Does lung volume size affect respiratory rate and utterance duration?

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Abstract

This study explored whether lung volume size affects respiratory rate and utterance duration. The lung capacity of four women and four men was estimated with a digital spirometer. These subjects subsequently read a nonsense text aloud while their respiratory movements were registered with a Respiratory Inductance Plethysmography (RIP) system. Utterance durations were measured from the speech recordings, and respiratory cycle durations and respiratory rates were measured from the RIP recordings. This experiment did not show any relationship between lung volume size and respiratory rate or utterance duration.

Introduction

This study aimed to investigate whether *lung volume size* affects respiratory behaviour in speech, and more precisely if lung volume, utterance duration and respiratory rate are correlated.

Lung volume size is known to be correlated with height, age, sex, and to some extent with weight and ethnicity. Generally, tall people have larger lung volume than short ones; young adults have larger lung volume than old ones; and males have slightly larger lung volume than females of the same height and age (e.g. Bellemare, Jeanneret, & Couture, 2003; Bhatti, Rani, & Memon, 2014; Boren, Kory, & Syner, 1966; Internmedicin, 2019a, 2019b; Morris, Jawad, & Eccles, 1992). Lung volume size is typically estimated using a spirometer in terms of vital capacity, which is the maximum amount of air a person can exhale after a maximal inhalation. Vital capacity is thus a reflection of the lung volume actually used, rather than the total lung volume.

Furthermore, previous research has suggested that a relationship exists between increasing age, larger lung volume and longer utterances (e.g. Boucher & Lalonde, 2015; Hoit & Hixon, 1987; Hoit, Hixon, Watson, & Morgan, 1990). In addition, it has been suggested that larger lung volume is correlated with larger absolute breath volumes used in speech (Hoit & Hixon, 1987; Hoit et al., 1990). Thus, the latter dependency is to some extent at odds with the effect of the former with respect to utterance duration.

We feel that it is warranted to revisit the issue of a possible relationship between lung volume size, respiratory rate and utterance duration, for several reasons. Previous studies have demonstrated that utterances are planned beforehand even in spontaneous speech (Winkworth, Davis, Adams, & Ellis, 1995). Furthermore, it has been shown that people tend to breathe at grammatically “appropriate” places when reading aloud – at the end of sentences, after commas, or after certain words that often appear at the end of phrases (Winkworth et al., 1995; Winkworth, Davis, Ellis, & Adams, 1994). Thus, read-aloud texts and possibly even spontaneous speech contain structures which may influence respiratory behaviour and hence the possibilities of detecting physiologically motivated dependencies between lung volume and utterance length. In addition, previous studies have measured utterance length in terms of number of syllables or morphemes without taking speech rate into account.

In this study, we tried to circumvent these issues by having the participants read a nonsense text without punctuation marks. We expected that such a material would be more likely to produce a situation where participants inhaled and exhaled when necessary rather than when they thought it was grammatically appropriate. Furthermore, we measured utterance length in terms of speech duration between inhalations in order to link the results as strongly as possible to physiological differences. Finally, we exposed the participants to pink noise to increase vocal loudness.

The experiment involved measuring lung volume size, utterance durations, and respiratory rate in subjects and correlating these measurements.

Method

Participants

In order to examine possible relationships between lung volume size, utterance durations and respiratory rate, we had to ensure that our data included a variation in lung volume size. To achieve this, we included four males and four females differing in height (range 163 cm to 184 cm) and age (range 22 to 31 years) as participants in the study (cf. Table 1). All were native speakers of Swedish and none reported any speech or hearing difficulties.

Materials

A digital spirometer (CareFusion Microloop) was used to estimate various lung capacity measures, including vital capacity. A Respiratory Inductance Plethymography (RIP) system developed in the Phonetics Lab at Stockholm University (RespTrack) was used to capture respiratory movements of the rib-cage and abdomen during speech. The RIP signals were recorded using an integrated data acquisition (DAQ) system (PowerLab and LabChart from AD Instruments).

During the reading task, pink noise from a noise generator (Superlux Pink Stick) was presented via headphones (Beyerdynamic DT 770). Speech was captured using a headset microphone (Sennheiser HSP 4) and this signal was also recorded with the DAQ.

Procedure

The subjects participated one at a time and the only other person in the room was the experimenter (the second author). After the subjects had signed a consent form, lung volume size (i.e. vital capacity) was estimated using the 'Relaxed spirometry' function in the spirometer. The subject was instructed to first breathe into the spirometer using tidal breathing until the experimenter told him or her to inhale as much as possible and then to exhale as much as possible, before returning to tidal breathing for a couple of breaths. This whole procedure was repeated at least three times for each participant, allowing the spirometer to obtain more robust estimates. Some participants had to repeat the procedure more than three times, as the spirometer indicated that the readings had not yet provided successful measurements.

The next step in the experiment was the recording of respiratory movements during speech. To this end, the participant first put on the RIP belts – one over the rib cage and one over the abdomen. As the relationship between respiratory movement and volume is not necessarily the same for rib cage and abdomen, the isovolume manoeuvre (Konno & Mead, 1967) was used to calibrate RespTrack so that a given amount of air would produce same signal in the the rib cage and abdomen belts.

Next, the actual text reading was performed where the subject sat straight-backed in a chair, and read aloud for about 7 minutes.

The nonsense text was based on an automatically generated "lorem ipsum"-text, which was simplified in order to make it easier to read. No words were longer than two syllables; C:s in the text were replaced with K:s to avoid confusion regarding whether to pronounce them [s] or [k]; Q:s were replaced with K:s as Q is not a naturally occurring letter in Swedish orthography; and vowel-combinations and certain consonant clusters that do not exist in Swedish were changed. In addition, all punctuation marks were removed and all capital letters were changed to lowercase.

While the participants read the text, pink noise at 60 dB SPS was presented via headphones. The pink noise was used to prevent very soft speech. The microphone was placed about two centimetres from the corner of the mouth.

The text was given to each participant approximately one minute before the recording started, so that they could familiarise themselves with it. Accordingly, they were instructed to read the text for 7 minutes without any interruptions and to try not to focus on pronunciation but to read freely.

Analyses

Utterance durations were estimated using the speech activity detection function *Annotate to Text-Grid (Silences)* in Praat using the following settings: 0.3 s minimum silence and 0.05 s minimum sound; and the lower threshold for fundamental frequency (f_o) was 75 Hz for men and 100 Hz for women. The automatic segmentations were manually examined in relation to the sound files and were corrected where necessary so that the only silences remaining were those that occurred when the subjects inhaled. That is, silences for instance during swallowing or hesitations without inhalations, were bridged.

Respiratory cycle durations and respiratory rates were estimated from the output of RespInPeace, a Python toolkit for processing and analysing breathing belt (RIP) data (Włodarczak, 2018, 2019). Statistical analyses were performed using SPSS (IBM SPSS Statistics version 25).

Results

Table 1 shows the distribution of estimated vital capacity across the subjects. In addition, it shows their height, age, and the relation between estimated and predicted vital capacity expressed as a percentage. The predicted vital capacity was calculated in the spirometer and the measure is based on factors such as sex, height, and age. In general, the expected patterns with respect to height, age and sex were reflected in this small sample.

Table 1. *Distribution of vital capacity (VC), height, age and relation between estimated and predicted VC across the eight subjects.*

ID	VC (l)	Height (cm)	Age	% pred. VC
F1	2.99	163	23	80%
F4	3.36	172	31	86%
F2	4.11	164	22	109%
M4	4.28	176	31	85%
F3	5.27	181	30	123%
M1	5.29	180	28	100%
M2	5.79	184	31	107%
M3	6.02	184	25	109%

Now to the issue of whether lung volume size affects utterance durations and respiratory rate. Figures 1 and 2 show the distribution of respiratory cycle (inhalation + exhalation) and utterance durations, respectively, across the participants (ordered by vital capacity in ascending order). Unsurprisingly, these two duration measures were closely correlated with slightly shorter utterances than respiratory cycles. The respiratory cycle durations correspond to median respiratory rates ranging from about 6.6 (F2) to 25.1 breaths per minute (M4).

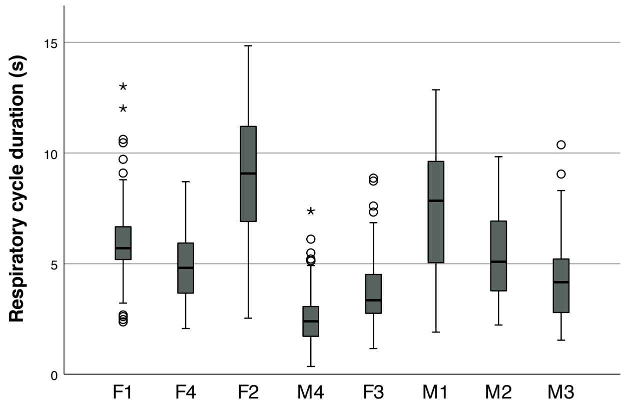

Figure 1. Distribution of respiratory cycle duration (in seconds) across female (F) and male (M) subjects. The subjects are ordered by vital capacity in ascending order (as in Table 1).

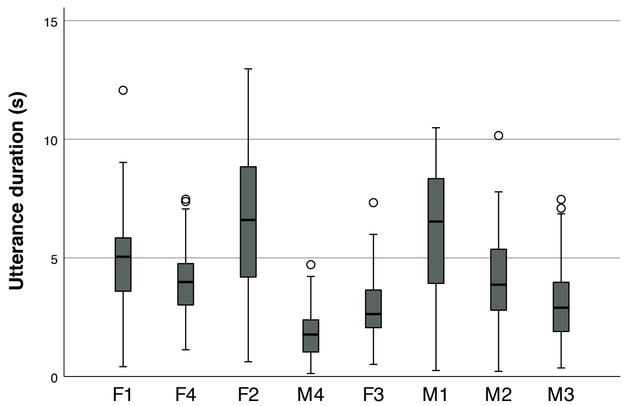

Figure 2. Distribution of utterance duration (s) across female (F) and male (M) subjects. The subjects are ordered by vital capacity in ascending order (as in Table 1).

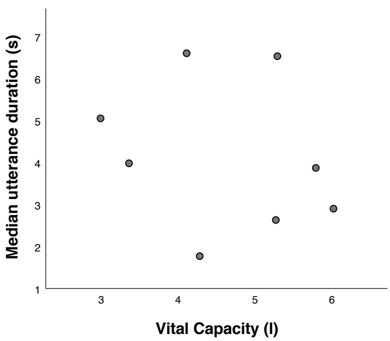

Figure 3. Scatter plot of median utterance duration (in seconds) versus vital capacity (in litres).

Figures 1 and 2 do not indicate any evident relationships between estimates of vital capacity and utterance duration or respiratory cycle duration. If subjects with a larger vital capacity generally would have produced longer utterances (and had longer respiratory cycles), we would have expected a positive trend in both figures.

However, assuming equal flow rates for long and short utterances, the intra-speaker variation evident in Figures 1 and 2 suggest that people did not always utilize the same air volume for each utterance. Given that the material was a nonsense text virtually without constraints on pausing, the difference could be brought about by non-physiological factors such as hesitations or linguistic processing.

Furthermore, while the female subjects (as a group) had lower vital capacity estimates than the males, their utterances were more than one second longer on average. Indeed, a regression analysis with vital capacity as a predictor of median utterance duration, illustrated with a scatter plot in Figure 3, gave a non-significant result $F(1,6) = .325$; $p = .59$.

Discussion

Given these results, we have to conclude that with this experimental paradigm and the limited number of subjects examined, we were not able to show any evidence of relationships between lung volume size, respiratory rate and utterance duration in a group of adults. Thus, people with larger lung volumes do not seem to produce longer utterances or to have a lower respiratory rate. Consequently, the results were not consistent with previous research based on comparisons of different age groups (Boucher & Lalonde, 2015; Hoit & Hixon, 1987; Hoit et al., 1990).

There is of course the risk that our group of subjects was just too small to show these kinds of tendencies, and consequently that the result was a negative one. However, there are also other more interesting possibilities that we would like to explore in future research. For example, although previous research seem to indicate the opposite (e.g. Hoit & Hixon, 1987; Hoit et al., 1990), it is possible that people with smaller lungs actually use a larger proportion of their lung capacity when speaking. Unfortunately, we did not record respiratory kinematics (RIP data) during the vital capacity manoeuvres in this study, which would have allowed relating the breath volume during speech to lung volume size.

As suggested by Hoit and Hixon (1987), it is also possible that (younger) people with smaller lungs use the airflow more efficiently (than older people with larger lungs) when producing speech. However, studying such relationships would have required the use of a flow-mask during reading.

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