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EFFECTS OF STRESS ON JAW MOVEMENTS IN AMERICAN ENGLISH

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Word accent in Japanese is called pitch accent and its principal acoustis correlate is the pitch pattern. Compared to this, word accent in (American) English is called stress accent. It is well known that stress is manifested in multiple acoustic dimensions such as pitch, intensity, duration and vowel quality. It has been suggested that the multiple acoustic effects of stress can be ascribed to a single factor, "extra physiological effort", in the production of the stressed syllable. As far as the supraglottal system is concerned, the more forceful articulations will result in faster movements of the articulatory organs and the more complete target attainments. However, it seems that there is no apparent reason that the more forceful movement necessarily has the longer duration. The force and duration of the movements may act as two independent mechanisms in the production of stress.

In the present study, the effects of stress on articulatory movements were observed using an x-ray microbeam method and the changes in the velocity and the duration of articulatory movements associated with stress contrasts were examined.

Experimental Procedure

Effects of stress contrasts on articulatory movements were observed for three types of speech material.

1) Emphatic stress

Má tots it. - Ma tóts it.	Má tats it. - Ma táts it.
Bée tots it. - Bee tóts it.	Bée tats it. - Bee táts it.
Bée hots it. - Bee hóts it.	Bée hats it. - Bee háts it.

2) Lexical stress

cóntact - contáct, ímpact - impáct, cómpact - compáct,
cóntest - contést, súspect - suspéct, ínsult - insúlt

3) Primary/secondary stress

cómplement - còmpleméntary, cóntinent - còntinéntal,
témpt - tèmptátion

In the above utterances, articulatory movements for the underlined vowels under different stress patterns were compared.

The first type of speech material pertains to emphatic stress in the sentence. These six simple sentences were uttered with emphatic stress either on the subject or on the verb of the sentence. Articulatory movements for the verbs /tots/, /tats/, /hots/, and /hats/ under two different

stress conditions were compared. The second type of speech material consisted of words which exhibited noun-verb oppositions under different stress assignments. In the first four words, underlined vowels are considered to remain unchanged in vowel color despite the stress alternations. In the last two words, the underlined vowel is /ʌ/ in vowel color when stressed, while it becomes /ə/ when unstressed. In the third type of speech material, the underlined vowels in each pair of words receive either primary or secondary stress.

Articulatory movements were observed by means of the x-ray microbeam method. As shown in Figure 1, three pellets were attached to the surface of the tongue and one pellet each was attached to the lower lip and to the lower incisor. The movements of the five pellets were recorded at a rate of 130 frames per second. For each speech sample, two or three tokens of the utterance were recorded, The subject was a native speaker of American English who was born and raised in the city of New York.

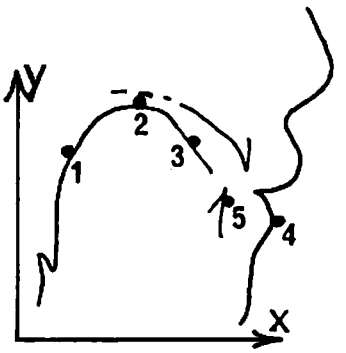


Fig. 1: Schematic illustration of the pellet positions on the tongue, lip and lower incisor.

Result

Figure 2 shows an example of the pellet data comparing the positions of pellet #2 and pellet #5 in the stressed and unstressed syllables. In this figure, pellet positions during the production of the verb /tats/ in the utterance 'Ma tats it' are shown for five individual utterances, where the two stressed pairs are indicated by filled circles and the three unstressed pairs are indicated by unfilled circles. For each individual utterance, pellet positions at the three selected time moments (the midportions of the syllable initial /t/, syllable medial vowel /æ/ and syllable final /ts/) are displayed with connecting lines between them. It can be seen in Figure 1 that there is a consistent difference in the position of the jaw pellet between the stressed and unstressed vowels in that the jaw position for the stressed vowel is about 2mm lower than that for the unstressed vowel. As for pellet #2 on the tongue, the difference between the stressed and unstressed vowels is not significant. For the utterances examined here, it was generally observed that the differences between the stressed and unstressed vowels were more apparent in the jaw movements than in the tongue movements. Therefore, in the following, effects of stress on jaw movement were analyzed in more detail.

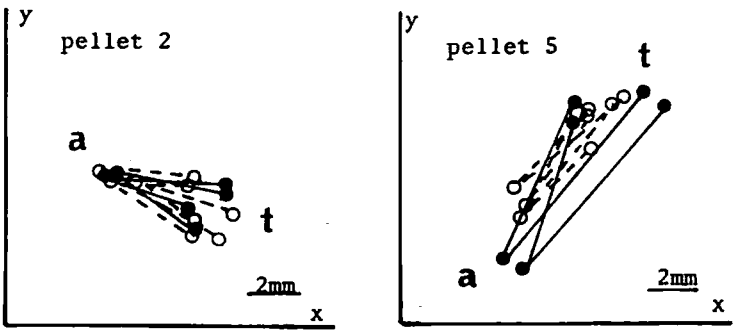
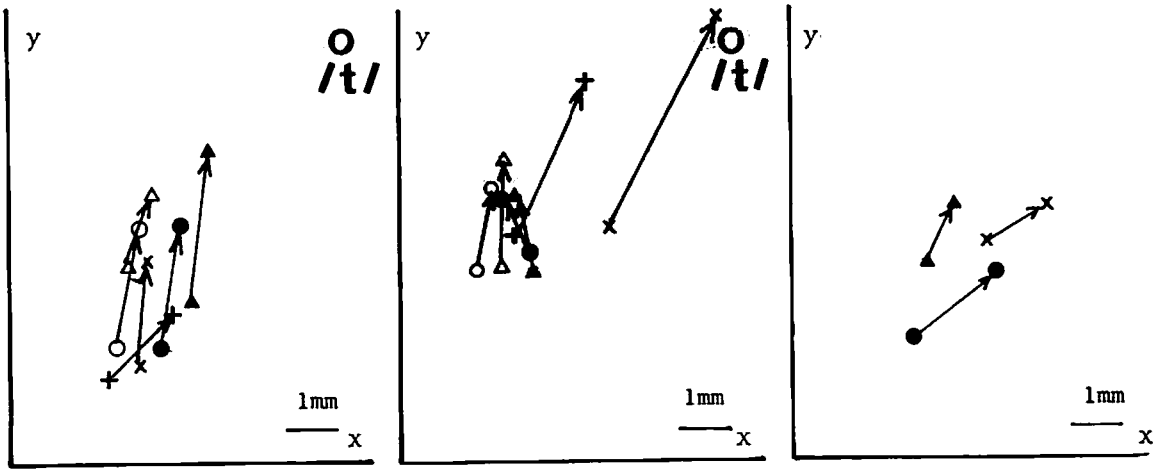


Fig. 2: Pellet movements for /tats/ in the utterance 'Ma tats it'. Pellet positions for word initial /t/, word medial vowel /æ/ and word final /ts/ in five utterances are shown. • with emphatic stress, o without emphatic stress.

Jaw position

Figure 3 shows the position of the jaw pellet at the moment of maximum jaw opening for the vowel. Each data point represents the average pellet position of several tokens for each utterance. A pair of data points for the stressed vowel and the corresponding unstressed vowel are connected by an arrow, the root of which represents the pellet position for the stressed vowel. A solid circle in the upper right corner in each figure indicates the mean position of the jaw pellet for /t/.

Figure 3(a) shows the effects of the emphatic stress. It can be seen that for all the utterances of the first type, the jaw opening for the stressed vowel was greater than that for the corresponding unstressed vowel. For the stressed vowel, lowering of the jaw with reference to the jaw position for /t/ had an average of about 6 mm, whereas for the unstressed vowel it was 4 mm. Reduction in the degree of jaw opening for the unstressed vowel can also be observed for the second type of the speech samples, which exhibit noun-verb oppositions under stress alternation (Figure 3 (b)). In the case of the utterances /insult/ and /suspect/, the variation in jaw position over different stress assignment is especially large, reflecting /ʌ/ to /ə/ vowel reduction in these utterances associated with the stress contrast. Even for the other four utterances, it can also be observed that the jaw position for the stressed vowel is lower than for the unstressed vowel. The difference in the jaw position is approximately 1.5 mm and a little smaller than in the case of the emphatic stress. The change from primary stress to secondary stress is also accompanied by reduction in the degree of jaw opening, as can be seen in Figure 3 (c).



(a) (b) (c)

Fig. 3: Position of the jaw pellet at the maximum opening of the jaw for the vowel in the stressed syllable (root of the arrow) and in the unstressed syllable (head of the arrow).
(a) Emphatic stress. • Ma tats it. ▲ Ma tots it. ○ Bee tats it. △ Bee tots it. + Bee hats it. × Bee hots it.
(b) Lexical stress. • impact ▲ compact ○ contact △ contest + insult × suspect
(c) Primary/secondary stress. × tempt/temptation ▲ continent/continental • complement/complementary

Velocity of Jaw Movement

Figure 4 compares the velocity of the jaw movement for the production of the stressed and unstressed syllables. In each figure, the abscissa indicates the velocity for the unstressed syllable and the ordinate indicates the velocity for the stressed syllable. The velocity was calculated by approximating the pellet movement over seven frames (50 msec) by linear function of time; and the peak value of the velocity during the period of jaw opening from the preceding consonant to the vowel or during the period of jaw closing from the vowel to the following consonant was obtained.

Jaw velocities for the first type of speech material are shown in Figure 4 (a). The magnitude of velocity shows considerable variation over different utterances, ranging from approximately 4 cm/sec to 11 cm/sec. However, all the data points lie above the dashed line in the figure, which is

drawn to indicate an equal velocity condition for the stressed and unstressed syllables. Thus, the velocity for the stressed syllable is always greater than that for the unstressed syllable both for the opening and the closing movements of the jaw. The difference is on the average about 2.5 cm. The tendency for the jaw velocity to be higher for the stressed syllable than for the unstressed syllable can also be observed for the second type of speech material (Figure 4 (b)). However, for these utterances, there are several cases in which the velocities for the stressed and unstressed syllable are nearly the same, and the difference between the stressed syllable and the unstressed is not as consistent as in the case of the emphatic stress.

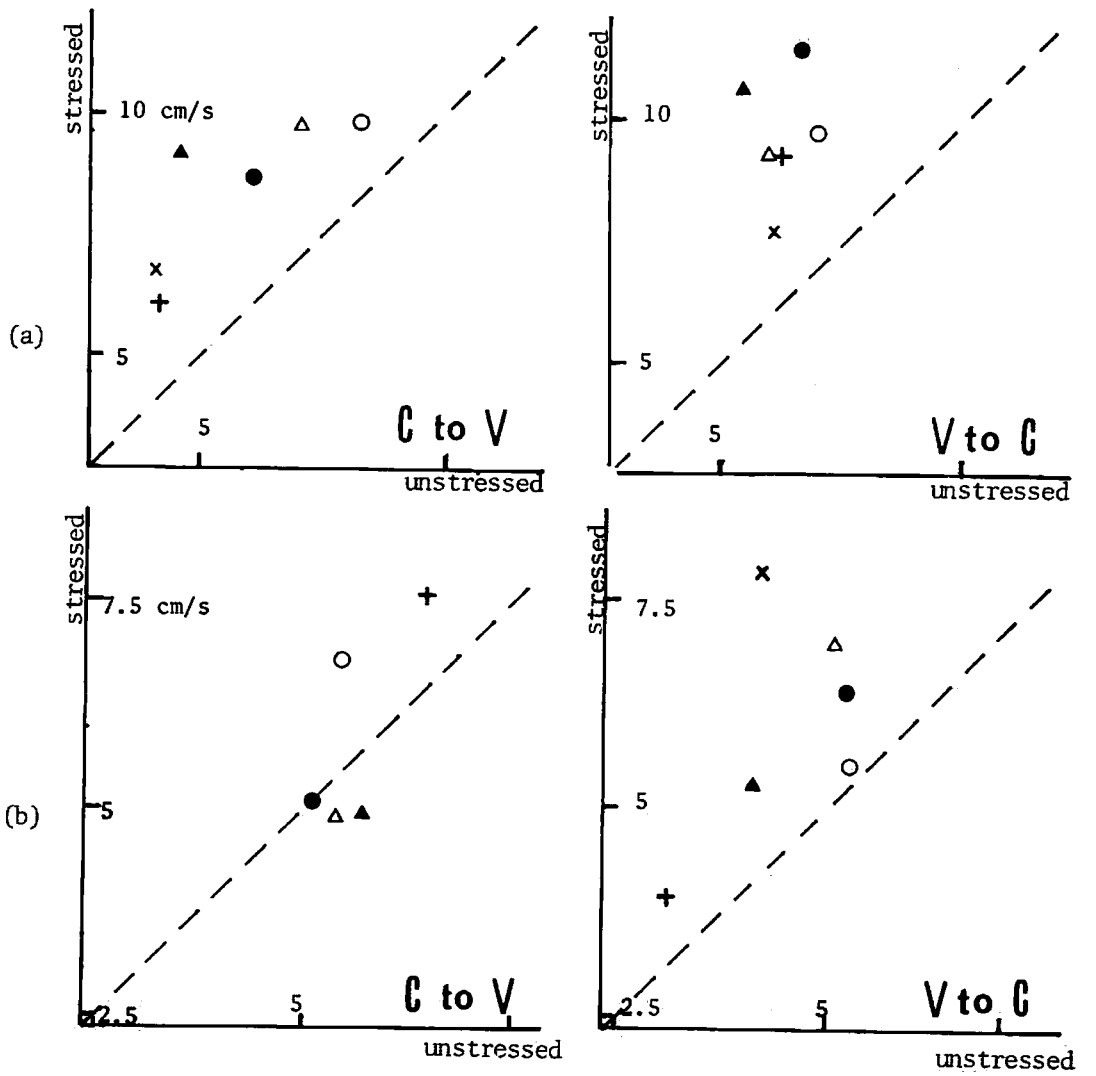


Fig. 4: Comparison of the velocity of the jaw movement in the stressed syllable (ordinate) and the unstressed syllable (abscissa). (a) Emphatic stress. (b) Lexical stress. The symbol for each utterance is the same as Figure 3.

Vowel duration

Figure 5 compares the durations of the vowels in the stressed and unstressed syllables. The abscissa indicates the duration of the unstressed vowel and the ordinate incicates the duration of the stressed vowel. (The vowel duration shown here is the time interval between the explosion of the preceding consonant and the implosion or the onset of the frication of the following consonant.) It can be seen that in the case of the emphatic stress shown in Figure 5 (a), there is no systematic difference between the duration of the stressed and unstressed vowels. On the other hand, in the case of the verb-noun oppositions in Figure 5 (b), the duration of the stressed vowel tends to be longer than that of the unstressed vowel. It appears that for this subject, there is a difference in the effect of stress on the vowel duration between the two types of speech material.

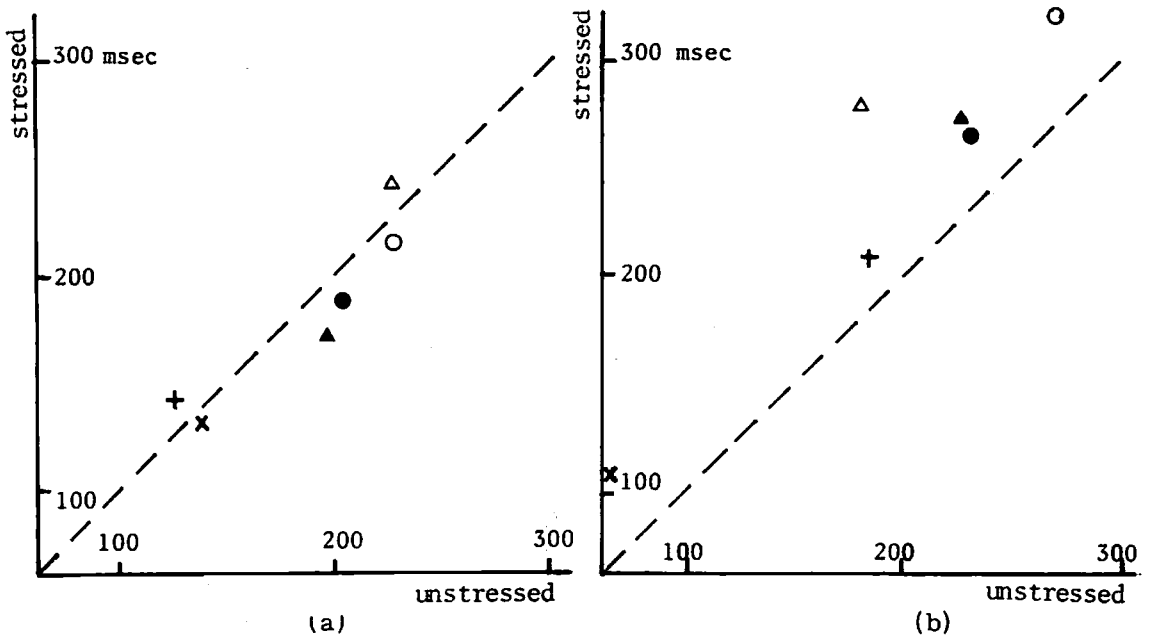


Fig. 5: Comparison of the vowel duration in the unstressed syllable (abscissa) and the stressed syllable (ordinate). (a) Emphatic stress. (b) Lexical stress. The symbol for each utterance is the same as in Figure 3.

Summary and comment

For the utterances studied in the present experiment, it was found that the jaw opening for the stressed vowel was greater than that for the unstressed vowel. This was true both for the emphatic stress in the sentence and for the lexical stress associated with the verb-noun opposition of the word. Corresponding to this, the velocity of the jaw movement for the stressed syllable tended to be greater than for the unstressed syllable Thus, it appears that the more complete target attainment for the vowel in the stressed syllable cannot be ascribed solely to the longer duration of the vowel, as has been suggested by Lindblom

As for the effect of stress on the vowel duration, the present subject showed different tendencies in the stress contrast for the verb-noun opposition and the emphatic stress in the sentence. For the lexical stress, the stressed vowel generally had longer duration than the unstressed vowel, while for the emphatic stress, there was no systematic difference between the stressed and unstressed vowel. Thus, the faster movement, which is considered to mean more forceful articulation, is not always accompanied by the longer duration of the pertinent vowel. It appears that the control of the duration and the force of the articulation are mechanisms independent of each other.

It may be considered that for producing the prominence of the stressed syllable, the speaker can utilize both of the mechanisms, and the two mechanisms may be exploited to different degrees depending on various environmental conditions. In the case of the emphatic stress, it may be that the present subject tried to keep the rhythmic pattern of the sentence unchanged, thus avoiding duration control in the production of stress. On the other hand, in the case of the verb-noun opposition, the elongation of the stressed syllable is generally compensated for by the shortening of other syllables within the same word, and in this situation, the present subject apeears to utilize the duration control mechanism more freely.

Naturally, the way of choosing control mechanisms for producing the prominence of the stressed syllable may vary from speaker to speaker and further data collection on different subjects is essential for this kind of discussion.

Acknowledgement

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