased the speaking rate. A breath group is defined as the speech produced between two inhalations.[10,11] Grosjean & Collins[9] also found increased speaking rate to cause shorter inhalations. The study did not report results regarding speaking lung volumes but it seems relevant to raise the question, if an increased speaking rate also results in lower speaking termination lung volumes due to greater air consumption per breath group as well as inhalation of less air between breath groups.

There are no simple technical ways to analyze lung volumes during speech and the number of studies on speaking lung volumes are restricted. Huber[10] studied correlations between breathing and breath group characteristics in spontaneous speech. Overall, Huber found that longer breath groups were associated with speech at higher speaking rates than shorter breath groups. Dromey & Ramig[2] investigated whether speaking rate influenced speaking lung volumes. In their study, 10 healthy participants produced a sentence in different conditions, where five of them varied with regard to speaking rate. Results showed, not surprisingly, that lung volume excursion, reflecting the amount of air consumed per sentence, decreased significantly as speaking rate increased. The authors explain this as a natural consequence of a bigger air consumption when a sentence is produced at a lower speaking rate. The study did not find significant effects of speaking rate on lung volume at sentence initiation and termination, which might be explained by the very small breath group size associated with a sentence stimuli.

Speech task might be a factor of relevance for speech breathing. Iwarsson & Sundberg[12] found a significant effect of speech task on breath group size and lung volume measures. Their participants produced more syllables per breath group in spontaneous speech than in text reading. This effect also applied to amount of air consumed per breath group. Furthermore, both initiation and termination lung volume levels for speech were higher in spontaneous speech than in reading. In line with this, Wang et al.[13] found significantly bigger breath group sizes for spontaneous speech compared to text reading. Furthermore, mean speaking f_O has been found to be significantly higher in text reading than spontaneous speech.[14-16] Summarizing, the existing research in this field indicate some correlations between voice, breathing and speaking rate. However, the field of research lacks studies on direct effects of changed speaking rate on acoustic and respiratory measures in connected speech. There seems to be a need to document with objective data if breathing pattern in terms of breath group size and speaking lung volume is affected by speaking rate. Such a contribution would be valuable in structuring behavioral voice therapy, where focus on respiration, speaking habits and speaking rate are common elements. Also acoustical analysis in terms of speaking fundamental frequency is of interest. A natural approach to investigate effects of speaking rate on breathing and voice behavior seems to be a study of healthy subjects instructed to consciously modify their speaking rate. The aim of the present study was therefore to study the effects of increased speaking rate on some respiratory and acoustic measures. In addition, we wanted to investigate the effects of speech task as well as the interaction effects between speaking rate and speech task.

The study design thus included two independent variables: speaking rate (habitual and fast) and speech task (reading and spontaneous speech) resulting in four experimental conditions. The dependent variables were six respiratory and one acoustic measure: breath group size (in syllables), breath group duration (in seconds), lung volume at breath group initiation (ILV), lung volume at breath group termination (TLV), lung volume excursion for each breath group in % vital capacity (%VC/bg), lung volume excursion per syllable in % vital capacity (%VC/syl) and mean speaking fundamental frequency (f_O).

METHODS

Subjects
19 candidates were recruited for the study by personal contact or through a Facebook group for university students. Inclusion criterion was Danish as native language. Exclusion criteria included reading disabilities, history of voice problems and experience with voice training. All 19 candidates met the inclusion and exclusion criteria. All subjects were students at University of Copenhagen or recent graduates. Two participants had to be excluded from the analysis due to technical problems during the data collection. Data from 17 subjects were included in the analysis, 10 women and 7 men ranging in age from 20 to 33 years.

Instrumentation
Breathing patterns were measured by means of respiratory inductance plethysmography (RIP). The device we used was RespTrack 1.1D, developed at Dept. of Linguistics, Stockholm University, Sweden. In RIP changes in lung volume can be estimated by two elastic bands measuring changes in cross-sectional area of the rib cage and abdomen shown in two separate channels. A third output shows the sum of the two, representing the total change in lung volume, due to calibration during an iso-volume maneuver.[17] The experimental setup involved two elastic bands (RIPmate, Pediatric #1903) connected to the RespTrack processor that transforms the movements to DC-voltages (-2V to +2V). For recording of the respiratory signals we used the software RTRecorder 4.2. All recordings were carried out in a sound treated studio. The equipment used for audio signal recording was a cardioid microphone (Sennheiser MKH40 P48) placed at face level in front of the subject at a distance of 30 cm, a Behringer Ultragain Microphone Amplifier and an HHB compact disc recorder CDR-850. All sound files were recorded in wave file format (sampling rate 44,1 kHz, 16 bite).

Speech tasks
The study included a reading task and a spontaneous speech task. A text extract from the book The Hedgehog[18] was chosen as the reading task. The text extract was slightly moderated by the authors to avoid extremely long sentences, that could have influenced the participants' reading fluency. In addition, the text chosen contained no lines representing direct speech, foreign words, numerals or abbreviations that could affect the participants' inhalatory behavior. The reading simplicity of the text extract was considered appropriate from test readings by pilot study subjects. The reading text was visually presented to the subjects in one paragraph with straight left and right margins.

The spontaneous speech task was chosen to represent semi-spontaneous speech, where the subject was instructed to describe how to make a pasta sauce. The reason for having a set topic for the spontaneous speech was to make the two speaking rate conditions more similar, as compared to a free choice of topic. Participants were told that the content of the spontaneous speech task in the two rate conditions did not have to be exactly the same.

Test procedure

The participants performed the test procedure in a standing position wearing the elastic bands. First, the participants did the isovolume-maneuvres with a closed glottis, to adjust the respiratory sum channel to reflect zero at no lung volume change. To determine the relaxation expiratory level (REL), the participants were asked just to relax quietly in a standing position for approximately 1−2 minutes to reach a relaxed tidal breathing pattern. During this, the experimenter observed the tidal breathing and registered REL as the level of the SUM channel signal after a relaxed exhalation. Then participants did maximum inhalations and exhalations to determine each individual's vital capacity. All participants started with the reading tasks. The text was printed and placed at eye level in front of the participant. For the habitual speaking rate condition, the participants were instructed to read the text aloud at a habitual pace. For the fast speaking rate condition, the participants were instructed to read the text aloud as fast as possible, with the speech still being intelligible. Then the participants did the spontaneous speech tasks in habitual and fast rate conditions. Here the speaking rate instructions were the same as in the reading tasks. The order of the speaking rate conditions was controlled such that half of the participants started with the habitual speaking rate condition and the rest started with the fast condition. This was done to prevent a bias in terms of an order effect. After finishing all the speech tasks, the participants repeated maximum inhalation and exhalation.

Measurements

The speaking rate was measured in syllables per second (syl/s). The number of syllables were counted manually as the orthographic representation corresponding to the spoken language, rather than the actually pronounced syllables. This was decided based on the assumption that articulatory reduction of syllables is a natural consequence of increased speaking rate and an attempt to measure such changes. The number of syllables was then divided by the duration of the speech task in seconds. Occurrences of misreadings or repetitions of syllables were included in the syllable count. Breathing measures were analyzed by means of the free sound editor software Sopran[19] using data from the respiratory sum channel. For each participant, vital capacity was estimated from maximum inhalations and exhalations. For one participant, a lung volume value below the range of estimated vital capacity was registered at a phrase termination.

In this case, this low lung volume value was used to represent minimum in the calculation of the vital capacity, from an assumption that this participant, in spite of the instruction, did not use his full expiratory reserve volume at the maximum exhalation. In the Sopran software, each breath group was manually identified from visual inspection and marked in the respiratory sum channel. In this way, data were collected regarding breath group duration (sec/bg), initiation lung volume (ILV) of breath groups and termination lung volume (TLV) of breath groups. ILV and TLV were expressed in percent vital capacity (% VC) based on the individually estimated vital capacity in each participant. The difference between ILV and TLV for each breath group was calculated as representing the lung volume excursion (%VC/bg). Mean lung volume excursion per syllable (%VC/syl) was calculated by dividing the summed LV excursion for all breath groups with total number of syllables in each condition. An example of audio- and respiratory signals for one participant is shown in Figure 1.

Mean fundamental frequency was analyzed in Hz using Praat.[20] The mean fundamental frequencies were then converted into semitones counted (sc) from the musical tone C_0 using a converting scale.[21,22]

Statistical analysis

Effects of speaking rate, speech task and interaction effects between speaking rate and speech task were tested for statistical significance by means of a two-way analysis of variance (ANOVA) with repeated measures on both factors for each of the seven dependent variables. The statistical analyses were done using vassastats.net.[23]

RESULTS

Speaking rate

Mean speaking rate (syl/s) for the two speech tasks are presented in Figure 2. As expected, mean speaking rate for the group were higher in the fast speaking rate condition than in the habitual rate for both speech tasks. This difference reached statistical difference, $F(1,16) = 46.3$, $P < 0.01$. In addition, the text reading task resulted in a significantly higher speaking rate than spontaneous speech for the group, $F(1,16) = 38.8$, $P < 0.01$.

Mean speaking rate for each participant in the four conditions are presented in Table 1. The difference in speaking rate between the two rate conditions showed great variation between the participants. All except one (subject 5 when reading) increased their speaking rate in the fast speaking rate condition compared to the habitual speaking rate condition.

Effects of speaking rate on breath group characteristics

Table 2 presents group means and standard deviations of the six dependent respiratory variables for the four conditions. A two-factor ANOVA with repeated measures showed a significant effect of speaking rate on breath group size, $F(1,16) = 14.63$, $P < 0.01$ and breath group duration, $F(1,16) = 4.65$, $P = 0.047$. For both reading
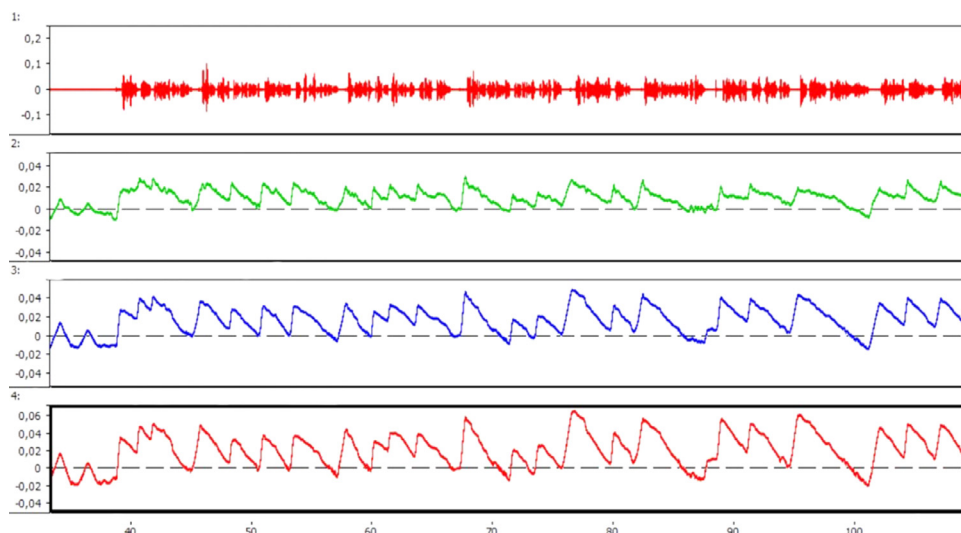
FIGURE 1. Measurements from RIP-equipment. From top to bottom the signals represent audio signal, abdominal movements, summed respiratory signal (abdomen and rib cage representing lung volume), and rib cage movements. Horizontal axis represents time and vertical axes represent relative changes in lung volume levels.

and spontaneous speech, participants increased their breath group size and thus produced more syllables per breath group in the fast speaking rate conditions. Also, duration of breath groups (in seconds) increased significantly when participants increased their speaking rate across speech task. Both these group effects on breath grouping behavior states that the subjects inhaled less often when they were instructed to speak fast as compared to speaking in a habitual rate.

Individual results reveal that a few participants (subject 7, 13, 15 and 16) produces fewer syllables per breath group in the fast rate condition than in the habitual rate condition in either both or one of the speech tasks. This is illustrated in Figure 3 and 4. Also for breath group duration in seconds, results show that some participants (subject 1, 2, 3, 7, 13, 15, 16) tend to produce shorter breath groups when they increase their speaking rate, as illustrated in Figure 5 and 6.
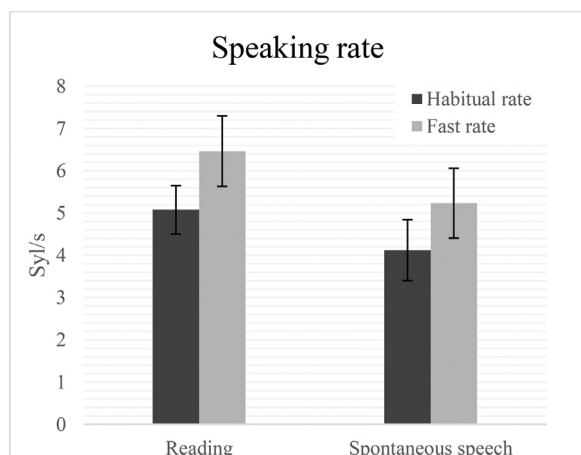
Effects of speaking rate on lung volume at breath group initiation and termination

The results showed no significant effect of speaking rate on lung volume at breath group initiation, $F(1,16) = 0.46$, $P = 0.507$ nor lung volume at breath group termination, $F(1,16) = 0.15$, $P = 0.707$. As seen in Table 2, the group averagely initiated breath groups at slightly higher lung volumes in the fast speaking rate condition compared to the habitual speaking rate, both in reading and spontaneous speech. However, this difference was not statistically significant. Group means for TLV show slightly lower lung volume levels in reading with fast speaking rate compared to reading with habitual speaking rate. Such difference is not seen for spontaneous speech, and neither result were strong enough to reach statistical significance.

Effects of speaking rate on lung volume excursion per breath group and lunge volume excursion per syllable

Results showed no significant effect of speaking rate on lung volume excursion per breath group, $F(1,16) = 4.34$, $P = 0.054$. Individual means and SD of %VC/bg are presented in Figure 7 and 8. All participants show relatively high standard deviations revealing big variation in lung volume measures within each participant. Effect of speaking rate on lung volume excursion per syllable reached statistical significance, $F(1,16) = 20.99$, $P < 0.001$. Group means for lung volume excursion per syllable reveal that participants consumed less % VC per syllable in fast speaking rate conditions than in habitual speaking rate conditions. Individual results on %VC/syl are presented in Figure 9 and 10.

FIGURE 2. Speaking rate as measured in syllables per second, in bars (mean) and whiskers (standard deviation) for the group.

Effects of speaking rate on speaking f_O

Two-factor-ANOVA analyses with repeated measures was carried out on f_O as measured in semitones counted (sc) from the musical note C_0. For the male participants, this

TABLE 1.
Mean speaking rates (syl/s) for each participant in the four conditions

	Reading		Spontaneous Speech	
	Habitual	Fast	Habitual	Fast
Subject 1	5.15	6.92	4.62	5.60
Subject 2	5.44	7.25	3.42	5.03
Subject 3	5.90	6.97	4.38	5.68
Subject 4	4.96	7.21	3.77	4.88
Subject 5	5.00	4.91	3.68	4.15
Subject 6	4.25	5.90	3.26	4.65
Subject 7	5.55	6.07	4.74	5.48
Subject 8	4.42	6.67	3.82	5.48
Subject 9	6.21	7.37	5.59	5.58
Subject 10	5.19	7.65	2.67	4.76
Subject 11	4.65	5.70	4.74	4.77
Subject 12	4.40	7.75	4.48	7.29
Subject 13	5.58	6.03	4.52	4.61
Subject 14	4.96	6.61	3.47	4.47
Subject 15	5.63	5.76	4.95	6.72
Subject 16	4.22	5.09	3.53	4.10
Subject 17	4.75	6.03	4.40	5.69
Group mean (SD)	5.08 (0.57)	6.46 (0.83)	4.12 (0.72)	5.23 (0.83)

TABLE 2.
Group Mean (SD) of the six respiratory variables for the four conditions. The respiratory variables are Syl/bg (syllables per breath group, or breath group size), Sec/bg (seconds per breath group, or breath group duration), ILV (initiation lung volume of breath groups), TLV (termination lung volume of breath groups), %VC/bg (percent vital capacity per breath group, or lung volume excursion per breath group), %VC/syl (lung volume excursion per syllable)

Variable	Condition			
	Reading Habitual	Reading Fast	Spontaneous Speech Habitual	Spontaneous Speech Fast
Syl/bg	19.30 (5.00)	29.96 (12.16)	17.28 (4.50)	22.17 (5.57)
Sec/bg	3.21 (1.34)	4.06 (1.34)	3.46 (0.83)	3.62 (0.69)
ILV	37.87 (8.78)	38.95 (12.76)	41.18 (9.88)	42.48 (12.03)
TLV	24.12 (8.91)	22.62 (12.07)	25.25 (9.44)	25.53 (11.58)
%VC/bg	13.75 (2.91)	16.18 (4.71)	15.93 (3.20)	16.96 (3.19)
%VC/syl	0.74 (0.17)	0.58 (0.13)	0.97 (0.27)	0.80 (0.27)

showed no significant effect of speaking rate on f_O across speech task, $F(1,6) = 1.35$, $P = 0.289$. Results for the female participants showed significantly higher f_O in the fast tempo conditions than in the habitual tempo conditions, $F(1,9) = 5.65$, $P = 0.041$. Table 3 presents group means and standard deviations of speaking f_O for the four conditions.

Individual results for males are illustrated in Figure 11 and 12 and for females in Figure 13 and 14.

Effects of speech task on breath group measures
Besides the main aim to study the effects of speaking rate, we also wanted to investigate if the two speech tasks (reading and spontaneous speech) differed with regard to the dependent values. Results from the statistical analysis

showed a significantly higher number of syllables per breath group in text reading than in spontaneous speech, $F(1,16) = 6.82$, $P = 0.019$. The effect of speech task on breath group duration in seconds was not significant, $F(1,16) = 0.16$, $P = 0.69$.

Effects of speech task on lung volume measures
The results showed no significant effect of speech task on ILV, $F(1,16) = 2.72$, $P = 0.118$ nor TLV, $F(1,16) = 0.89$, $P = 0.359$. The effect of speech task on lung volume excursion per breath group did not reach statistical significance either, $F(1,16) = 3.03$, $P = 0.101$, although the mean values for the group indicate that participants tended to spend more % VC per bg in spontaneous speech than in reading.
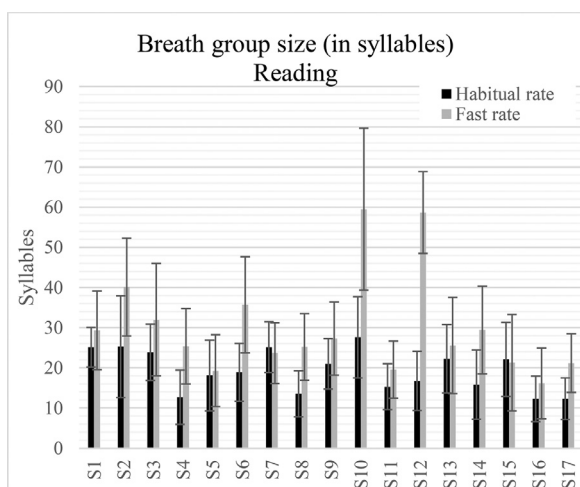
FIGURE 3. Mean breath group size (bars) and SD (whiskers) for each subject in text reading. Habitual and fast rate conditions are in black and grey bars respectively.

The effect of speech task on %VC/syl was significant, $F_{(1,16)} = 21.44$, $P < 0.001$, revealing that participants consumed a significantly greater amount of their VC per syllable in spontaneous speech than in reading.

Effects of speech task on speaking f_O

Speech task did not have a significant effect on mean f_O measured in semitones counted from C_0 for neither male participants, $F_{(1,6)} = 1.72$, $P = 0.237$, nor female participants, $F_{(1,9)} = 0.72$, $P = 0.417$.

Interaction effects between speaking rate and speech task on breath group measures

Taking a closer look at the interaction between speaking rate and speech tasks revealed some interesting effects. A significant interaction effect between speech task and
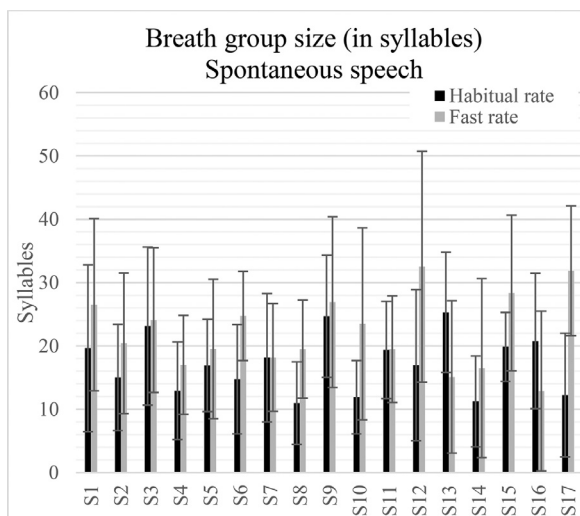

FIGURE 4. Mean breath group size (bars) and SD (whiskers) for each subject in spontaneous speech. Habitual and fast rate conditions are in black and grey bars respectively.
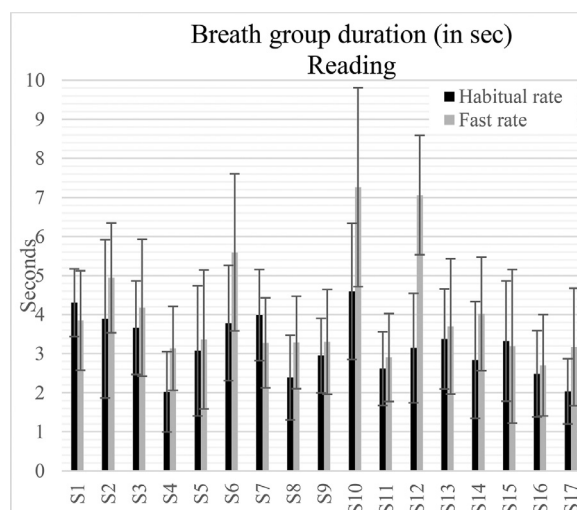

FIGURE 5. Mean breath group duration (bars) and SD (whiskers) for each subject in reading. Habitual and fast rate conditions are in black and grey bars, respectively.

speaking rate was found on breath group size, meaning that the increase in syllables produced per breath group was bigger in reading than spontaneous speech, $F_{(1,16)} = 6.22$, $P = 0.024$. Results for breath group duration in seconds also showed a significant interaction effect between speech task and speaking rate, $F_{(1,16)} = 4.58$, $P = 0.048$, meaning that the increase in breath group durations between the two speaking rate conditions was bigger in reading than in spontaneous speech.

Interaction effects between speaking rate and speech task on lung volume measures and speaking f_O

No interaction effects were found between speech task and speaking rate on ILV, $F_{(1,16)} = 0.01$, $P = 0.914$, TLV, $F_{(1,16)} = 0.48$, $P = 0.497$, % VC/bg, $F_{(1,16)} = 1.01$, $P = 0.329$ nor % VC/syl, $F_{(1,16)} = 0$, $P = 1$. Furthermore,
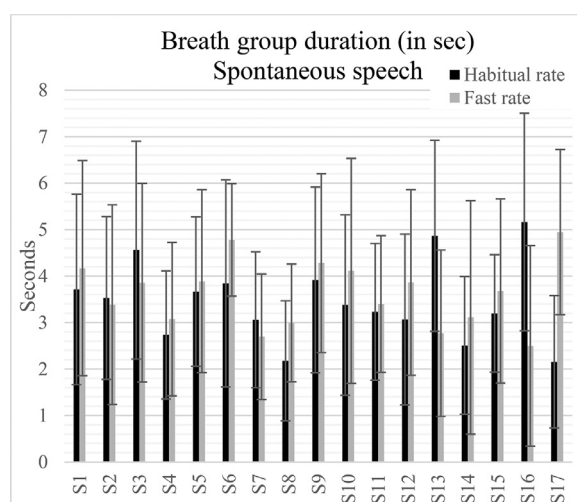

FIGURE 6. Mean breath group duration (bars) and SD (whiskers) for each subject in spontaneous speech. Habitual and fast rate conditions are in black and grey bars, respectively.
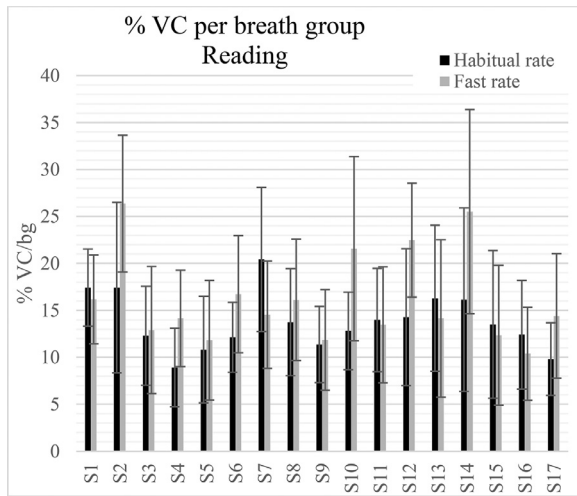
FIGURE 7. Mean % VC/bg (bars) and SD (whiskers) for each subject in reading. Habitual and fast rate conditions are in black and grey bars, respectively.

no significant interaction effects between speech task and speaking rate were found for speaking f_O as measured in sc from C_0, neither for males, $F(1,6) = 2.84$, $P = 0.142$ or females, $F(1,9) = 0.29$, $P = 0.604$.

DISCUSSION

The present study aimed to investigate effects of speaking rate (habitual and fast) and speech task (reading and spontaneous speech) on six respiratory and one acoustic measure. Our results showed that the subjects as a group increased breath group size and duration significantly when increasing speaking rate. In other words, the fast rate made the subjects inhale less often. This is in line with the findings by Grosjean & Collins[9] where speakers produced more words per breath group when consciously increasing speaking rate in text reading. Also Huber[10] found a correlation between breath group size (measured in
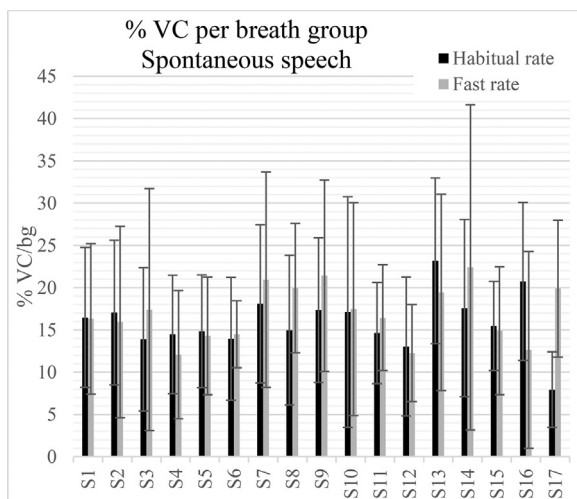

FIGURE 8. Mean %VC/bg(bars) and SD (whiskers) for each subject in spontaneous speech. Habitual and fast rate conditions are in black and grey bars, respectively.
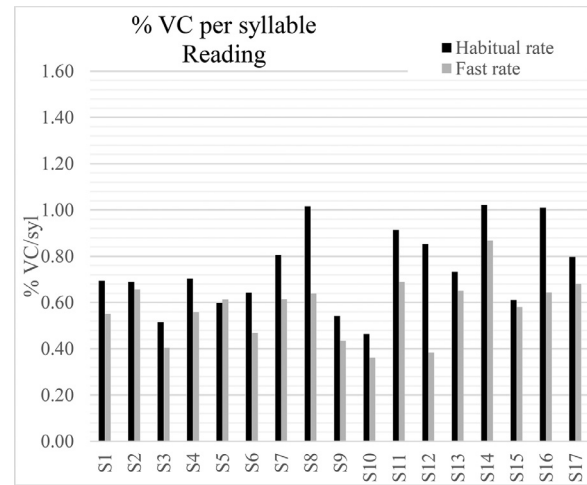

FIGURE 9. Mean %VC/syl for each subject in reading. Habitual and fast rate conditions are in black and grey bars, respectively.

syllables) and speaking rate. Such a correlation is supported by the authors' clinical experience from the work with hyperfunctional voice disorders, implying that focusing on flow phonation and using shorter breath groups as a consequence of the increased air flow, can induce speaking rate to decrease, even without paying specific attention to speaking rate. Such a strategy of flow phonation might be beneficial for fast speaking patients by preventing them from vocal trauma and hyperfunctional voice disorders, which are suggested risks for habitual fast speaking persons.[1] Individual results for breath group size and duration in our study (Figure 3-6), revealed a great variation between the subjects, indicating different speech breathing behaviors. Apparently, most participants inhaled more sparsely in the fast speech condition, while others seemed to care for their inhalations in spite of an increased speaking rate. These variations in patterns of inhalations revealed by the result for each individual, could imply that other internal or external factors might have impact on the speech breathing behaviors. Such
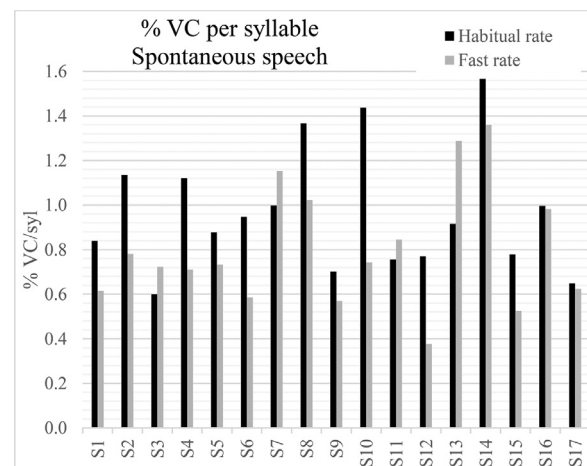

FIGURE 10. Mean % VC/syl for each subject in spontaneous speech. Habitual and fast rate conditions are in black and grey bars, respectively.

TABLE 3.
Group Mean (SD) of Speaking fundamental frequency (f_O) for the four conditions in males and females respectively. Fundamental frequency is presented in Hertz (Hz), Notes and Sc (semitones counted) from C_0

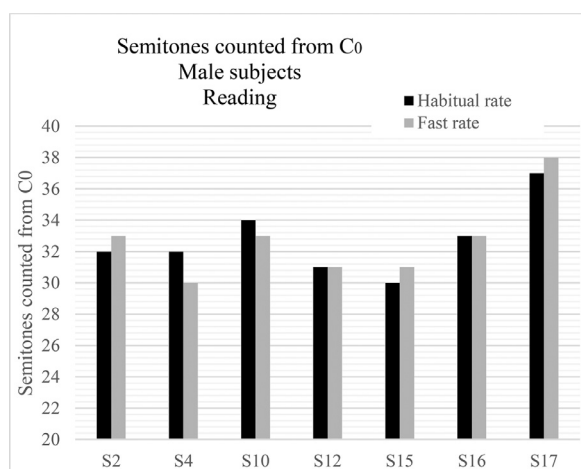|		Condition			
	Variable	Reading Habitual	Reading Fast	Spontaneous Speech Habitual	Spontaneous Speech Fast
Males	f_O in Hz	109.47 (13.81)	109.28 (16.69)	102.92 (12.80)	107.83 (16.84)
	Note	A_2	A_2	$G\#/Ab_2$	A_2
	Sc from C_0	33	33	32	33
Females	f_O in Hz	199.44 (20.35)	202.61 (16.81)	192.09 (24.72)	201.03 (27.42)
	Note	G_3	$G\#/Ab_3$	G_3	A_3
	Sc from C_0	43	44	43	43

FIGURE 11. Mean fundamental frequency (semitones counted from C_0) for male subjects in reading. Habitual and fast rate conditions are in black and grey bars, respectively.

FIGURE 13. Mean fundamental frequency (semitones counted from C_0) for female subjects in reading. Habitual and fast rate conditions are in black and grey bars, respectively.
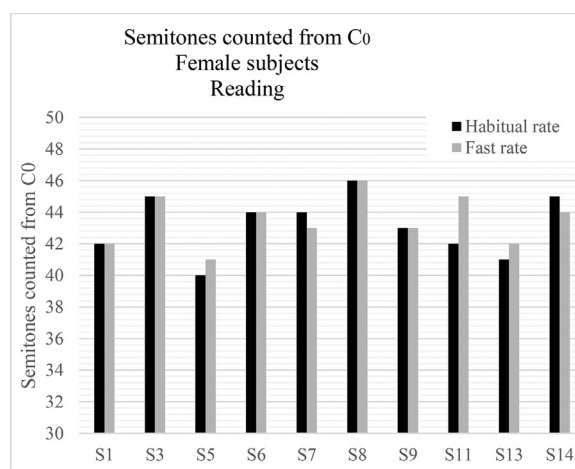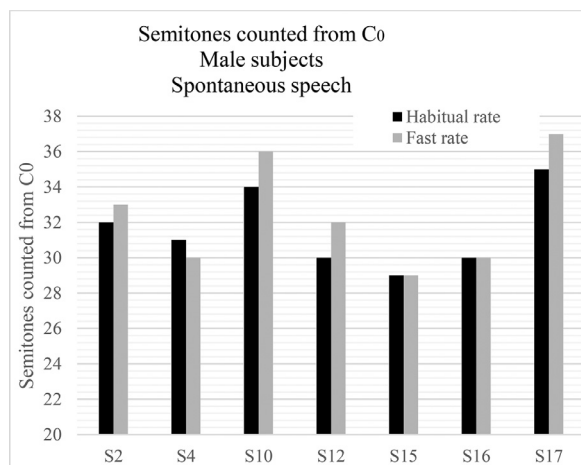

FIGURE 12. Mean fundamental frequency (semitones counted from C0) for male subjects in spontaneous speech. Habitual and fast rate conditions are in black and grey bars, respectively.
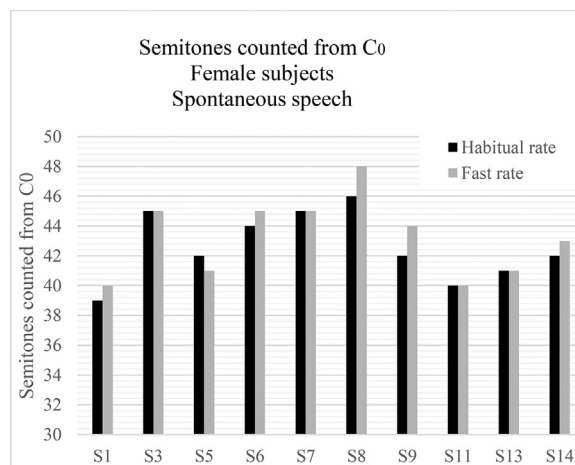

FIGURE 14. Mean fundamental frequency (semitones counted from C_0) for female subjects in spontaneous speech. Habitual and fast rate conditions are in black and grey bars, respectively.

factors have not been investigated in this study, however it could be of interest for future studies.

Speaking rate did not show significant effects on ILV and TLV in our data. In general, participants showed very different patterns regarding effects of speaking rate on ILV and TLV, indicating that most participants to some degree changed their speaking lung volumes when increasing speaking rate. Similar to our findings, Dromey & Ramig[2]

found no influence of speaking rate on ILV and TLV. In contrast to this, other studies have found longer breath groups to be initiated at higher lung volumes,[10,24] as well as terminated at lower lung volume levels[10] than shorter breath groups. One could expect that the increased breath group size associated with fast speech in the present study would influence initiation and termination lung volume levels. However, this was not the case. Neither the results showed a significant effect on % VC/bg, reflecting the amount of air consumed per breath group. As opposed to this, the results for %VC/syl showed a significant effect of speaking rate. The participants consumed less % of their vital capacity per syllable in fast speaking rate than in habitual speaking rate. This result indicates that the glottal airflow decreases when participants use a fast speaking rate, supporting the hypothesis that a fast speaking rate can induce greater glottal compression, which is associated with a more hyperfunctional type of phonation.[1]

In line with previous literature,[1,25,26] subjects in this study increased speaking f_O in fast speaking rate conditions, although this effect was only significant in female subjects. In opposition to this, Dromey & Ramig[2] only found an effect of speaking rate on f_O in male participants. In contrast to the mentioned studies, we measured speaking f_O in semitones counted from C_0, to secure a linear pitch scale. Regarding the second aim; to study the effects of speech task, results revealed significantly higher speaking rates in reading than in spontaneous speech across speaking rate conditions. This could be due to more hesitations and pauses in spontaneous speech than in reading and the finding is in line with other studies describing increased speaking rates in reading compared to spontaneous speech.[12,27,28] The results also showed a significant increase in syllables produced per breath group in reading as compared to spontaneous speech, meaning that the subjects inhaled more rarely in text reading. This result is not in line with the findings in Iwarsson & Sundberg,[12] where subjects produced significantly more syllables per breath group in spontaneous speech than in reading. Differences regarding text material may explain the different findings. In this study, there were no effect of speech task on breath group duration. No significant effects of speech task were found on ILV, TLV nor % VC/bg. From previous findings indicating that breath group size is linked to lung ILV and TLV,[10,24] one could have expected ILV to be higher and TLV to be lower in reading than in spontaneous speech, since the reading task induced bigger breath group sizes, but no such effect was found. The results showed a significant effect of speech task on %VC/syl, revealing a greater air consumption per syllable in spontaneous speech than in reading. This indicates a greater glottal airflow and thus less glottal compression in spontaneous speech than in reading. It is stated in multiple previous studies, that reading induces higher speaking f_O than spontaneous speech.[14-16] An explanation to this could be greater occurrence of vocal fry in spontaneous speech, causing a lowered mean f_O as compared to reading. Our results revealed a slightly but not significantly higher f_O in reading

than in spontaneous speech for both male and female participants. The last aim of the study was to investigate interaction effects between speaking rate and task. Significant interaction effects were found for breath group size and breath group duration, meaning that the effect of speaking rate was stronger in reading than in spontaneous speech. This was in alignment with the findings of our second aim; that breath group size and duration were greater in reading than in spontaneous speech. Apparently, the subjects were more sensitive to the influence of speaking rate in reading than in spontaneous speech. One could imagine that speakers are more likely to maintain to breath group patterns in spontaneous speech, where the spoken content and thus the distribution of inhalations is solely up to the speaker. In text reading on the other hand, the breath group patterns might be more likely to be affected by linguistic demands.

Some methodological decisions deserve to be commented. The RIP-belts are known to be sensitive to body movements, meaning that movements of arms or change of position can be interpreted as respiratory movements. For this reason, the participants were instructed to keep the same position during the calibration procedure and all conditions. However, it cannot be ruled out that non-respiratory body movements can have affected the signals. Also, there is a risk that the belts were not tightened properly and therefore could have moved slightly downwards. In one subject, a lung volume registration during speech exceeded the range for maximum inhalation and exhalation performed to represent vital capacity, and this individual range had to be readjusted. Excluding this subject from the group result did not cause any change of main results regarding lung volume levels, and the subject's results were therefore included in the data set. Except for this single participant we did not discover any signs of levels systematically decreasing or increasing, inducing systematic error.

With the main aim to investigate effects of speaking rate, we chose a research design instructing the subjects consciously to modify speaking rate in an experimental setup rather than to study naturally fast speaking individuals in natural situations. Similar study designs, where speaking rate is modified by instructing the participants, have been used in comparable studies in the field of speaking rate, respiration and voice behavior.[2,25,29] Results for the group showed a higher mean speaking rate in the fast speaking rate conditions than in the habitual speech, implying that the instructions worked as intended. With this design, the measured effects cannot be verified necessarily to be caused by speaking rate itself, since it cannot be ruled out that the instruction has caused the participants to change these parameters as well. It is not unlikely that in untrained speakers, the intention of increasing the speaking rate instead can result in e.g. increased mean speaking f_O or production of more syllables per breath group.

Articulatory reduction of syllables is a known phenomenon in connected speech and has been shown to be a natural consequence of increased speaking rate.[30] There seems to be no ideal way of counting syllables in connected speech due

to reductions of speech segments.[31] Particularly in Danish, assimilations of sounds and syllables frequently occur, resulting in disagreement on what should count as a syllable.[32] Looking at previous articles, the exact method of syllable counting is not always clear,[10,28,33] however the method of counting intended syllables has previously been described.[12] The results regarding breath group sizes and %VC/syl in this study are based on manual syllable counting, where all intended syllables were counted instead of the actual produced syllables thus reflecting articulatory reductions. An increased speaking rate can in it self result in a higher count of syllables than actually pronounced. It cannot be ruled out that the increase of breath group sizes as a result of increased speaking rate might reflect a reduction of syllables thus leading to more intended syllables per breath group, rather than an increase of actual pronounced syllables. Also, it must be mentioned that the results regarding %VC/syl reflect the amount of air consumed per intended syllable, not necessarily the actual pronounced syllables. This factor must be taken into consideration when interpreting the results on %VC/syl as an indication of decreased glottal airflow and increased glottal compression.

The choice of task for spontaneous speech might be of importance when comparing to a reading task. The spontaneous speech task in this study was a retelling of a procedural task, thus representing semi-spontaneous speech and not true spontaneous speech. A retelling task was chosen to make the two spontaneous speech conditions more comparable. Investigations of more free spontaneous speech are relevant for future studies on effects of speech task.

Some of the dependent variables showed significant effects of speech task (reading and spontaneous speech). The research design did not control for an order effect of speech task, since all subjects carried out the reading condition prior to the spontaneous speech task. Thus, any bias in terms of a possible effect of order of speech tasks cannot be ruled out. As mentioned in the introduction, speaking rate seems to be a factor of relevance for speech and voice therapy. In dysarthric patients, a slower habitual speaking rate has been shown to increase speech intelligibility[25] and in functional voice disorders, a fast speaking rate has been described to increase the risk of inducing more vocally traumatic behavior.[1] The present study shows with empirical data, that increased speaking rate affected the participants' breath group size, breath group duration, %VC/syl and for the females also mean speaking fundamental frequency. The increased f_O is in accordance with clinical experience from fast speaking females with hyperfunctional voice disorders. The finding could eventually support the hypothesis that a fast speaking rate involves increased laryngeal tension.[1] The longer breath groups associated with fast speech in the present study, support the experience of an association between short breath groups and slower speech accordingly. Professionals in voice and speech training may have experienced that modifying one speech parameter in a patient might induce changes on other speech or breathing measures.[2] There is not general agreement on weather

working directly with modification of speaking rate is beneficial for patients with functional voice disorders.[33] The results in the present study indicate possible relations between a fast speaking rate and vocally inappropriate voice and breathing behaviors. Such relations between speaking rate and vocal behaviors should be an area of concern in voice therapy as well as it needs to be investigated further in future studies.

CONCLUSION

Our respiratory data from 17 vocally untrained, healthy subjects showed that breath group size and breath group duration were significantly increased for both reading and spontaneous speech in fast rate of speech compared to habitual rate of speech. Females also showed a significant increase in f_O during fast speech. Lung volume excursion per syllable in % VC decreased significantly in fast speech compared to habitual speech. The lung volume levels for initiation and termination of breath groups, as well as lung volume excursion per breath group in % vital capacity showed great individual variations and no significant group effects of speaking rate. Regarding the effect of speech task, the participants showed significantly increased lung volume excursion per syllable in reading than in spontaneous speech. Main effect of task also showed significantly greater values for breath group size in reading as compared to spontaneous speech and interaction effects between rate and task showed that the increases in breath group size and breath group duration associated with fast speaking rate, were significantly bigger in reading than in spontaneous speech. Thus, the changes in breath group patterns as a consequence of fast speech seems to be dependent of the speech task.

APPENDIX
Supplementary material related to this article can be found online at doi:10.1016/j.jvoice.2021.09.005.

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21. Acoustic Society of America. Table 3 − Frequencies in hertz (Hz) and frequency levels in semitones counted (sc) up from C0 for the usual equal-tempered scale. Available at: https://asastandards.org/Terms/table-3-frequencies-in-hertz-hz-and-frequency-levels-in-semitones-counted-sc-up-from-c0-for-the-usual-equal-tempered-scale-subscripts-by-octaves-above-c0-c0-approximately-equals-16-352/. (Accessed dec 30 2020).

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