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A Study of Timing in a Manual and a Spoken Language: American Sign Language and English

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A comparative analysis of the time variables in the production of speech and sign reveals that signers modify their global physical rate primarily by altering the time they spend articulating, whereas speakers do so by changing the time they spend pausing. When signers increase or decrease their pause time, however little they do so, they alter the number and the length of the pauses equally, whereas speakers primarily alter the number of pauses and leave their pause durations relatively constant. An analysis of the durations of signs reveals that signs are longer at the end of sentences than within sentences and that the first occurrence of a sign is longer than the second when syntactic location is controlled (both these findings have already been reported for spoken language). The inherent duration of a sign can be accounted for almost totally by the movement characteristic; handshape, location, and number of hands in a sign are of little importance. Finally, signers retain their regular "quiet-breathing" respiratory pattern across signing rates and inhale at locations independent of syntactic importance. In this they are quite unlike speakers, who breathe at syntactic breaks.

INTRODUCTION

In a study that compared sign language and spoken language, Bellugi and Fischer (1972) showed that ASL-English bilinguals took the same amount

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of time to tell a story in American Sign Language (ASL) as in English, produced the same number of propositions in the two languages, but paused 13% less in Sign than in English and articulated half as rapidly in Sign.

This first study of timing in Sign produced some fascinating results and raised a number of questions which pertain to the temporal variables of sign and speech. For example, the study was based on spontaneous production, which naturally involved large amounts of pausing of a varied nature including hesitation pauses and grammatical pauses. Suppose signers were given a task that invited no hesitation pauses—practiced reading, for example—would they still pause less than speakers? And if so, how is that reduced pause time organized? Do signers, for example, pause as often as speakers, but for a much shorter time? A second group of questions concerns global rate. Bellugi and Fischer report the amount of time their subjects spent pausing and articulating but do not present the global signing rates. A large number of studies have examined the perception and production of speech rate, but no normative values for signing rate have yet been published. These are of importance for psycholinguists (who would like to know at what rate of presentation a sign passage or a list of signs should be produced) and for applied linguists (who need to use rate of presentation as one of the variables to control or manipulate in the comprehension tapes they make for sign classes). Furthermore, it is of interest to examine what happens to production rate when signers speed up or slow down. How do signers modulate their articulation rate and the number and the length of pauses when they change their number of signs per minute (spm)? Do they, like speakers primarly change the number of pauses and hardly alter the articulation rate and the length of the pauses (Grosjean, 1972; Lane and Grosjean, 1973)?

A third group of questions concerns the actual signing stream: how much time is spent on each sign? Are all signs of equal duration, or do they differ in length? If they differ, as one would suppose just by looking at a person signing, which characteristics account for this inherent duration: the number of hands used in the sign, its location, the movement, the handshape of the sign, or a combination of all these parameters? When rate is altered, which of these characteristics are involved in the change of sign duration?

A final group of questions helps to set the stage for this attempt to compare further the timing of sign and speech: pausing and breathing interact naturally in speech with breathing controlled by pausing—as soon as the syntactic break is important enough and the ensuing pause long enough, the speaker will take a breath (Grosjean and Collins, 1979). What about in sign? Does one breathe at important syntactic locations, or is breathing quite independent of signing? Answers to these questions will help us isolate and understand further the aspects that are common to both the speech and signing modalities and those that are modality specific.

METHOD

Subjects

The first of two groups of subjects was made up of five adult native signers of American Sign Language (ASL) with deaf parents. Three subjects were congenitally deaf and two subjects were hearing ASL-English bilinguals (Grosjean and Lane, 1977). The second group consisted of five native speakers of English taken from a larger group of 11 subjects who took part in a preceding rate experiment (Grosjean, 1977). They were picked so as to match the autophonic scales of the five signers; the autophonic scale relates the signer's or speaker's subjective impression of his own change in rate to the actual change in rate by a power function. The mean exponent was 1.73 for the five signers (SD = 0.42) and 1.74 for the speakers (SD = 0.43). Signers and speakers thus covered comparable ranges (about 4.5:1) when going from slow to fast signing or speaking (one-fourth normal to three times normal rate as they perceived it).

Materials

An English-ASL bilingual signer was asked to sign a story that she learned as a young child from her deaf parents, and a video recording was made (Sony AVC 3250S and VTR 3650). The first part of the story, "Goldilocks," was transcribed literally into English, giving the following 52-sign passage[2]:

[2]Hyphenated glosses correspond to a single sign. It is important to recognize that the ASL passage reported here is not translated into English; rather than use a transcription system for ASL (e.g., Stokoe *et al.*, 1965), we have transliterated the passage by substituting an English gloss for each sign. The choice of English glosses is somewhat arbitrary; for example, the eighth sign (INTO) might be glossed as GO-INTO or ENTER, the 30th sign

LONG-TIME-AGO GIRL SMALL DECIDE WALK IN WOODS INTO WOODS SEE HOUSE INTO VERY HUNGRY THEN SIT-DOWN SEE BOWL BIG-BOWL EAT DON'T LIKE COLD MOVE-ON BOWL HOT REALLY DON'T LIKE IT MOVE-ON SMALLEST BOWL EAT-EAT PERFECT HUMM EAT ALL-GONE THEN SIT THREE DIFFERENT CHAIRS SAME THING HAPPEN ONE HARD ONE SOFT ONE PERFECT

The passage was used to obtain five different rates of signing from each native signer. The idiomatic English translation of the above passage was then given to hearing subjects and similar reading rates were obtained in English:

A long time ago a little girl decided to take a walk in the woods. In the woods she saw a house and went in. She was very hungry, so she sat down. She saw a big bowl and began to eat. She didn't like it because it was too cold. She went to the next bowl. This one was too hot and she really didn't like it. Then she went to the smallest bowl and ate and ate. It was good, really good and so she ate it all up. Then she saw three different chairs and sat on each of them. One was too hard, one was too soft, and one was just right.

Procedure

In order to avoid the variations in timing associated with spontaneous utterances (hesitation pauses, false starts, and so on) and to obtain the identical passage at several rates of utterance, each subject (from both groups) first practiced reading or signing the transcribed story. Once familiar with the story, the subject read or signed the passage at normal rate. To the apparent rate of his reading or signing, the experimenter assigned the numerical value 10. A series of values (2.5, 5, 10, 20, 30) was then named in irregular order, four times each , and the subject responded to each value by reading or signing the passage with a proportionate apparent rate. The subject was urged to use exactly the same words or signs at each rate. The English passage was typewritten double spaced. The sign passage was printed in English glosses on a 70- by 55-cm panel;

(IT) as THAT, and the 37th sign (EAT) as FOOD. In many cases these different translations would be captured by an adequate transcription system, but, for our purposes here, unmodified English glosses are sufficient. Our informants have also pointed out certain English influences in the sign passage, e.g., IT in REALLY DON'T LIKE IT and THEN in VERY HUNGRY THEN SIT-DOWN and in THEN SIT THREE DIFFERENT CHAIRS. But these in no way affect the results we obtained.

the letters were 12 mm high. The panel had a 9- by 9-cm hole at its center so it could be slipped over the lens of the video camera, located 2 m from the subject. The speech productions were tape-recorded (Crown SS800) in a audiometric room and the sign productions were video-recorded (Sony AVC 3250S and VTR 3650) in a television studio.

Two subjects, one hearing speaker of English and one congenitally deaf signer, were retained at the end of the testing session so that their respiratory activity could be analyzed while they read or signed at varying rates. The speaker's breathing was measured as a function of ribcage contraction and expansion. A strain gauge consisting of an expandable rubber tube was fitted across the thoracic cavity of the subject; it was linked to a pressure transducer (Sanborn 268B) which changed pressure variations into electrical energy. This signal was amplified (Sanborn transducer converter 592-300) and read on an oscillograph (Minneapolis Honeywell Visicorder, paper speed 2 inches/sec); the subject's speech was detected by a microphone and recorded on a second track of the oscillograph.

For the signer, breathing was measured by means of a thermistor-bridge attached to one of the subject's nares (the subject was asked to breathe only through his nose). Changes in temperature due to inhalation and exhalation were thus transformed into electrical energy which in turn was amplified and fed into a pen-recorder (Gould Brush 200, paper speed, 5 mm/sec) (both the thermistor and the amplifier are prototypes constructed by Dr. W. Coan, Boston University). In order to obtain a simultaneous visual record of breathing and signing, the signer was instructed to stand next to the pen-recorder while his sign productions were video-recorded.

Data Analysis

Sign

With five signers producing the passage at five different rates, four times each, 100 recordings were made. We retained for analysis a representative sample of 25 by selecting for each signer, at each apparent rate, that recording whose signs per minute (spm) was closest to the mean spm of the four replications of that apparent rate.

The durations of these passages were measured first to an accuracy of greater than 1% with a chronoscope (Standard timer S1). Then an initial componential analysis of the signing stream examined the number and length of the pauses in the sign productions. Two native signers of ASL, one congenitally deaf, the other a hearing ASL-English bilingual, independently measured the durations of the pauses in the five recordings selected for the first signer. Each of the judges separately viewed the recording at normal speed (Sony CVM 950 monitor) and noted the locations of the pauses. Then the passage was played back at one-sixteenth normal speed (Sony 3650 VTR) and the judge pressed a telegraph key for the duration of each pause. This response supplied a 1000-Hz coding tone to an audio tape-recorder (Tandberg 1600X). The recording was subsequently analyzed with a frequency counter: each pause duration in milliseconds was equal to the number of cycles of the coding tone, divided by 16.[3]

Although the two judges worked independently and were not coached on their criteria for a pause, both delimited pauses in the same way. By their account, they detected a pause between two signs when either (1) a sign executed with continuous or repeated movement was extended by holding the hand(s) without movement in the terminal position or (2) a sign executed with such a hold was extended by sustaining the hold. This type of pause corresponds to the "single-bar juncture, 'sustain' /|/," proposed by Covington (1973): "During the pause. . . the hands are held in the position and often the configuration of the last sign." The judges also included as part of the pause the out-transition of the first sign, giving the following segmentation of the signing stream around each pause:

In-transition	Sign	Hold	Out-transition	Neutral	In-transition
Key up		Key down		Key up	

[3]The reduction in the speed of the video playback was calibrated as follows: a running chronoscope, graduated in centiseconds (Standard timer S1), was videotaped at normal speed. The tape recording was played back at reduced speed and the same chronoscope was used to measure the time it took for the recording to show an elapsed time of 1 sec. There were an undershoot of about 5% early in the ½-inch reel and an overshoot of about 5% late in the reel. Consequently only the first 40% of the reels were recorded in the experiment and the mean reduction was computed to be 1/16 ± 2%. The frequency of the recorded coding tone was calibrated with a frequency counter (Hewlett-Packard, 204A) and a correction was applied to the pause durations measured by counting cycles of that tone so that the readings were expressed in milliseconds.

Table I. Intrajudge Reliability in Reporting Pause and Sign Duration in ASL[a]

Rate (signs/min)	Judge 1 Evaluation 1	Judge 1 Evaluation 2	Judge 1 r	Judge 2 Evaluation 1	Judge 2 Evaluation 2	Judge 2 r
Pauses						
30	0.79	0.73	0.95	0.72	0.71	0.91
52	0.51	0.52	0.86	0.47	0.52	0.80
80	0.31	0.32	0.91	0.32	0.33	0.91
147	0.15	0.15	0.83	0.14	0.12	0.93
193	0.00	0.00	1.00	0.00	0.00	1.00
Signs						
30	1.09	1.00	0.94	1.02	0.98	0.82
52	0.67	0.69	0.93	0.58	0.58	0.92
80	0.47	0.47	0.86	0.52	0.39	0.92
147	0.27	0.25	0.89	0.20	0.19	0.83
193	0.16	0.19	0.74	0.13	0.14	0.78

[a]A passage signed at five different rates was analyzed twice by each of two judges. Shown are the rates of the passage, the average duration of pauses between every pair of signs and of signs on the first and second measurements, and the correlation between these two sets of measurements for each of the judges. (There were no pauses reported at the highest signing rate.)

The intrajudge reliability was generally quite good (Table I), with a mean correlation of $r = 0.89$. The interjudge reliability was slightly lower: the correlation between the duration reported by the two judges at each rate was $r = 0.80$ (they agreed on pause emplacements 88% of the time). Consequently, the recordings for the remaining four signers were analyzed by one judge, a congenitally deaf native signer of ASL.[4] This first

[4]A college student unfamiliar with ASL was also asked to analyze one passage (30 spm) in the same way to determine if a knowledge of ASL is required to identify and measure pauses. It is not. He agreed 86% of the time with judge 1 and 80% of the time with judge 2 on pause emplacements (the two judges agreed with each other 86% of the time on this passage). His duration measures correlated $r = 0.85$ and 0.70 with those of the two judges, respectively, whereas their measures on this passage correlated $r = 0.76$. This naive observer did not include out-transitions in his measurements of pause duration; hence his reported mean was 0.57 sec, contrasted with 0.76 and 0.72 for the two judges. (His test-retest reliability was $r = 0.97$.) Nothing here gainsays the possibility that our native informant judges would report pauses even if all stops were deleted from the signing stream— as Martin (1967) found for speech—but that is another matter.

analysis yielded, for each passage, the number and the duration of the pauses and consequently the total pause time (number of pauses times the mean duration of pauses), the articulation time (total passage time minus the pause time), the articulation rate (number of signs in the passage divided by the articulation time) expressed in signs per second, and the global signing rate (number of signs divided by the total signing time, times 60) expressed in spm.

A second analysis examined the duration of the signs. These were measured in an identical manner in 20 of the 25 productions of the passage (four signers, five different rates). The two judges, again working independently, deliminated a sign in the following manner. A sign starts as soon as it is recognizable, even though the handshape configuration is not quite in its final form, the location has not quite been reached, and the movement may not have started (this is the "in-transition"); it continues in its regular form where all the parameter are combining naturally (this is the sign itself); and it ends in the "out-transition." The sign is considered as completed when it cannot be recognized any longer. This analysis gives the following segmentation of the signing stream around each sign:

Neutral	In-transition	Sign	Out-transition	Neutral	In-transition
	Key down			Key up	

As in the measurement of the pauses, the intrajudge reliability was quite good (see Table I), with a mean correlation of $r = 0.86$. The interjudge reliability was again relatively high (the mean correlation between the durations reported by the two judges for all rates was 0.76), and consequently the sign durations of the remaining three signers were analyzed by the same congenitally deaf native signer of ASL.

Speech

A sample of 25 reading productions was chosen in the same fashion as the sample of sign productions. Their pen-recorder tracings were measured with dividers to an accuracy of ±0.02 sec. These measures yielded, for each passage, the number and duration of the pauses and the runs (the stretches of speech between the pauses), with a pause defined as an interruption of the sound wave lasting more than 0.24 sec. The following measures were then calculated: global rate (words per minute), articulation time, pause time, articulation rate (number of syllables divided by the articulation time), and number and mean length of pauses.

Respiration

An analysis of the oscillographic tracings of the breathing of both the signer and the speaker yielded the number of respirations per minute and the percentage of the respiratory cycle spent inhaling. In addition, a congenitally deaf native signer viewed the videorecordings, which also contained the tracings of breathing, and noted the locations of the inhalations during the signing stream.

RESULTS AND DISCUSSION

Production Rate and Its Component Variables

Table II presents the mean values of the temporal variables at each of five rates for signers and speakers. For the values obtained at normal rate (subjective rate of 10), we can compare some of our findings to those reported by Bellugi and Fischer (1972); these have been regrouped in Table III. In both studies, signers spend more time articulating than do speakers: the articulation time ratio, i.e., the articulation time divided by the total production time, is about 88% in sign and 78% in speech (averages across the two studies). Also, signers articulate more slowly: an average of 1.94 signs per second as opposed to 4.57 words per second. It should be noted, however, that the two studies diverge on the absolute values of these two variables. The articulation time ratio is higher for both sign and speech in this study, and the articulation rate, although virtually identical in speech, is in sign much higher in the Bellugi and Fischer study. These differences could be due to a number of factors: sampling error arising from the small number of subjects in the studies—five in this study and three in that of Bellugi and Fischer; the different experimental tasks—telling a story as compared to reading or signing a passage (there is usually a lower articulaton time ratio and a slower articulation rate for story telling as opposed to reading in speech (Grosjean, 1972; Grosjean and Deschamps, 1973); and, finally, the different criteria for deliminating a pause in sign. Did Bellugi and Fischer, for example, count the

Table II. Temporal Properties of Speech and Sign at Each of Five Production Rates

Language	Subjective rate	Articulation time(sec)	Articulation rate (signs or words/(sec)	Pause time(sec)	Total time(sec)	Articulation time ratio(%)	Words or signs/min	Percent increase in rate	Number of pauses	Percent of pause slots filled	Mean length of pauses (sec)
English	2.5	47.5	2.44	27.44	74.94	63.38	92.87	0	45.73	39.76	0.60
116 words	5	38.48	3.01	13.33	51.81	74.27	134.34	44.65	22.22	19.32	0.60
($n = 5$)	10	26.11	4.44	4.96	31.07	84.04	224.01	141.21	10.78	9.37	0.46
	20	20.42	5.68	1.82	22.24	91.82	312.95	236.98	5.06	4.4	0.36
	30	16.24	7.14	0.50	16.74	97.01	415.77	347.69	1.92	1.67	0.26
ASL	2.5	69.19	0.75	14.86	83.55	82.81	37.34	0	24.26	47.57	0.59
52 signs	5	46.62	1.12	7.97	54.59	85.40	57.15	53.05	19.73	38.68	0.40
($n = 5$)	10	34.77	1.50	3.76	38.53	90.24	80.98	116.87	12.97	25.43	0.29
	20	23.41	2.22	0.85	24.25	96.54	128.66	244.56	4.89	9.59	0.17
	30	18.19	2.86	0.01	18.20	99.95	171.43	359.11	0.8	1.57	0.02

Table III. Comparison of Articulation Time Ratio and Articulation Rate in Sign and Speech in Bellugi and Fischer (1972) and in the Present Study

	Studies	Sign	Speech
Articulation time ratio (%)	Bellugi and Fischer	85	72.2
	Present	90.2	84
Articulation rate (signs or words/sec)	Bellugi and Fischer	2.37	4.7
	Present	1.5	4.44

out-transition of the sign when measuring the length of the pauses in sign? Despite these differences, two of the main findings obtained by Bellugi and Fischer are confirmed in this study: namely, signers spend more time articulating than do speakers and they also articulate more slowly.

A further examination of the temporal variables in sign and speech at normal rate (Table II) shows that a speaker produces 2.77 words in the time it takes a signer to produce one sign (the global physical rates are, respectively, 224.01 wpm and 90.98 spm); this of course has no effect on the number of propositions per minute, as Bellugi and Fischer have shown. Furthermore, the smaller pause time ratio in sign (9.76% as compared to 15.96% for speech), hence the greater articulation time ratio, is due mainly to shorter pauses in sign. Even though signers pause more often than speakers when relative frequencies are examined (25% of the 51 pause slots are filled with a pause in sign but only 9% of the 115 pause slots in speech have a pause) and pause about the same number of times when absolute frequencies are tabulated (13 times in sign and 11 times in speech), they do so for a much shorter time; pauses are 37% shorter in sign than in speech (0.20 sec and 0.46 sec, respectively).

How do signers and speakers change their production rate, and hence the componential variables of rate, when asked to speed up or slow down? Figure 1 gives a first indication of the strategies used, For both modalities the articulation time ratio grows larger with increasing rate; but it does so much more quickly in speech than in sign (the articulation time ratio covers a 34% range in English but only half that range, 17% in Sign). This suggests that signers will not change their global physical rate by modifying the amount of pausing they put into their signing stream (at the slowest rate only 17% of the total signing stream is made up of pauses as compared to 37% in English) but will prefer to change their global signing

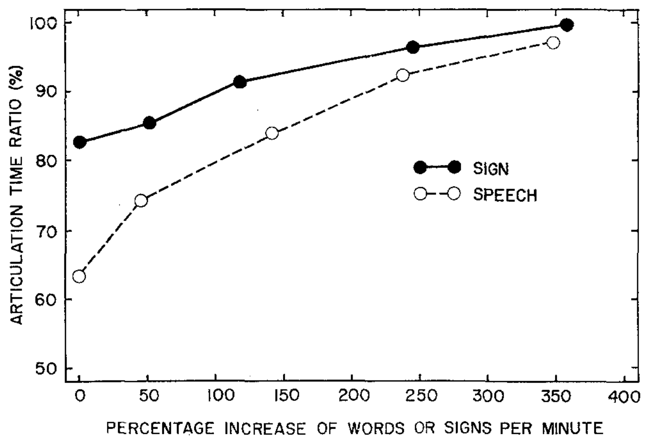

Fig. 1. Articulation time ratio (expressed as a percentage) in sign and speech as a function of the percentage increase of words or signs per minute. Each point (filled for sign, unfilled for speech) is the mean of five values, one by each of five subjects.

rate by altering their articulation rate. Speakers, however, will modify their pause time above all else and will not alter their articulation rate to any great extent.

This is confirmed in Fig. 2, where it can be observed that articulation time in sign covers a much wider range than in speech (51 sec in sign and only 32 sec in speech). And, inversely the pause range in sign is only 15 sec whereas it is 27 sec in speech. A closer examination of the figure shows that signers and speakers diverge in their strategies especially at slow rates: here, a signer will decrease his physical rate by articulating more slowly whereas a speaker will pause more often; at fast rates, however, the two will follow similar tactics—both will alter their articulation time more than their pause time.

When a signer alters his pause time, however little he does so, when modifying his physical rate does he alter both the number and length of pauses to the same extent or does he prefer, as for speech, to alter the number of pauses much more? Figure 3 gives the answer to this. The results obtained for speech confirm the data presented by Grosjean (1972), Lane and Grosjean (1973), and Grosjean and Collins (1979): the mean length of pauses changes only slightly as physical rate is increased (a 0.34 range is covered) but the number of pauses is altered considerably: from one pause every 2.54 words at the slowest rate (93 wpm) to one

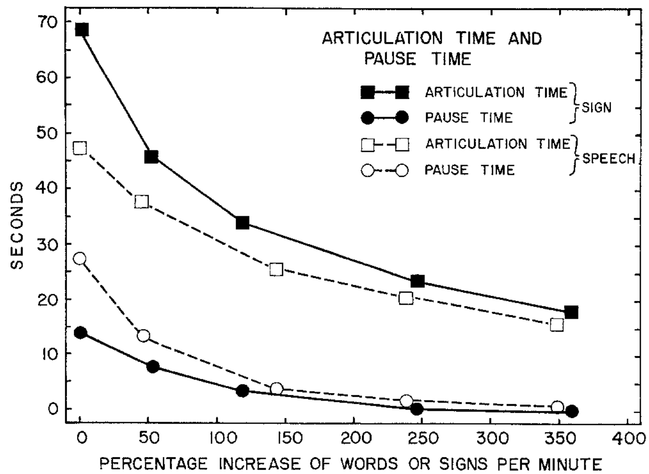

Fig. 2. Articulation time and pause time in sign and speech as a function of the percentage increase in words or signs per minute. Each point (filled for sign, unfilled for speech) is the mean of five values, one by each of five subjects.

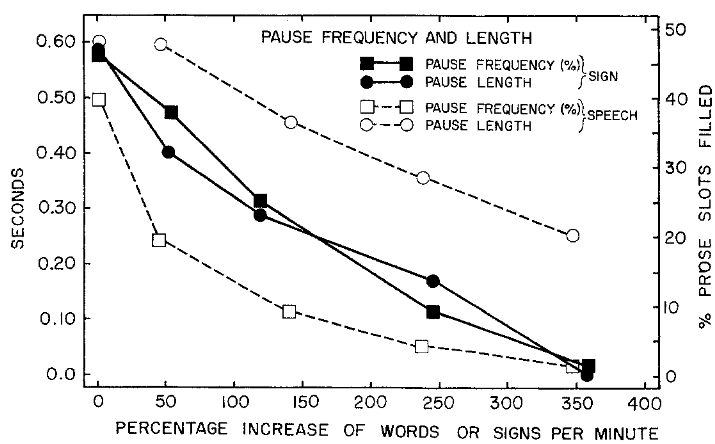

Fig. 3. Pause length and number of pauses (expressed as the percentage of the pause slots in the passage that are filled) in sign and speech as a function of the percentage increase in words or signs per minute. Each point (filled for sign, unfilled for speech) is the mean of five values, one by each of five subjects.

pause every 60.42 words at the highest rate (416 wpm). In sign, however, both variables appear to decrease simultaneously and regularly as physical rate is increased; this is shown by the close proximity and overlapping of the two curves (percent of pauses and length of pauses) in Fig. 3.

The reason for these different strategies in sign and speech is probably linked to the respiratory activity in the two modalities. As will be seen below, the signer's breathing is almost totally independent of his signing; respiratory activity can take place during a sign, during a pause, or during both. In speech, on the other hand, inhalation can of course take place only during the pauses and must be of a minimum duration. Despite the speaker's desire to articulate continuously, especially at fast rate, he is forced to breathe at regular intervals, hence the smaller range for pause length in speech (2.31:1). Consequently, as pause durations cannot be compressed beyond a certain point, a speaker will compensate for this by pausing less often—this results in the two differing slopes for speech. Were breathing not linked to speech in such a way, one would expect the functions for the number and the length of the pauses to be parallel to each other, as they are for sign.

The Duration of Signs

In order to examine the duration of signs at normal rate and across rates, a decision had to be taken as to which signs to include in the analysis. The passage contains 52 signs, some of which are repeated two or three times, e.g., BOWL, WOODS, LIKE, PERFECT. Before choosing a particular tactic, an examination of the effect of the repetition of a sign on its duration was made. Table IV presents the results obtained for

Table IV. Duration of Signs at Normal Rate (79 spm) as a Function of Repetition and Syntactic Location

Syntactic position	*N*	First occurrence	Second occurrence	Percent difference
Same	6	0.29	0.26	−10
Different	5	0.33	0.37	+12
	N	Within sentence	End of sentence	Percent Difference
	5	0.33	0.37	+12

signs at normal rate (79 spm). Signs which occur twice in the same syntactic position (e.g., THEN, DON'T, LIKE) are on the average 10% shorter on their second occurrence. This is not true, however, for signs whose repetitions occur in different syntactic positions (e.g., BOWL, WOODS). As the syntactic location of a sign appears to be of importance in accounting for duration, the signs which occur both at the end of a sentence and within a sentence (as defined empirically by Grosjean and Lane, 1977) were compared. It was found that signs at the end of a sentence are about 12% longer than within a sentence. Even though the number of signs under study here is very small (and no test of significance is therefore possible), both these results (the first occurrence of a sign is longer than the second when controlling for syntactic position, and signs at the end of a sentence are longer than within a sentence) have already been obtained for words in speech (Klatt, 1976; Umeda, 1975). For the analysis of sign duration, it was decided then to take the mean of all occurrences of a sign of a particular grammatical type. Thus the mean of the first and second occurrences of INTO (ENTER) was calculated but IN was kept as an individual type (in the passage it behaves like a preposition). This reduced the corpus to 39 signs.

Klatt (1976) lists a number of factors that influence the durational structure of units in speech: the psychological and physical state of the speaker, speaking rate, position of the element within a paragraph, emphasis and semantic novelty, phrase-structure lengthening, word-final lengthening, inherent phonological duration of a segment, effect of linguistic stress, effect of postvocalic consonant, and segmental interactions (e.g., consonant clusters). Most of these factors, restated in terms of a visual-manual language as necessary, probably also influence the duration of signs. There is some indication, as we have seen above, of lengthening in sign due to semantic novelty and to phrase structure. The present study examines two of these factors in detail: the inherent formational (analogous to phonological) duration of a sign and the effect of change of rate on sign duration.

Stokoe (1960), Bellugi *et al.* (1975), and Bottison (1978) have shown that signs may be described as a combination of handshapes, locations, movements, and orientations in addition to being one- or two-handed or compounds. These different characteristics interact with one another to make up a sign and seem to have different inherent lengths associated with them. As our corpus was small (39 signs), it was decided not to take into account the interaction of the different characteristics but to examine each separately, by pooling across the others. The premise was that one or two characteristics at the most would be of more importance than the others in accounting for the inherent duration of signs and that the interaction among characteristics would not play a very large role. The following characteristics were therefore studied one at a time: location, one- vs. two-handed articulation, handshape, and movement.

Duration of Signs at Normal Rate

The frequency distribution of the 39 sign durations at normal rate (79 spm) is presented in Fig. 4. The distribution is right-skewed, indicating that a small number of signs are much longer than the majority of the signs. The mean duration of the signs is 0.36 sec (median 0.33 sec) and the range is 0.5 sec [the shortest signs are IT (THAT) and THREE (0.18 sec) and the longest is LONG-TIME-AGO (0.68)]. How can one account for this 3.8:1 range in duration?

Figure 5 presents duration as a function of six location categories that were obtained from a multidimensional scaling solution of actual physical distance by Poizner and Lane (1978). The first two clusters (filled-in bars) separate the upper locations (full face, midface, forehead, chin, cheek, neck, upper and lower arm) from the other locations (neutral space, trunk, supine and prone wrist and hand), and, as can be seen in Fig. 5, the

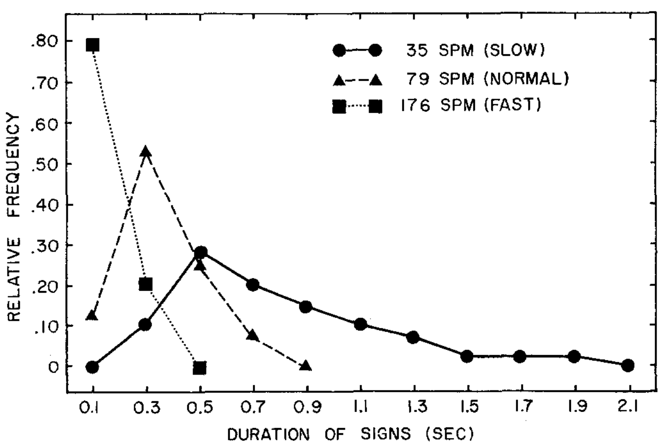

Fig. 4. Frequency distribution of the duration of 39 signs at three production rates (35, 79 and 176 spm). Each duration is based on the mean of four values, one by each of four subjects.

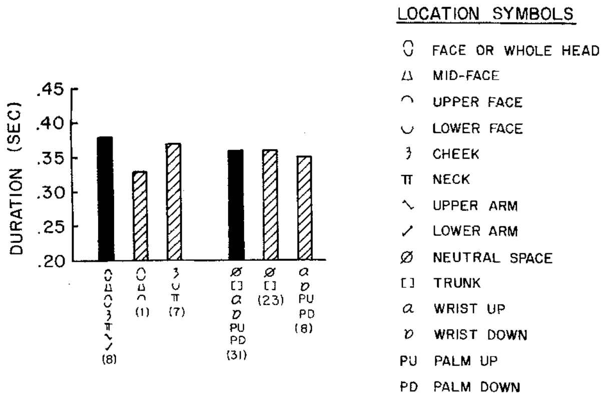

Fig. 5. Duration of signs at normal rate (79 spm) as a function of the physical location of the signs (Stokoe *et al.*, 1965; Poizner and Lane, 1978). Each of the two major categories (filled-in bars) is subdivided into two smaller categories (bars with diagonal lines). The number of values in each category is put in parentheses on the abscissa.

difference in mean duration of the two categories is neglible (0.38 and 0.36 sec). Each category was then divided into two smaller categories (bars with oblique lines); for example, the lower locations category was separated into the neutral space and trunk primes and the hand and wrist primes. Again no significant difference in duration was found between the categories. It appears therefore that location is not an important factor in accounting for the duration of signs.

The classification of signs proposed by Battison (1978) was used to examine the effect of one-handed and two-handed signs on duration. One-handed signs may be divided up into signs with no contact (∅), e.g., SMALL, and contact signs (X), e.g., HUNGRY. Two-handed signs are separated into symmetrical signs with two hands active (1), e.g., COLD, HOUSE; signs with identical handshapes but only one hand active (2), e.g., SIT, HARD; asymmetrical signs with one hand active (3), e.g., IN, ALL-GONE; and compound signs which combine two or more signs from the above types (C), e.g., SMALLEST. Figure 6 presents the results obtained using this system; two-handed signs are not significantly longer than one-handed signs (filled-in bars: 0.34 and 0.37 sec), and, inside each of these categories, no subgroup is significantly different. The slightly lower value of the nonsymmetrical sign category (0.27 sec) is probably due to the small number of elements it contains (three signs) and not to the

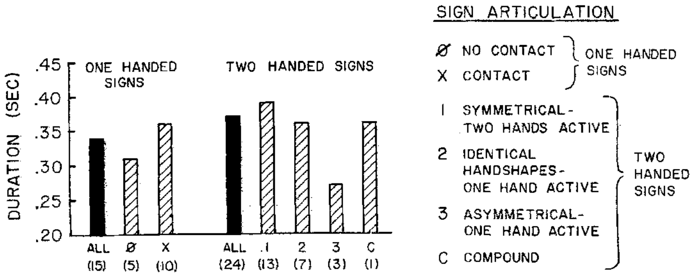

Fig. 6. Duration of signs at normal rate (79 spm) as a funcion of number of hands used in the signs and symmetricity (Battison, 1978). Each of the two major categories (filled-in bars) has been subdivided into smaller categories (bars with diagonal lines).

fact that nonsymmetrical signs are inherently shorter. We can conclude therefore that the number of hands used in a sign and whether a sign is symmetrical or not do not seem to determine its inherent length.

Does the handshape of a sign determine its length? To study the role of this factor on sign duration, it was decided to examine only the shape of the active hand(s); this was justified by the fact that 35 out of 39 signs in the corpus were either one-handed signs (one hand active, one passive) or two-handed symmetrical signs (both hands symmetrically active). The distinctive feature model of handshape proposed by Lane *et al.*, (1976) was used to classify the 20 significant handshapes into the following categories: the first division was between [+compact] handshapes (in Stokoe notation: O, C, X, bO, E, A) and [−compact] handshapes (5, B, 8, F, W, Y, I, V, R, H, L, G, 3, K); [+compact] handshapes were then divided into [+concave] handshapes (O, C) and [−concave] handshapes (X, bO, E, A), and [−compact] handshapes were separated into [+broad] handshapes (5, B, 8, F, W) and [−broad] handshapes (Y, I, V, R, H, L, G, 3, K), and each of these categories was divided one last time: [+broad] handshapes were either [+full] (5, B) or [−full] (8, F, W), and [−broad] handshapes were either [+dual] (V, R, H) or [−dual] (L, G, 3, K). Figure 7 presents the results obtained for each of these categories. No significant difference was found between [+compact] and [−compact] handshapes (filled-in bars) or between [+concave] and [−concave] handshapes (bars with oblique lines). Handshapes in the [+broad] category were on the average 0.08 sec longer than those in the [−broad] category, and, when the former category was further examined, it was found that [+full] handshapes (5 and B) were significantly longer than [−full] handshapes (8, F, W) (difference of 0.15 sec, $t = 1.83$, $p < 0.05$). Five of the signs

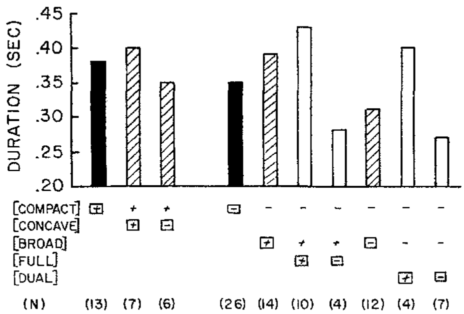

Fig. 7. Duration of signs at normal rate (79 spm) as a function of the handshape in the signs based on the distinctive feature model proposed by Lane *et al.*, (1976). Signs with the [+compact] handshape (first filled-in bar) have been subdivided into the [±concave] categories (bars with diagonal lines), and signs with the [−compact] handshape (second filled-in bar) have been separated into the [±broad] categories (bars with diagonal lines). Each of these two categories has then been subdivided into [±full] handshapes and [±dual] handshapes (empty bars).

sharing the [+full] handshape were among the ten longest signs of the corpus, and, of these, four belonged to the three longest movement categories. It would seem therefore that an interaction between handshape and movement exists in the corpus; the B or 5 handshape accompanies three long movements: the circular, twisting, and to-and-fro movements. Could it be that handshape and movement primes interact in some way in the language, with certain handshapes accompanying specific movements, as is the case here? A survey of the movements that are listed with the 5 and B handshapes in Stokoe *et al.*, (1965) does not confirm this, and we can therefore conclude that the interaction observed in the study is adventitious.

As for the 0.13-sec difference between [+dual] and [−dual] handshapes, it is mainly due to one sign (CHAIRS) in the former category, which has a repeated movement. Handshape cannot therefore account for the 0.50-sec range in sign durations found in the corpus, and those handshapes that are linked to longer signs (e.g., [+ full] handshapes) are not in fact directly responsible for the observed durations.

The last factor to be studied was movement. To do this, we used the movements listed by Stokoe *et al.*, (1965) and examined each separately, although most signs are characterized by more than one movement (33% of the signs in the corpus were transcribed with one movement, 44% with two, 21% with three movements, and 2% with four). Again the premise was that certain movements would be much more influential than others in accounting for the duration of a sign. Thus each sign was entered into as many categories as it had movements (this increased the number of items from 39 to 75). Figure 8 presents the mean duration of the signs in each movement category. A rapid glance at Fig. 8 reveals that the movement characteristic is the most important variable in accounting for the inherent duration of signs: the range of the bars is 0.33 sec whereas it nevers exceeds 0.15 sec for the other three characteristics (and this latter range, which separated the signs characterized by [± full] handshapes, was in fact accounted for by the movement parameter). Even though the number of signs in the different categories is at times quite small, the rank-ordering of the movements is logical: signs that have a movement involving both the arm(s) and hand(s) [e.g., a circular movement (LONG-TIME-AGO), a twisting movement (WOODS), or a to-and-fro movement (WALK)] take much more time to make (from 0.50 to 0.60 sec) than signs in which only the hand moves [e.g., a closing movement (SOFT) or a pronating rotation (BOWL)] (these signs last from 0.27 to 0.31 sec). In addition, those signs with movements that have opposites (e.g., upward-downward; convergent-divergent; rightward-leftward) take about the

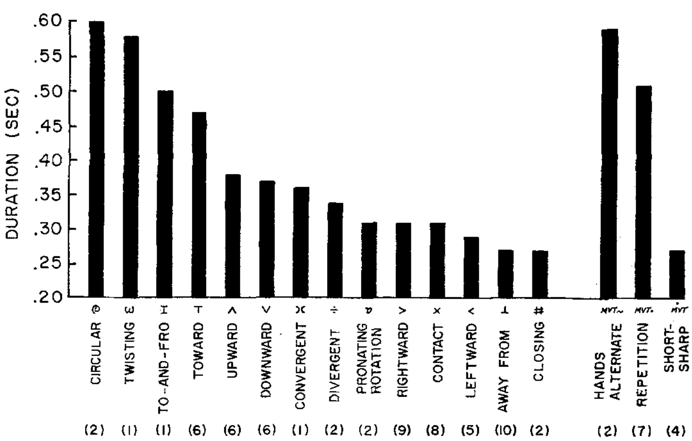

Fig. 8. Duration of signs at normal rate (79 spm) as a function of the movement in the sign (Stokoe *et al.*, 1965). Each sign has been entered into as many categories as it has movement symbols in its dictionary notation.

same amount of time as the signs that contain the opposite movement. The only exception to this is for signs containing a "toward signer" movement; these are 0.20-sec longer than signs having the opposite movement ("away from signer"). The difference may be due to the fact that a greater distance can be covered physically toward the signer than away from him (if neutral space is taken as an example of a frequent location, the distance from neutral space toward a part of the body is about 12–18 inches, but from neutral space forward, away from the body, it is only about 6 inches). When special movement characteristics are examined (right side of Fig. 8), again the results obtained show a pattern. Signs in which hands alternate (e.g., WALK, LONG-TIME-AGO) or in which a repetition of the movement occurs (e.g., CHAIRS, COLD) will naturally last longer than signs in which a short-sharp movement is used (e.g., HARD, HOT, HAPPEN).

We can conclude therefore that the inherent duration of a sign can best be accounted for by the movement characteristic but that some interaction of characteristics may also play a role in this determination. Inherent duration of a sign can now be added to the other domains in which movement plays an important role: modification of adjectives; form class marking (e.g., distinguishing between nouns and verbs); aspectual modulation on verbs; time signs (e.g., numbers); stress; "shouting and whispering" in sign (Battison, 1978; Klima and Bellugi, 1978; Friedman, 1974; Frishberg and Gough, 1973; Supalla, 1976).

Duration of Signs Across Rates

Figure 4 also presents the frequency distribution of sign durations at the signer' two extreme rates (35 spm and 176 spm). As can be seen, the right skew that characterized the distribution at normal rate is maintained across all rates. The mean duration of signs at the highest rate is 0.16 sec (median 0.14 sec) and the range goes from 0.07 sec (REALLY) to 0.33 sec (CHAIRS); the mean duration at the slowest rate is 0.79 sec (median 0.62 sec), with the values ranging from 0.28 sec (HARD) to 1.90 sec (LONG-TIME-AGO).

The correlation between the duration of the signs at normal rate and at fast rate (176 spm) is 0.81, and between those at normal rate and at slow rate (35 spm) the correlation is 0.85. This means that the duration of a sign at a rate faster than or slower than normal can be predicted quite accurately from its duration at normal rate. Thus the role of the parameters in accounting for sign duration across rates will be the same as it is at normal rate—a long sign at fast rate will again have a twisting, rotating, or to-and-fro movement whereas a short sign at the same rate will again be one with a short-sharp movement. It would be of interest, nevertheless, in a subsequent study, to examine those points which fall some distance away from the regression line (e.g., WALK is only the seventh longest sign at normal rate but the third longest at slow rate and THREE is the second shortest sign at normal rate but the seventh shortest at the fast rate).

Respiratory Activity in Sign and Speech

Figure 9 presents the number of respirations per minute as a function of percentage increases in signs or words per minute. Both subjects have about the same number of respirations during quiet breathing (15 and 16.3 respirations per minute). As production rate increases, the number of respirations increases for both the signer and the speaker. The function for the signer increases regularly and reaches 23.3 respirations per minute at the fastest rate, but the speaker's respiration pattern is much more complex. It is identical to that for the signer at normal or below normal

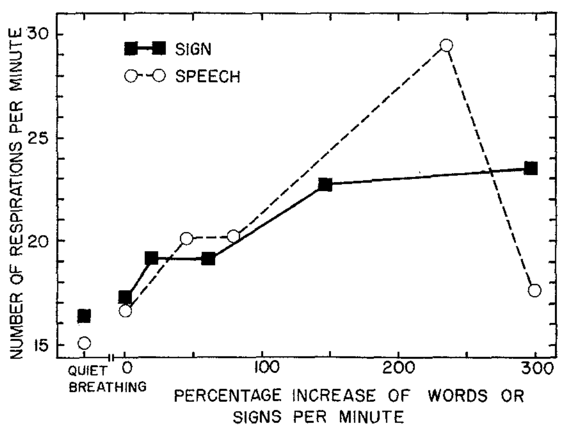

Fig. 9. Number of respirations per minute during quiet breathing and as a function of percentage increase of words or signs per minute for one hearing speaker and one congenitally deaf signer. Each point (filled for sign, unfilled for speech) is based on one value.

rate of speech but increases considerably for speaking rates above normal. It reaches a peak of 30 respirations per minute at a 235% increase in rate and then falls steeply to its level at baseline rate. Grosjean and Collins (1979) found the same steep drop at the highest rate for three other hearing subjects. The significant difference in the two functions is due to the fact that the signer is breathing regularly and independently of his signing; his respiratory cycles are very regular at all rates (the coefficient of variation of the duration of respiratory cycles during quiet breathing is 17.47% and the mean coefficient of variation across rates is 18.45%). The increase in his physical activity from slow to fast signing is naturally accompanied by an increase in the number of respirations per minute. For the speaker, on the other hand, breathing and speaking are very strongly interrelated. At slow rates, the speaker has many opportunities to breathe since the number of pauses he puts into his speech is numerous. As he increases his rate, he starts breathing more often since a fast articulation rate uses up the air reserve much more quickly. Under these conditions, the speaker may breathe as many as 30 times a minute, twice as often as during quiet breathing, although this need for air forces him to pause and thereby to diminish his global speaking rate. At the highest rate of speech, a sudden change of strategy occurs (especially when the passage to be read is not too long, as in this study): so as not to stop too frequently while articulating at fast rate (the breathing pattern predicts 45 respirations a minute at a 500% increase in rate, hence a stop every 1.33 sec), the speaker will choose to underventilate by breathing much less often; thus he uses up his air reserve completely by the time he reaches the end of the passage.

Figure 10 presents the percentage of the respiratory cycle spent inhaling as a function of increase in rate; it further illustrates the difference of the breathing patterns in sign and speech. Both the signer and speaker spend about the same amount of time inhaling during quiet breathing (36% and 42.5% of the total breathing time; this confirms the report by Miller, 1951, that between 40% and 45% of the respiratory cycle during quiet breathing is spent inhaling). The signer continues with exactly the same inhalation pattern across the five production rates, but the speaker, once again, changes tactics. During speech he spends about 15% of the breathing cycle actually inhaling (the remaining time is spent speaking), and, as he increases his rate, this percentage will decrease so that, at his highest rate, only 6% of the total cycle will be spent inhaling.

This difference in inhalation patterns is further illustrated in Fig. 11, where we present the first sentence of the "Goldilocks" passage pro-

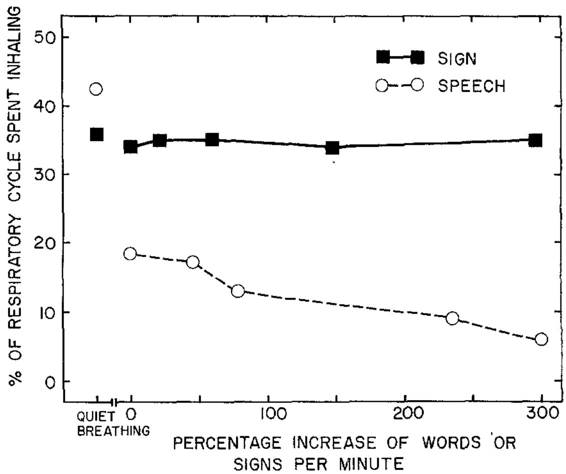

Fig. 10. Percentage of respiratory cycle spent inhaling during quiet breathing as a function of percentage increase of words or signs per minute for one hearing speaker and one congenitally deaf signer. Each point (filled for sign, unfilled for speech) is based on one value.

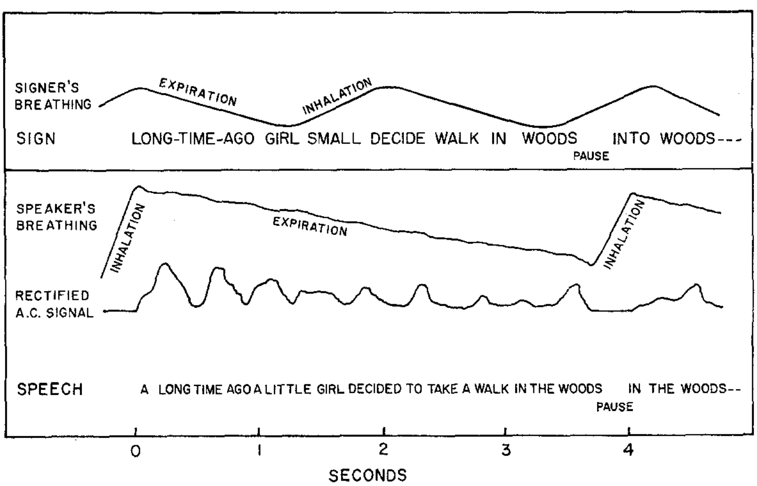

Fig. 11. Breathing patterns in signing and speaking at normal rate. The AC signal for speech has been full-wave rectified and filtered.

duced at normal rate in both English and Sign and the accompanying breathing patterns of the signer and speaker. The signer's respiratory cycle is very regular throughout the sentence whereas the speaker inhales rapidly at the beginning of the sentence, adjusts his expiration to serve the needs of speech production, and inhales again rapidly during the pause at the end of the sentence.

Thus the respiratory cycle during signing remains regular and contracts only slightly as rate is increased, whereas in speech the breathing pattern is totally reorganized to accommodate the needs of the speaker. It should be noted finally that 19% of the inhalations in sign take place during pauses (as compared to 100% in speech; inhalation in speech can of course occur only during pauses) and the remaining inhalations take place randomly within signs and during transitions.

CONCLUDING REMARKS

This investigation of timing in a manual and a spoken language has shown that signers and speakers cover identical ranges of rate when asked to speed up or slow down and that they do so by modifying both the articulation time and the pause time in their productions. The relative importance of these two variables will differ, however, in the two modalities; as signing is an activity that is independent of breathing ("quiet-breathing" respiratory patterns are observed across signing rates), signers will alter their rate by mainly changing the time they spend articulating, whereas speakers, especially at slow rate, are compelled by breathing demands to put numerous pauses into their speech and must therefore use this approach to alter their rate. When signers increase or decrease their pause time, however little they do so, they alter the number and length of the pauses equally, whereas speakers primarily alter the number of pauses and leave their pause durations relatively constant; this again is due to the interaction that exists between breathing and speech: inhalation takes place only during the pauses and must be of a minimum duration.

The two modalities have in common a number of factors that influence the durational structure of the languages: speaking rate, semantic novelty, and phrase-structure lengthening will influence the duration both of signs and of words. As for the inherent durations of segments, it can best be accounted for in sign by the movement parameter, whereas handshape, location, and number of hands in a sign are of little importance.

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