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Speech and Respiration

B. Conrad* and P. Schönle**

Abteilung Neurologie, Universität Ulm, D-7900 Ulm, Bundesrepublik Deutschland

Summary. This investigation deals with the temporal aspects of air volume changes during speech. Speech respiration differs fundamentally from resting respiration. In *resting respiration* the duration and velocity of inspiration (air flow or lung volume change) are in a range similar to that of expiration. In *speech respiration* the duration of inspiration decreases and its velocity increases; conversely, the duration of expiration increases and the volume of air flow decreases dramatically. The following questions arise: are these two respiration types different entities, or do they represent the end points of a continuum from resting to speech respiration? How does articulation without the generation of speech sound affect breathing? Does (verbalized?) thinking without articulation or speech modify the breathing pattern? The main test battery included four tasks (spontaneous speech, reading, serial speech, arithmetic) performed under three conditions (speaking aloud, articulating subvocally, quiet performance by trying to exclusively 'think' the tasks). Respiratory movements were measured with a chest pneumograph and evaluated in comparison with a phonogram and the identified spoken text.

For quiet performance the resulting respiratory time ratio (relation of duration of inspiration versus expiration) showed a gradual shift in the direction of speech respiration—the least for reading, the most for arithmetic. This change was even more apparent for the subvocal tasks.

It is concluded that (a) there is a gradual automatic change from resting to speech respiration and (b) the degree of internal verbalization (activation of motor speech areas) defines the degree of activation of the speech respiratory pattern.

Key words: Speech (loud, subvocal, quiet) – Articulation – Reading – Arithmetic – Respiration – Inspiration-expiration relation

* Present address: Abteilung Klinische Neurophysiologie, Universität Göttingen, Robert-Koch-Str. 40, D-3400 Göttingen, Federal Republic of Germany

** Department of Psychology, MIT, E 10-019A and Boston U.A., Aphasia Research Group, Cambridge, MA 02139, USA

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Zusammenfassung. Die vorliegende Untersuchung befaßt sich mit den zeitlichen Aspekten der Atmungsvorgänge während des Sprechens. Die Sprechatmung unterscheidet sich grundsätzlich von der Ruheatmung. Bei der *Ruheatmung* liegt die Dauer und Geschwindigkeit der Einatmung (Luftfluß oder Volumenänderung der Lunge) in der gleichen Größenordnung wie bei der Ausatmung. Bei der *Sprechatmung* nimmt die Dauer der Einatmung ab und die Geschwindigkeit des Luftstroms entsprechend zu, während bei der Ausatmung die Dauer der Expiration zunimmt und die Geschwindigkeit des Luftstromes drastisch abnimmt. Hierbei entstehen verschiedene Fragen: Stellen diese Atemtypen zwei verschiedene funktionelle Einheiten dar, oder repräsentieren sie nur die Extreme eines Kontinuums von der Ruhe- zur Sprechatmung? Wie beeinflußt reine Artikulation ohne Lautproduktion die Atmung? Wie beeinflußt (verbalisiertes) Denken ohne Artikulation oder Sprechen das Atemmuster. Atembewegungen wurden mit einem Gürtelpneumographen registriert und zusammen mit dem Phonogramm und dem identifizierten Text ausgewertet. Die Untersuchungen umfaßten 4 Sprechaufgaben (Spontansprechen; Lesen; Reihensprechen; Rechnen), die unter 3 verschiedenen Konstellationen (lautes Sprechen; reines Artikulieren; leise „gedachte" Ausführung) durchgeführt wurden.

Bei lautloser, gedachter Ausführung zeigte der Atemzeitquotient (Verhältnis von Einatmung zur Ausatmungsdauer) eine allmähliche Verschiebung in Richtung der Sprechatmung, am wenigsten für Lesen, am stärksten für Rechnen. Diese langsame Verschiebung war bei den subvokalen Aufgaben deutlich stärker ausgeprägt.

Aus den Untersuchungen wird geschlossen, daß es a) eine allmähliche automatische Verschiebung der Ruheatmung zur Sprechatmung gibt und b) daß das Ausmaß der internen Verbalisation (Aktivierung von motorischen Sprechzentren) das Ausmaß der Aktivierung der Sprechatmungsmuster bestimmt.

Schlüsselwörter: Sprache (laut, leise, still) – Artikulation – Lesen – Rechnen – Atmung – Ein- und Ausatmungs-Beziehung

Introduction

Many basic motor functions of the central nervous system can effectively be studied in animals. However, to consider the motor aspects of speech we must extract our knowledge exclusively from studies of man. As a complex motor act, speech requires close neuromuscular coordination of the articulatory process and the phonatory and respiratory processes. The latter regulate the subglottal pressure and glottal air flow needed to drive the sound generator (Bouhuys et al., 1966). Two functions of the respiratory system can be differentiated (Hixon, 1973): one provides for the gas exchange necessary for life purposes; the other the constant air pressure and air flow required for the production of speech sounds. Speech respiration occurs as long as the primary function, the physiologically required oxygen and carbon dioxide exchange, is maintained; but the present paper will deal exclusively with the act of breathing during speech.

Quiet breathing under resting conditions does not depend primarily on cortical structures but is regulated in the brainstem centers and differs fundamentally from speech respiration. Speech respiration involves—in addition to brainstem centers—the corticalized functions of speech and language which have to be integrated and coordinated in a complex manner with respiration to produce speech.

The main function of speech respiration, then, is to enable oral communication, i.e., to 'provide the driving forces necessary for the generation of sounds' (Hixon, 1973). In this sense, speech breathing manifests one of the fundamental physiologic processes underlying speech motor mechanisms.

In quiet respiration, the duration and velocity of inspiration (air flow or lung volume change) are equivalent to those of expiration. In contrast, the velocity of air flow increases in speech inspiration and consequently, the duration of inspiration decreases; the duration of expiration, however, increases up to ten times that in quiet breathing. Lung volume decreases at a very constant rate during speech expiration; i.e., air flow and alveolar pressure are kept constant during the utterance (Draper et al., 1960; Proctor, 1974).

The question arises as to whether these two types of respiration are the only ones that can be realized, or whether they are extremes in a continuum of respiratory types.

In order to assess these two possibilities, breathing was observed in a number of conditions which gradually reduced the required motor activity from (a) normally uttered speech (overt, *vocal* speech) through (b) *subvocal* speech consisting only of articulatory movements without sound production, and (c) *inner* speech (silent speech) without articulation or vocalization (see Table 1). This permits us to observe the variability of respiration by relating breathing patterns to various degrees of speech. Surprisingly enough, speech respiration has, so far, been regarded as a uniform and homogeneous phenomenon. Its heterogenity has never been the topic of a systematic investigation, even though both physiologic and linguistic aspects of speech respiration have been studied in detail (Bouhuys, 1968; Wyke, 1974). Only Klestadt (1923), Schilling (1925), and Golla et al. (1929) made attempts in this direction, but their 'qualitative study of speech respiration' was in another context and has largely been overlooked.

A second aim of this investigation is to clarify the temporal characteristics of speech respiration itself: variations in the duration of inspiratory versus expiratory phases during a variety of tasks such as spontaneous speech, reading, and counting.

This study, therefore, is directed to the following questions:

(a) Does a continuum of respiratory types exist between resting respiration and speech respiration?

(b) Does breathing reflect different types of mental tasks?

(c) How does the articulatory motor act of speech affect breathing, even when sound (phonation) is not generated?

(d) Does arithmetic problem solving, even if performed internally, modify breathing?

(e) Do such modes of speech as spontaneous speech, automatic speech and reading aloud result in distinct respiratory patterns?

(f) Which factors influence the initiation of a new breathing cycle during speech?

Method

Fifteen healthy male adults (graduate students, laboratory personnel, physicians) served as subjects for this study. Their ages ranged from 22 to 37 years with an average of 29 years. All experiments were performed with subjects seated in a chair which supported the arms, but left the back unsupported. The subjects were not instructed as to the purpose of the investigation, and all subjects stated at the end of the experiment that they had not paid conscious attention to their breathing.

A chest pneumograph which measured changes in the circumferences of the thorax was used to measure respiration. This measuring device (type 7101 Atembewegungsmesser, Fa. Hugo-Sachs-Electronics) consisted of a resistance transducer connected to an inelastic plastic band bound tightly around the thorax at the level of the nipples. The transducer was sufficiently sensitive to record the percussions of the heart. The subjects were asked to remain quiet once they had found a comfortable position to minimize disturbances of the pneumographic trace by body movements.

Respiratory movements and voice signal (via a condenser microphone) were registered simultaneously on a polygraph (Siemens Mingograph) (see Fig. 1). The paper speed was set to 2.5 cm or 1 cm per second. The voice signal was also recorded on a conventional cassette tape recorder. The phonograms on the polygraph were identified in a provisional manner by writing fragments of the text below the phonograms during the speech experiments. Later the text belonging to the polygraph phonograms was completed by listening to the cassette tapes.

The experimental conditions are presented in matrix form (see Table 1). The content of each task is listed along the abscissa; the response modes are listed along the ordinate. Content varies from automatic sequences (SEQ), i.e., counting from 121 to 200, through reading a standard text of about 100 words three times (READ), to spontaneously produced biographical material (SPONT).

The response modes were comprised of a 'thinking' condition (QUIET) in which the subjects were urged only to think of the content but *not* to verbalize, a subvocal condition (SUBVOCAL) in which such articulatory movements as moving the lips were carried out, without producing audible sound, and a vocal condition (ALOUD) with full articulation and vocalization.

In addition, an arithmetic task in which the subjects had to count backwards continuously from 300 by sevens was performed in the same response modes.

In addition to these 12 tasks (see also Fig. 2)—each lasting roughly 2 min—the following tasks were carried out: resting breathing for 5 min, maximum inspiration and expiration, maximum duration of phonation by singing an 'a', 'e', and 'o' and counting aloud from 0 to 10, 10 to 20, 20 to 30 up to 90 to 100 while omitting any number containing a 3 (3, 13, 23, 33, etc.). This last task was carried out under three conditions (a) trying to 'think' or 'imagine' the omitted number no articulation, no vocalization, (b) articulating the number without vocalization, and (c) neither thinking nor articulating the number, but trying to pause for the estimated duration of the omitted number.

Quantitative analysis of the respiratory movements was based on the mean duration of the inspiratory and expiratory phase from 30 breathing cycles. Measuring the termination point of the quiet expiration phase sometimes proved difficult because the recorded thoracic excursion could approach the lowest level 'asymptotically' (see Fig. 1).

The qualitative analysis of speech respiration involved contrasting the polygraph recordings (thoracic movements and phonograms) with the verbal transcripts from cassette tapes of the phonograms in order to identify distinguishable and characteristic respiratory patterns.

Results

A. Quantitative Analysis of the Respiratory Time Quotient

The essential differences between quiet breathing and speech breathing can be expressed by the duration of inspiration (I) relative to that of expiration (E). Figure 1 gives an example of an individual original record. These tracings illustrate two well-known observations during speech: inspiration decreases and expiration time increases, and expiration time greatly exceeds inspiration time. We will express the relation of inspiration and expiration as the duration of inspiration divided by that of expiration, the so-called respiratory time quotient (RTQ).

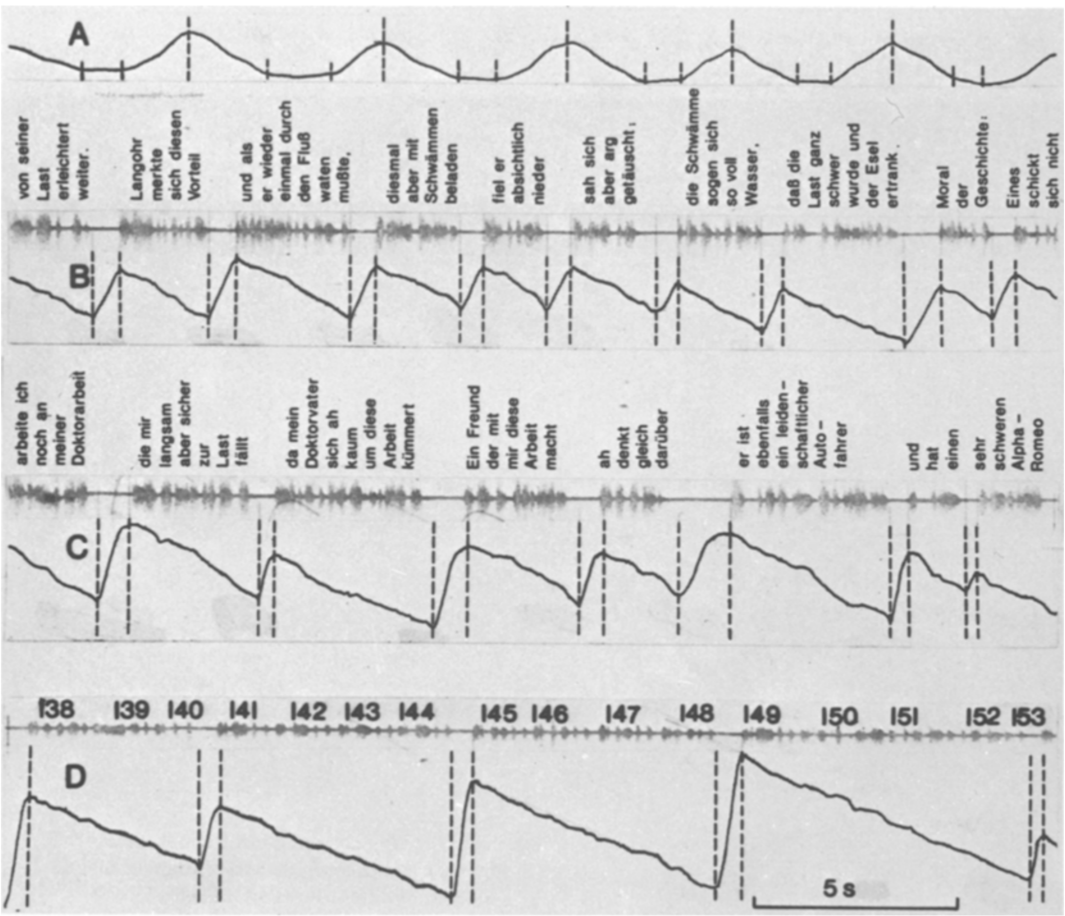

Fig. 1 A–D. Original pneumographic and phonographic records of one subject: **A**, resting respiration; **B**, reading aloud; **C**, spontaneous (vocal) speech; **D**, counting aloud (sequential, automatic speech). Calibrated text is written above the phonogram. Interrupted lines mark beginning and end of inspiration

Resting Respiration. The contrast between resting respiration and respiration in the different mental tasks for all 15 subjects is shown in Figure 3. The average resting RTQ of each person is shown in solid circles of Figure 3. Although the respiratory frequency during quiet breathing differs considerably across subjects, it is evident that RTQ stays fairly constant. Expiration time always slightly exceeds inspiration time (see also Fig. 6). There is a positive correlation between inspiration time and expiration time with a regression line following $y = 0.661x + 0.339$. The thoracical excursions observed during resting respiration varied from between 10 and 45% of maximum thoracical excursions (the greatest amount of air that could be expelled from the lungs after maximum inspiration).

Respiration During Vocal Tasks (see Table 1). RTQ changes dramatically during speech respiration (see Figs. 1, 2, and 4). The relation between inspiration and expiration is characterized by the regression equation $y = 0.035x + 0.4$, with respiratory frequency becoming mainly dependent on expiration time. It is obvious from the records of the subject shown in Figure 1 that during the different speech tasks (SPONT, SEQ, READ, ARITH), it is mainly the duration of expiration that changes.

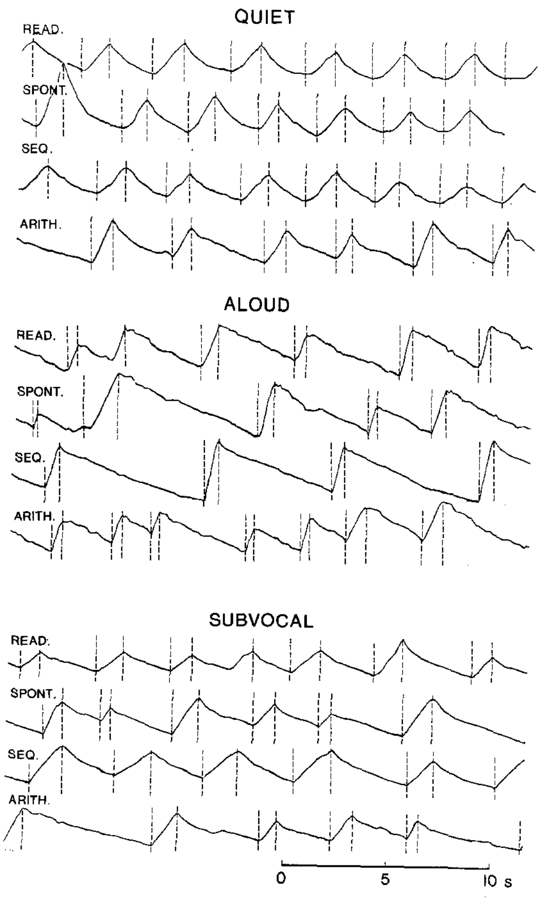

Fig. 2. Original pneumographic records of one subject during four different tasks (READ, SPONT, SEQ, ARITH) executed under three different conditions (quiet, aloud, subvocal). (For details see method and Table 1)

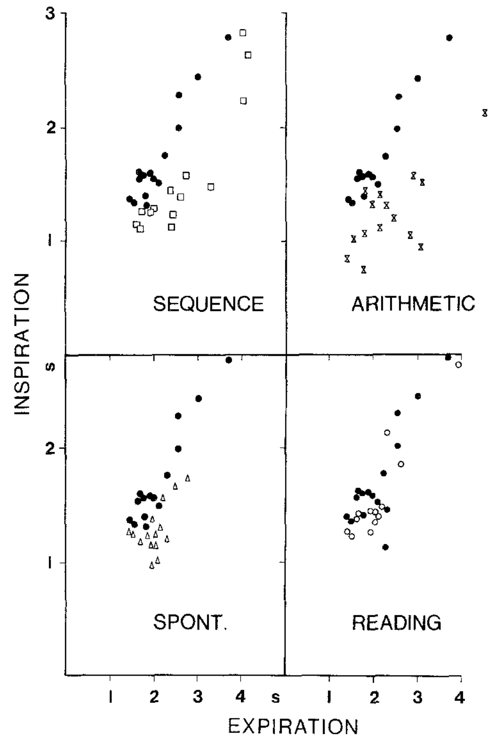

Fig. 3. Respiration during quiet (inner) performance of tasks vs. resting respiration. Change of the respiratory time quotient (RTQ, duration of inspiration divided by duration of expiration) from resting respiration (filled circles) of 15 subjects when quietly performing four different tasks. Each point represents the average of 30 breathing cycles

Table 1. Matrix of speech tasks. The matrix illustrates the different speech tasks in the automatic-spontaneous dimension (abscissa) and the inner-outer performance dimension (ordinate). In the inner stage, the tasks were performed only by thinking them, in the subvocal—by moving the articulatory organs (lips etc.) without vocalization and in the outer stage, by uttering aloud (articulation and vocalization). Breathing patterns were recorded for all combinations of the matrix

	Ideational content of tasks		
Response mode of task	Automatic sequence	Reading	Spontaneous biography →
Inner stage (covert speech) (QUIET)	SEQ QUIET	READ QUIET	SPONT QUIET
Subvocal stage	SEQ SUBVOCAL	READ SUBVOCAL	SPONT SUBVOCAL
Outer stage (overt, vocal speech) (ALOUD)	↓ SEQ ALOUD	READ ALOUD	SPONT ALOUD

Inspiration time remains relatively constant. Average RTQs for all subjects and for all four tasks are illustrated in Figure 4. The regression equations for all four tasks are given in Figure 6 (see ALOUD-blocks).

For reading and spontaneous speech the average expiration times, although similar, were clearly shorter than those for repetitive sequences. The standard deviation of the main expiration time was much higher for spontaneous speech

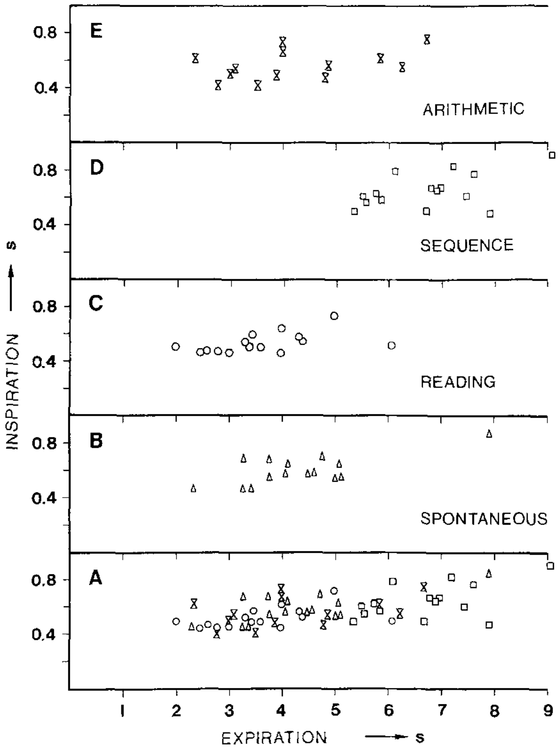

Fig. 4. Vocal performance (ALOUD) of tasks. Respiratory time quotient (RTQ, duration of inspiration divided by duration of expiration) for different vocal tasks in 15 subjects (A, all tasks together; B, spontaneous; C, reading; D, sequence; E, arithmetic). Each point represents the average of 30 breathing cycles

than for reading (not illustrated). The variability of the expiratory time is even more pronounced in the vocal SPONT and ARITH tasks.

Intuitively, there seem to be more mental computations involved in solving arithmetic and in speaking spontaneously than in automatic speech or in a reading task where understanding is not required. For convenience, we will describe this as a difference in difficulty. In these terms, it would be assumed that expiration time is modified according to the difficulty of the task.

Respiration During Quiet Tasks. One of the questions of highest interest was whether and if so, in what manner, RTQ during various quiet tasks (see Table 1) would differ from RTQ in rest conditions and in the aloud conditions. The subjects were instructed not to speak, i.e., not to articulate motorically, but instead to imagine or think the tasks. Recounting one's life history would become 'thinking or imagining' one's life history. Similarily reading aloud would change to silent reading of the given text, and counting task and arithmetic would become 'imagining' a continuous series of numbers or calculated values.

Figure 3 gives the average RTQ (open symbols) for all subjects and task conditions. Figure 6 (lower part) illustrates the corresponding regression lines (numerical values given in the legend of Fig. 6). It is obvious from Figure 3 that for the quiet reading condition, RTQ deviates least from resting respiration and most for quiet arithmetic. This distinction can best be seen from the decrease of the slope of the regression line (see Fig. 6). From reading through spontaneous 'thinking' to arithmetic, there is a gradual change of the respiratory pattern in the direction of a prolonged expiration time.

Respiration During Subvocal Tasks. One other point of interest was the effect of the articulatory motor act of speech on respiration. The subjects were instructed to articulate only with their lips without vocalization (see Table 1). Figure 2 offers a complete polygraphic example of the subvocal respiration patterns in one subject (traces 8—12) compared to all other respiration patterns during quiet tasks (1—4) and vocal (aloud) tasks (5—8). From this one polygraphic view alone it is clear that the subvocal respiratory pattern differs both from that during quiet tasks and from that during vocal tasks.

A more detailed analysis of RTQ is given in Figure 5. The regression lines for the subvocal RTQs are given in Figure 6. It is obvious that subvocal tasks shift expiration time toward that of vocal tasks, with the order of succession SEQ, READ, SPONT, ARITH. This means that even during tasks where only articulation is required, respiratory patterns are similar to those during vocal speech. The expiratory phase is prolonged and the inspiratory phase reduced although the latter change is less pronounced than the former.

The respiratory transformation is still more pronounced for those tasks which seem to imply a higher degree of difficulty (see Fig. 7). The order of succession SEQ, READ, SPONT, ARITH may be explained by this increase in difficulty.

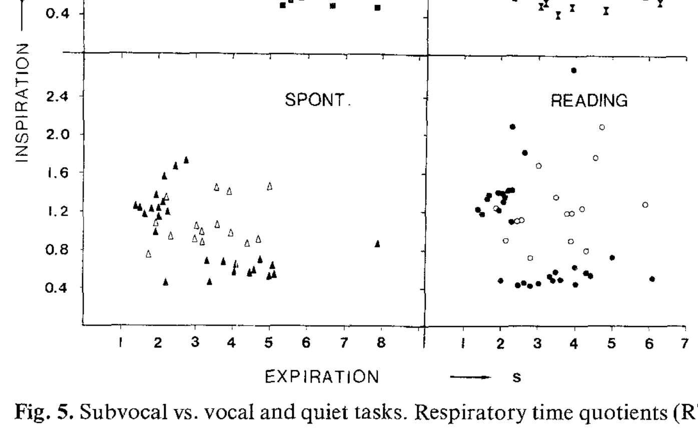

Fig. 5. Subvocal vs. vocal and quiet tasks. Respiratory time quotients (RTQ, duration of inspiration divided by duration of expiration) for four different subvocal tasks (open symbols), in comparison to the corresponding quiet (see Fig. 3) and vocal (see Fig. 4) tasks (filled symbols). Each point represents the average of 30 breathing cycles

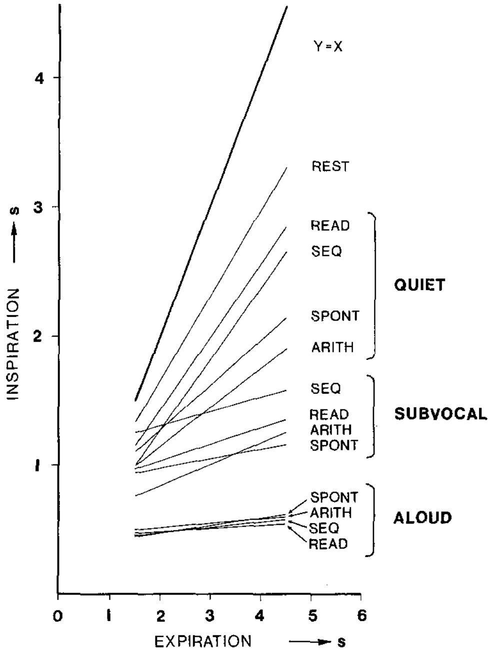

Fig. 6. Regression lines of the respiration time quotients for the four tasks (spontaneous, reading, sequence, arithmetic) performed under different response modes (aloud, subvocal, quiet). The equations of the regression lines are: resting respiration $y=0.66\ x+0.33$; QUIET READ $y=0.57\ x+0.29$; QUIET SPONT $y=0.33\ x+0.57$; QUIET SEQ $y=0.56\ x+0.14$; QUIET ARITH $y=0.30\ x+0.52$. ALOUD SPONT $y=0.05\ x+0.36$; ALOUD READ $y=0.02\ x+0.43$; ALOUD SEQ $y=0.037\ x+0.40$; ALOUD ARITH $y=0.03\ x+0.44$. SUBVOCAL SPONT $y=0.06\ x+0.84$; SUBVOCAL READ $y=0.12\ x+0.79$; SUBVOCAL SEQ $y=0.10\ x+1.10$; SUBVOCAL ARITH $y=0.15\ x+0.53$

Thus it can be concluded that resting respiration cannot be maintained during subvocal tasks and that the articulatory act alone changes the respiratory pattern automatically in the direction of (vocal) speech respiration.

B. Qualitative Analysis of Single Inspiratory and Expiratory Excursions

The respiratory time quotient tells us something about the time relation between inspiration and expiration, but nothing about the changes of single inspiratory or expiratory volume events themselves. Although numerical values can not express these changes, inspection of the polygraph nonetheless gives us some valuable information concerning cortical influences on single speech breathing acts.

Respiration During Quiet Tasks. Again comparing the inspiratory and expiratory chest pneumographic movement tracings for resting respiration and respiration during quiet tasks (READ, SPONT, SEQ, ARITH), there is a consistent change of the slope of the respiratory trace (see Fig. 7, I). Thus it is possible to predict with some certainty, from the pneumograph recordings alone, which mental task the subject was actually performing. The two main changes (illustrated in Fig. 7, I) were: (a) a sharper or more abrupt transition from inspiration to expiration and (b) a straighter expiration and inspiration trace compared to the more bell-shaped trace during resting respiration.

It must be stressed that such changes occurred to a minor degree within some breathing cycles at rest. However, they clearly were more likely to occur in quiet reading, quiet sequences, quiet spontaneous thinking, spontaneous inner speech, and quiet arithmetic.

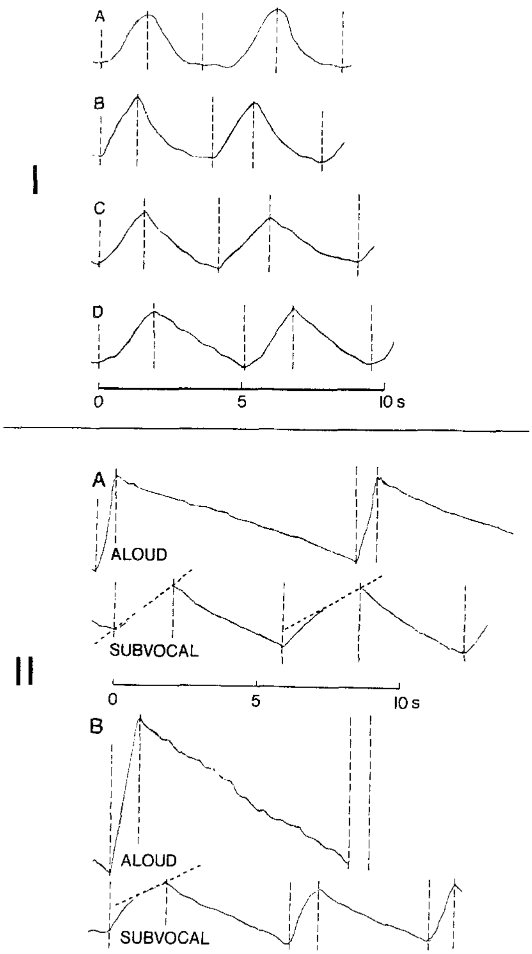

Fig. 7. I: Representative respiratory cycles of one subject during quiet performances of mental tasks (B, reading; C, sequence; D, arithmetic) compared with resting respiration (A). Note the gradual (a) straightening of the expiration trace, (b) the increasing acuteness of the angle as the trace changes from inspiration to expiration; and (c) the prolongation of the expiration phase. II: Respiratory cycles of two subjects (A, B) when speaking sequences aloud and subvocally. Note that during subvocal speech the inspiration traces indicate that subjects articulated within the inspiratory phase

In addition to the above changes, there was rarely a clear plateau at the end of expiration as observed frequently in resting respiration (see Fig. 7, I A for intercyclic plateau).

Respiration During Subvocal Tasks. As has already been shown, respiration during subvocal tasks differs in many respects from that during spoken tasks. From observation of the lips during subvocal tasks, it became clear that—in tasks other than speaking aloud—the subjects usually were articulating also during inspiration, especially within its second half (see Fig. 8).

Respiration During Vocal Tasks. So far, respiratory changes have been related to different performance levels (inner, subvocal levels; resting repiration). However, differences in the respiratory pattern can be observed for the different tasks (SEQ, READ, SPONT, ARITH). For spontaneous speech, as well as for arithmetic, the switch from inspiration to expiration was often slightly (100—500 ms) delayed compared to that for reading and sequential speech (see Fig. 1)—a delay which produces the (slightly) steeper regression lines of ARITH and SPONT (Fig. 6).

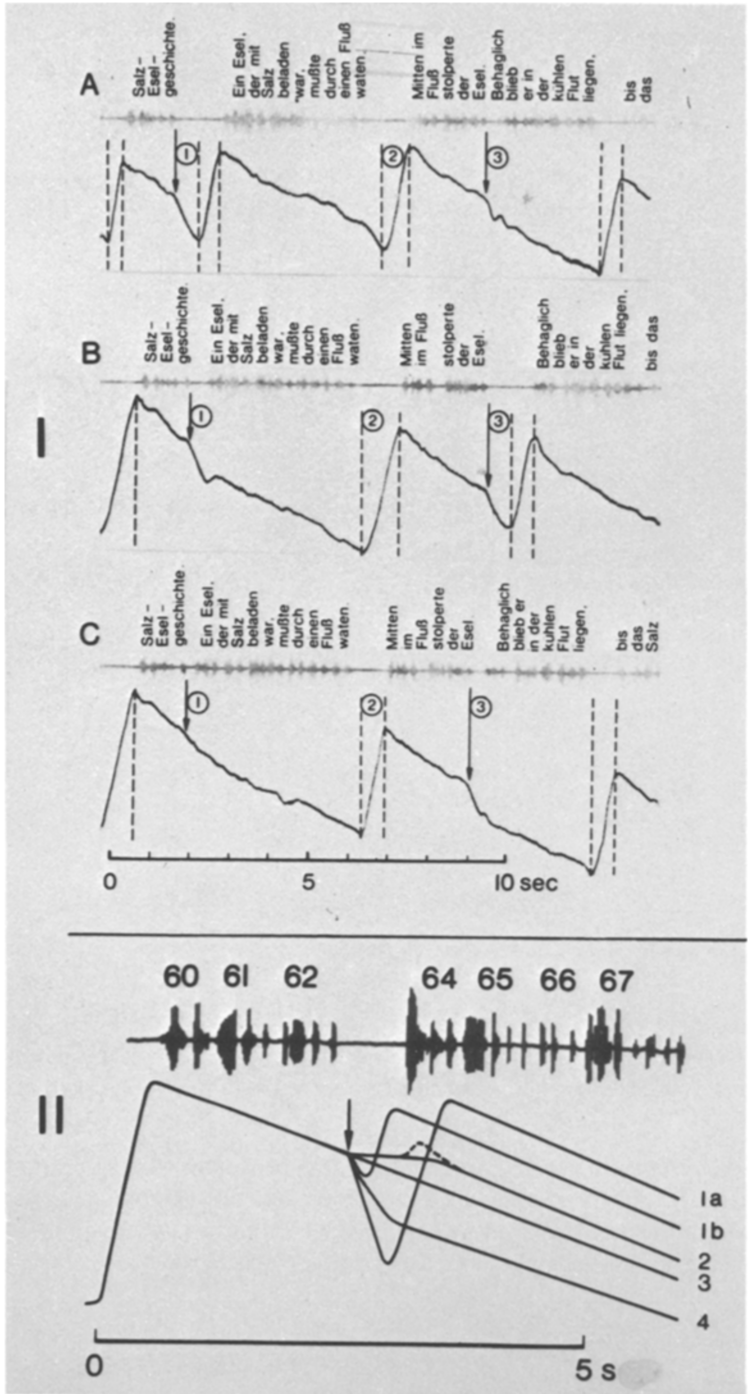

Fig. 8. I: Original pneumographic and phonographic traces of one subject, reading a standard text three times consecutively (A—C). The identifying text is written above the phonogram. Interrupted lines mark beginning and end of the first three breathing cycles. For details concerning the events 1—3, see text. II: Schematic drawing of possible breathing patterns during a speech pause. For detail see text

A quick transition from inspiration to expiration, resulting in a sharp angle in the polygraph trace is typical for the SEQ task and, to a lesser degree, for the READ task. Both these tasks are characterized by the verbal material being pregiven by the sequence of numbers or the text.

In arithmetic and spontaneous speech, however, the verbal material is not pregiven. It has to be produced by the subject himself. It may be conjectured that a delay in this process underlies the delay in the transition from inspiration to expiration; the required verbal material is not yet provided at the time of the final period of inspiration. This view is supported by the SEQ task, which clearly exhibits the highest constancy and stability and the least fluctuation of thoracic expiratory excursions (see Fig. 1, D), while at the same time being the most pregiven verbal material.

Central Factors Influencing Breathing. The need to breath anew (rebreathing) determines the duration of expiration. This observation leads to the question— which central factors, apart from the need of new oxygen supply, determine this need during speech? From analysis of the normal speech pattern, as well as from analysis of speech pauses during the expiration, it was clear that the slow and strikingly constant movements of the chest wall common to speech respiration are not maintained beyond the termination of the speech production.

This is illustrated for reading aloud in Figure 8, I, which shows the beginning part of the standard text, which had to be read three times. Within this part of the text there are three speech pauses related to content: first, after the heading; second, after the end of the first sentence; and third, after the end of the second rather short sentence. These events are identified by the numbers 1—3. At event 2, expiration clearly had reached the normal standard end expiratory level, and the subject thus was forced to rebreath in A2, B2, and C2. This was not the case for event 1 or 3. For these events the subject was still far away from end expiratory levels. The subject paused spontaneously for varying lengths of time at 1 and 3 in A, B, C. At the beginning of the speech pause (normally within 300—500 ms after the end of a recognizable phonogram trace) there is a sharp drop of the expiratory line of the pneumogram. After renewed speech production, the expiration continues (see B1, A3, C3, Fig. 8, I), or the subjects begin a new inspiration. In the subject illustrated in Figure 8, I the probability of rebreathing was higher, the longer the speech pauses lasted. This was not the case for all subjects.

In order to examine the relation between speech pauses and rebreathing more systematically, subjects were asked to create a pause. Three different strategies of pausing by omitting a word were applied (see method). The result of this study is summarized in Figure 8, II.

This figure illustrates four principle reflexes of voluntarily induced pauses: 1) rapid drop of the expiratory line for the time of the pause, then continuation of expiration (Fig. 8, II, 4), 2) rapid drop followed by a new inspiration (Fig. 8, II, 1a, 1b), 3) holding the breath for the time of the pause (Fig. 8, II, 2), 4) a more or less unchanged continuation of the expiratory line (Fig. 8, II, 3).

In realizing one or the other of these four pause patterns the subjects seem to be influenced greatly by the pausing strategy dictated by the task. Table 2 shows

Table 2. Percentages of different breathing patterns (see Fig. 10) for different experimental speech pauses

Types of respiratory speech pauses	Conditions of pausing (no vocalization)		
	Pausing by trying to 'think' the number (no articulation, no phonation)	Pausing by subvocally articulating the number	Pausing for a time equivalent to saying the number (without thinking or articulating)
	Per cent	Per cent	Per cent
1	35	10	80
2	30	10	5
3	10	20	15
4	25	65	0

the relative frequency of pause patterns in relation to pausing strategy. When the subjects made a pause, trying neither to articulate nor to think the number, pause pattern 1 was realized in 80% (Fig. 8, II, 4); when they made the pause but went on articulating, pattern 2 was realized in 65%. When the subjects thought the number without articulating it, the pattern varied.

Discussion

When quiet respiration changes to speech breathing, the most striking alterations are an acceleration and consequent temporal reduction of the inspiratory phase, and a deceleration and prolongation of the expiratory phase. These two variables combined in the respiration time quotient, RTQ, (inspiration/expiration) were used as the basic measure of respiratory speech patterns.

One main intention of this study was to discover whether resting respiration and speech respiration are mutually exclusive modes of respiration or whether there are various subtypes representing a transition from the former to the latter. This question was examined by a series of experiments varying the content of the task (SEQ, READ, SPONT, ARITH) and the response mode in which the tasks had to be performed (thinking the task, inner speech), articulation without vocalization (subvocal speech), normal speech with articulation, and vocalization (vocal speech). The content variable was intended to reflect the degree of difficulty; whereas, the mode of performance varied the degree of motor or muscular contribution to speech respiration.

The significant results are as follows:

(1) Resting respiration changes to speech respiration along a continuum from inner, through subvocal, to vocal speech. This transition manifests itself in a progressive increase in the duration of the expiratory phase (see Fig. 6). Since the typical speech respiratory pattern stops at the moment the utterance ceases (see below), it must be concluded that speech respiration is intimately coupled with the motor processes underlying speech production. Progressive changes towards speech respiratory patterns seem to indicate a progressive 'activation' of the

speech motor system, possibly in the sense of an increasing activation or readiness reaction of the motor speech system.

(2) It is most remarkable, that even in the 'inner' stage, respiration changes to resemble speech respiration. Quantitatively these changes consist in an increase in the duration of expiration from the READ task (the lowest increase) through the SEQ and SPONT task, to ARITH (greatest prolongation). The qualitative changes (Fig. 7, I) are disappearance of the intercyclic plateau, straightening of the expiratory and inspiratory legs, and more instantaneous change between these two legs.

That reading respiratory patterns display the lowest degree of change may result from quiet reading being a 'mere sensory or receptive' process. It thus produces the lowest level of activation of motor speech mechanisms. On the other hand, the slight activation which does result makes it clear that even sensoric processes such as silent reading are embedded in the more complex and integrated sensorimotor system involved in speech respiration. One has to take into consideration that the READ task did not require 'reading for meaning'. A higher degree of activation of the speech motor system might have resulted and, consequently, a closer approximation to the actual speech respiration pattern might have been obtained in a reading task where comprehension is controlled.

In contrast to quiet reading (see Table 1), the quiet SPONT task and the quiet ARITH task exhibit an increasingly pronounced pattern of expiratory prolongation and inspiratory reduction. This more prominent transformation of the respiratory pattern might be an outcome of the higher degree of forced verbalization within the SPONT and ARITH tasks, perhaps resulting from the greater difficulty they obviously presented to the subjects.

It is intriguing, that the presence of such respiratory patterns provides the possibility for drawing conclusions about internal states of activation, the degree of difficulty of mental tasks, and the degree of inner verbalization associated with different mental processes.

Furthermore, respiration, which normally is controlled by brainstem centers, must have been submitted to the control of cortical structures not only when the speech act itself is performed, but even in the most 'internal' stage of speech generation.

(3) The subvocal stage is characterized by a prominent prolongation of the expiration (decrease in RTQ) and a more marked speech respiratory pattern. These changes presumably reflect more pronounced speech motor activation, contingent on the degree of difficulty of the task. Here the reading process, which is primarily sensory, is combined with articulation and requires a relatively higher motor activation than a merely internal task such as silent reading and, consequently, the expiratory phase becomes relatively longer. The degree of transformation to speech respiration reflects the order SEQ, READ, ARITH, SPONT (see Fig. 6).

(4) A further important feature of speech respiration is that it is by no means a conscious, voluntary or voluntarily initiated act. The characteristic speech respiration pattern is present already in internal tasks and to a far greater extent, in subvocal tasks. In other words, this transformation takes place automatically, even if vocalization itself is not produced.

In the SEQ task the only variable which disturbs the speech respiration pattern seems to be the amount of air exhaustion. This depends on the linguistic characteristics of the units uttered (Klatt et al., 1968; Isshiki and Ringel, 1964). It appears plausible that a continuous sequence of numbers can be uttered until the end expiratory level is reached since unbounded amounts of language material are at the speaker's disposal (counting can go on indefinitely). The fluency of the utterance depends mainly on the continuity of what may be called the generation of ideas (ideation); in the automatic, semantically empty speech, this ideation process is minimized. Thus, the speaker need never find himself not knowing what to say next. The SEQ task probably reduces the speech act to mere phonomotoric processes. This reduction may also explain the much higher degree of homogenity and uniformity in the SEQ tasks (see Figs. 1 and 2).

One might speculate however, that during spontaneous speech, ideational and semantosyntactic processes are superimposed on the phonomotoric component: the outcome of ideation is fed into a phonomotoric component in which motor programing takes place. Discontinuities in ideation lead to discontinuities in phonomotoric programing and non-fluent speech performance. This kind of discontinuity generally leads to a new breathing cycle (cf. to Fig. 1 C), even if the expiratory phase has not reached the end expiratory level (see Fig. 8, II).

Pauses in the uttered speech seem to be primarily the outcome of a slowdown or stop of ideational processing—or in an alternative interpretation—they may represent the initiation of new ideational cycles. It could be argued that an ideational cycle, corresponding to a 'sense unit' in speech, begins with the initiation of a new respiratory cycle, marked by a new inspiration phase. The timing and duration of these phases will obviously be more variable in spontaneous speech than in the other speech modalities studied here.

The characteristic features of spontaneous speech are (a) higher variability of expiration, with a tendency to shorter durations, (b) a higher rate of rebreathing, apparently under the control of the linguistic aspects of the speech being produced, (c) more variability in the duration of inspiration, and (d) deceleration in the final stage of the inspiratory phase.

As a task, reading aloud lies between the sequence and spontaneous speech tasks. In reading, spontaneous ideation is not required; rather the ideas to be uttered are given by the text. In this respect, the task resembles sequences. On the other hand, the text is structured semantosyntactically, as is spontaneous speech, and thus contrasts with the sequences. The respiratory graphs document this intermediate position. The expiratory phase on average is shorter and only infrequently reaches the end expiratory base as is the case in spontaneous speech. However, the variability in the duration of the expiration phase is less than during spontaneous speech. Furthermore, the inspiratory phases coincide with speech pauses marking semantosyntactically structured parts of the text, a phenomenon which is in common with spontaneous speech, but contrasts to sequences.

A further phenomenon observed during these experiments, but not quantified or studied systematically, concerns so-called filler words ('ah', 'äh' in German) (see Fig. 1, C). They usually occur in normal speech when the speaker seems not to 'know' how to continue. Evidently these filler words convey no meaning in the ordinary sense. They bridge one part of an utterance with a following one. In the framework of this study, it can be conjectured that filling words represent phonomotoric verbal material used to maintain the flow of speech and speech respiration. The occurrence of filler words could well represent a discontinuity in ideation which is compensated for (and masked) by uttering semantically empty phonomotoric material, possibly in order to improve breathing economy.

The outstanding feature of the relation between speech pauses and speech respiration is that any cessation of the speech flow results in a change of the expiratory line.

In the SEQ tasks most pauses occur when rebreathing is required for gas exchange, i.e., when the end expiratory level is reached. In the other tasks (SPONT, READ) the interruption of the speech flow is clearly not motivated by these primary needs, but by linguistic considerations: that is, speech is generally not stopped for the sake of gas exchange but for the sake of the speech-generating system itself. In this case the expiratory phase can be altered in various ways (see Fig. 8, I and 8, II). The change may take the form of (a) a sharp increase in the rate of expiration (Fig. 8, I, A1, A2, B3; Fig. 8, II, 1a and b), followed by a new breathing cycle, (b) a sharp rate increase, followed by a continuation of the expiratory line (Fig. 8, I, A3, B1, C3; Fig. 8, II, 4), (c) mere continuation of expiration without any change in rate (Fig. 8, I, C1; Fig. 8, II, 3), and (d) a mere holding of the breath (horizontal trace) (Fig. 8, II, 2). The main factor which determines the respiratory pattern seems to be the duration of the speech pause. As the length of the pause increases the likelihood of rebreathing increases. The effect of increasing automatization on speech respiration can be seen in Figure 8, I. Trace A (first reading of the text) shows at A1 a sharp drop of the expiratory lines followed by a new inspiration; in the second reading the drop is followed only by a continuation of the expiratory line (B1), and in the third the expiratory line continues without a drop (A3) (see also B3 and C3, Fig. 8, I). With the increasing familiarity with the text, the respiratory pattern changes towards that typical for automatic speech.

In conclusion, the qualitative analysis clearly demonstrates:
(1) Respiration during speech is influenced by a superimposed linguistic system;
(2) Specific speech tasks are reflected in specific speech respiration patterns;
(3) Ongoing processes in the linguistic system seem also to be reflected in speech respiration. Hence speech respiration may be a useful tool in the investigation of the ongoing processes of speech production and perception, and perhaps of other mental activities.

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