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Abstract--The main thrust of this investigation is to examine timing of gemination in Tarifit Berber (spoken in Northern Morocco) in order to find out if spatiotemporal phonetic characteristics underlying the production of Tarifit geminates may be captured from a phonological standpoint by a structural representation of these segments as two consecutive timing units associated with one simultaneous segmental slot. The investigation is based on acoustic data for six native speakers and on X-ray data for two native speakers. It presents results of singleton and geminate voiced and voiceless consonants, produced in word-initial, word-medial, and word-final positions, at a normal and at a fast speaking rate. Speech rate is varied in order to evaluate the robustness of the phonological contrast. Special attention is paid to the timing of tongue gestures in producing this phonological contrast.

Key-words: gemination, tarifit berber, acoustic study, articulatory study, X-ray data.

I. THE PROBLEM

On the *acoustic* level, several studies (see e.g. [1] and [5]) have been conducted in different languages with singleton / geminate distinction in order to identify acoustic cues which may underlie this phonological distinction. Hence a set of parameters have been examined such as the duration of the adjacent vowels, duration of occlusion, duration of VOT, the duration of fricatives, the amplitude of the burst and the fundamental frequency of the following vowel. These authors identified several cues that distinguish singletons from geminates. Most of these studies found that the duration of the consonantal closure was the principal cue in distinguishing the two main categories.

On the *articulatory* level, several works (see e.g. [9], [6], [4] and [2]) have been conducted on different languages with the singleton / geminate distinction so as to determine the articulatory cues responsible for this contrast. Different methods have been used to observe the phenomenon of gemination on both glottal and supraglottal levels.

Within the perturbation paradigm, some studies have examined singleton and geminate consonants on the acoustic and articulatory level, varying speech rate (see [3], [7] and [9]). The objective was mainly to determine the impact of speech rate on these consonants: the compressibility, incompressibility of some categories and the robustness of geminates with increased speaking rate.

In this study, we present results of an investigation on the acoustic and articulatory correlates that may purportedly distinguish singleton stops and fricatives from their geminate counterparts in three positions: word-initial, word-medial, and word-final. Our aim is also to determine whether position in the word shapes variability in singleton/geminate contrast. In addition, we varied speech rate in order to find out whether the geminate contrast is resistant to increased speaking rate.

II. HYPOTHESES

It is *hypothesised* on the *acoustic level* that: (1) geminates would have longer closure durations than singletons as reported in the literature. (2) The duration of flanking vowels may be affected by that of geminate consonants: they would be shorter in this environment in case of syllable isochrony. (3) Acoustic silence for voiceless stops and (4) consonantal occlusion for voiced stops, two intrasegmental consonant intervals, should underlie this phonological contrast as a gauge of potentially reinforcing the main cue of consonantal closure. (5) VOT could be longer for geminates, as their occlusion phase is usually remarkably long, thus retarding onset of voicing, due to high intra-oral pressure. (6) It is likely that VTT (Voice Termination Times) would be longer for singletons than for geminates. Indeed, the shorter the consonantal closure, the higher the proportion of voicing decay within this consonantal closure would be. (7) The speech signal is intrinsically elastic; all segments are expected to undergo compression with increasing speaking rate. This compression of the speech signal should, however, not prevent preservation of phonological contrasts.

On the *articulatory level*, (8) contact-extent for plosives and length of maximum constriction for fricatives, partly underlying consonantal closure, respectively for these two categories, would be correlatively longer for geminates. (9) The differences of duration between singleton and geminate consonants observed acoustically should also be visible primarily in the temporal control of articulatory parameters. (10) These durational differences could be accompanied by differences in critical articulator displacements, hence in the spatial dimension. (11) Spatiotemporal differences between the two speakers could be observed in this investigation, if one takes into account factors usually related to specific-speaker differences. (12) We shall examine the phenomena of anticipation. Assuming potentially longer gestures for geminates, it would be necessary to anticipate critical parameters underlying them earlier. As a corollary, it is likely that the onset of post-consonantal vocalic gesture would be: (a) delayed in the context of geminates, the time to properly obtain a sufficiently long contact or constriction and (b) anticipated in the context of singletons, where contact would require relatively less time. (13) At the *glottal* level, the difference between singletons and geminates would be the same as that between the production of implosive and ejective consonants. The set larynx-hyoid bone position should be higher for geminates, as for ejectives, due to the rate of intraoral pressure which is usually higher for geminates.

III. METHOD

The entire *corpus* (voiced and voiceless plosives for apicals /t, d/, for velars /k, g/, for the uvular /q/, and voiced and voiceless fricatives for alveolars /s, z/, for postalveolars /ʃ, ʒ/) consisted of 54 sentences of 4 to 6 syllables, comprising 27 minimal pairs that were inserted in meaningful carrier sentences, pronounced 10 times by six native speakers of Tarifit, at normal and fast speaking rates.

All X-ray data were extracted from the Phonetics Institute of Strasbourg database [8]. In this X-ray experiment (25 frames /sec), these minimal pairs were produced once at a normal (self-selected) speaking rate by two speakers.

The *X-articulator* software, developed at LORIA in Nancy within the DOCVACIM project [8], includes various tools devoted to processing cine-radiographic data. These tools comprise semi-automatic algorithms to monitor speech articulators, a graphic interface which allows editing the contours, and also tools devoted to data analyses and elaboration of articulatory models.

Temporal events were detected on the *audio* signal, and specific intersegmental and intrasegmental timing relations between these events allowed determining acoustic durations (ms) which correspond respectively to articulatory opening and closing gestures, and also to timing between supraglottal and glottal gestures. Thus, for intersegmental timing relations, vowel durations were specified as intervals between onset and offset of a clear formant structure, for V1 and V2. Corollary, consonantal closure duration was measured, between vowels, from offset to onset of clear vocalic formant structures. As concerns intrasegmental timing relations, VTT (Voice Termination Time, measured from vowel offset to the last voicing pulse within the voiceless plosive), plosive occlusion (i.e. closure duration excluding VOT for voiced plosives), the acoustic silent phase (for voiceless plosives) and VOT (the interval between the burst-release of the plosive and onset of a clear formant structure of the subsequent vowel) were also acquired. Hence these intrasegmental durations, which only concerned plosives, were embedded within the consonantal closure duration of the plosive.

IV. RESULTS

All acoustic measurements, extracted automatically using the software PRAAT, were analysed using the GraphPad Prism® software.

The first question regarding the distribution of singleton and geminate consonants was to find out if both length categories behaved in a similar way with variation of speech rate. To do so, a pair-by-pair comparison (T-test) was conducted between singleton and geminate pairs, at each speech rate, and between singletons and geminates in the two speech rate conditions. The variance is given with the *f* and *df* factors, as well as the significance of the difference of compared data with the *p* value.

We also analysed interactions between gemination and speech rate. Thus a two-factor ANOVA was conducted by considering the average of 10 repetitions of each speaker as an unpaired repetition and as two analysed factors: gemination and speech rate. For the ANOVA analyses, we give the variance data with the *F* ratio, corresponding to variability between subjects, and the *p* value.

In addition to the two-factor ANOVA analyses, we also carried out a T-test between the duration of the singletons in normal speech and the geminates in fast speech.

Only results with a probability of less than five percent ($p < 0.05$) were considered significant and reported *infra* (statistical details are provides *in* [2]).

The *acoustic data* reveal that consonantal closure and the occlusion/silent phase of geminates, in *absolute* values, are significantly longer than corresponding singletons, for all consonants, and in both the voiced and voiceless contexts, for all six subjects, in the two speech rate conditions (see Figure 1). Thus, apart from consonantal closures, acoustic silence for voiceless stops and consonantal occlusion for voiced stops, two intrasegmental consonant intervals, do underlie this phonological contrast of gemination. These findings are in line with hypotheses 1, 3 and 4 respectively. These durational differences between geminates and singletons are maintained in fast speech (Figure 1, on the right), thus confirming hypothesis 7 in absolute terms. However, if all consonantal closures undergo compression, compression is more pronounced in geminates than in singletons. Indeed, segmental elasticity is usually more prominent in longer phonological entities [3], [9]. It was noticed that consonantal gemination did not affect the duration of adjacent vowels V1 and V2, contrary to our expectations (hypothesis 2). Likewise for intrasegmental VOT and VTT values, which are also similar for both categories (Figure 2), thus in contradiction with hypotheses 5 and 6, respectively.

The *acoustic data* further show that consonantal closure and the occlusion/silent phase of geminates, in *relative* values, take up a higher proportion of the CV domain ($p<0.0001$), compared with their singleton counterparts (Figure 3), thus underpinning the robustness of the phonological distinction, regardless of compression induced by increased speaking rate. Proportions remain relatively stable in fast speech, as they are comparable in this speaking condition for geminates and for singletons (hypothesis 7 is verified in relative terms). Therefore, relative stability seems to be the major timing manoeuver deployed in preserving phonological distinctions. Position in the word does not seem to shape variability in the singleton/geminate contrast, hence reinforcing the relevance and the robustness of gemination in Tarifit Berber.

Results concerning the consonants highlighted in this paper can indeed be generalised to all other consonants examined in a longer investigation (see [2]).

Articulatory results given here are based on raw data due to the relatively low quantity of available X-ray data.

Measurements obtained from mid sagittal profiles show, for plosives, that contact-extents (maximum value for contact) are larger for geminate consonant stops than for their singleton counterparts (Figure 4). This observation also applies to fricatives, where maximum constriction length is higher for geminates (as conjectured in hypotheses 8 and 9 respectively). Indeed, these two spatial parameters seem to partly underlie a critical acoustic temporal cue for gemination, *i.e.* acoustic consonantal closure. It is also worthwhile mentioning that contact-extent increases from alveolar, to velar (rather palatal here), and then to uvular consonants (with a few exceptions in the latter case). The articulatory duration of geminate consonants (constriction opening or *articulatory closure*, in ms) is longer than that of their singleton counterparts (Figure 5), as was observed in the acoustic level. These differences of durations are accompanied by differences in the duration of critical articulator positions (pharynx constriction and lip aperture, in ms), *i.e.* in the spatiotemporal dimension, as predicted in hypothesis 10.

Considering relations between articulatory parameters, the data show a sort of basic preassigned values for plosives : longer articulatory closures have longer contact-extents, and *vice versa*.

Looking at articulatory-acoustic relations, we note that the combination of contact-extent and the acoustic duration of consonants allows more clear-cut distinctions in the terms of contrasting the two phonological categories. Examination of the data reveals that when two temporal parameters are combined, *i.e.* articulatory consonantal closure and acoustic consonantal closure, they have a notorious power to clearly distinguish the two phonological categories, for both voiceless and voiced consonantal, and as much as for plosives as for fricatives. The phonological phenomenon of gemination decidedly relies primarily on a temporal physical substrate.

Although minor spatiotemporal differences between the two speakers were observed in this investigation, however, no remarkable speaker-specific strategies were seen in the production of the phonological contrast (not as expected following hypothesis 11). One may therefore say that gestural control is quite constrained by phonological requirements for maintaining the distinctive feature.

In producing geminates, both speakers precociously anticipate critical parameters underlying the emergence of the target consonants (Figure 5, on the right). Hence, onsets for constriction opening, pharynx constriction and lip aperture are initiated in vocal tract configurations corresponding to onset of the preceding vowel /a/ (frame 631). Similarly, onset of post-consonantal vocalic gestures (constriction opening, pharynx constriction and lip aperture) are indeed delayed in the context of these geminates, thus obtaining sufficiently and desired long contacts or constrictions for such consonants (frame 636). As regards the production of singletons, the abovementioned anticipatory gestures are observed only within /a/ vocal tract configurations, *i.e.* comparatively later than for geminates (Figure 5 on the left, frame 186). The post-consonantal vocalic gestures, in the case of singletons, are not delayed as was the case for geminates, but well anticipated in this context (frame 188), where contacts or constrictions do seem to require relatively less time for their acoustic emergence. Such findings generally corroborate our initial predictions relating to anticipatory behaviour (hypothesis 12).

The position of the larynx-hyoid bone couple (Figure 6) is comparable for both terms of the phonological contrast. Therefore, producing geminate consonants, which usually implies high intraoral pressure, did not show any positive correlation between increased sub-glottal pressure for geminates and vertical elevation of the larynx-hyoid bone couple (contrary to hypothesis 13). Future investigations might need to rather focus on physiological data and vocal fold activity in order to underpin potential differences in the production of the two phonological categories.

V. CONCLUSIONS

A close look at both the articulatory and the acoustic data suggests that all speakers adopt comparable strategies in contrasting singletons and geminates. Specifically, it is shown that the most systematic acoustic and articulatory correlate distinguishing Tarifit Berber singletons from geminates is consonant duration. This difference holds for all types of obstruents in the three word positions, including word-initial and word-final voiceless stops, and operates at a normal as well as at a fast speaking rate.

It is in within a perspective of articulatory-acoustic relations that we propose to treat the phonological phenomenon of gemination in Tarifit as follows:

1) Singletons in Tarifit would correspond to: a) a single gesture with its specific spatiotemporal organisation, *i.e.* one supraglottal occlusion / constriction of a certain duration, accompanied by a contact-extent of a given width; b) an acoustic consonantal closure, reinforced by an acoustic silent phase or by an acoustic occlusion of specific durations.

2) Geminates would correspond to: a) a single gesture comparable to that of its singleton counterpart, but having a supraglottal occlusion / constriction of a duration greater than that of the singleton, accompanied by a contact-extent also larger than that of the singleton; b) an acoustic consonant consonantal closure, reinforced by an acoustic silent phase or by an acoustic occlusion with durations higher than those of the singleton

counterparts.

Thus, Tarifit geminate plosives (and constrictives) would be "shaped" from their singleton counterparts, the speaker having learned to trigger adequate articulatory and acoustic spatiotemporal reorganisations in going from one entity to the other. Indeed, according to our articulatory and acoustic data, the speaker would be *doing the same thing once, but for a longer time lapse* ("*doing the same thing once, for a longer period of time*"; see [2, 7 & 9]), since for plosives: 1) spatiotemporal articulatory patterns are structurally comparable between singletons and geminates; 2) only a single and prolonged contact was observed for geminates; 3) the nature of this contact is qualitatively but not quantitatively similar to that of singletons; 4) the acoustic signal, therefore, reveals no rupture, neither in the silent phase of voiceless consonantal closures, nor in that of the consonantal occlusion of voiced consonants.

Hence gemination in Tarifit would be, among others, a phenomenon of temporal *rescaling* of phasing patterns and of reorganisation of a critical spatial parameter.

Some of these phonetic characteristics of Tarifit geminates may be captured, from a phonological standpoint, by a structural representation of these segments as two *consecutive* timing units associated with one *simultaneous* segmental slot, the most relevant timing measure being the duration of the consonant. This point of view will be taken up in detail in a forthcoming investigation.

VI. REFERENCES

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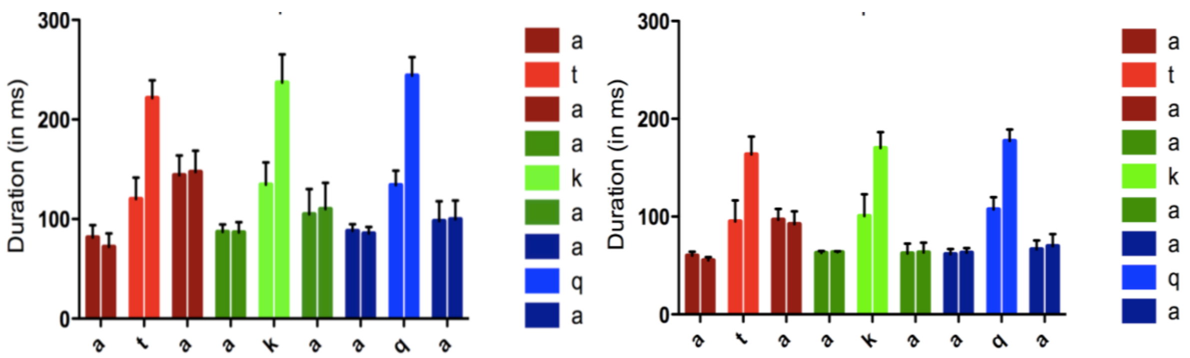

Figure 1: Duration (ms) of intersegmental parameters of singleton and geminate voiceless stops in intervocalic positions, at normal (left) and fast speaking rates (right). See text for details.

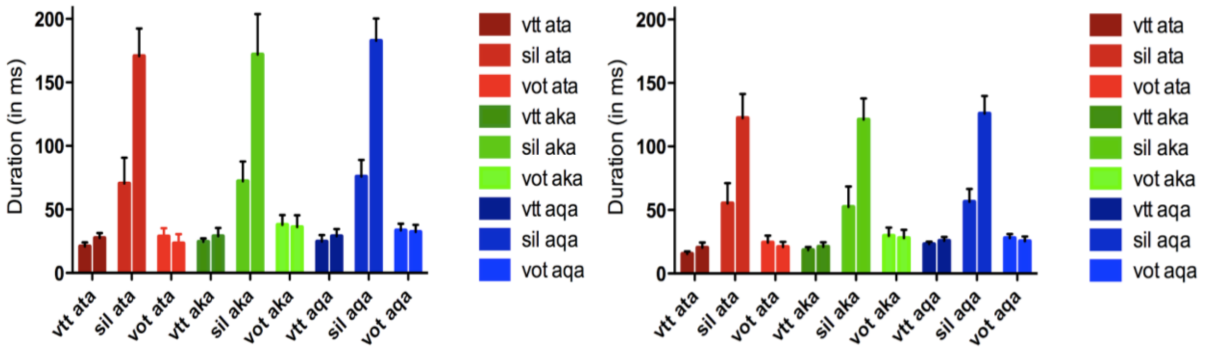

Figure 2: Duration (ms) of intrasegmental parameters of singleton and geminate voiceless stops in intervocalic positions, at normal (left) and fast speaking rates (right). See text for details.

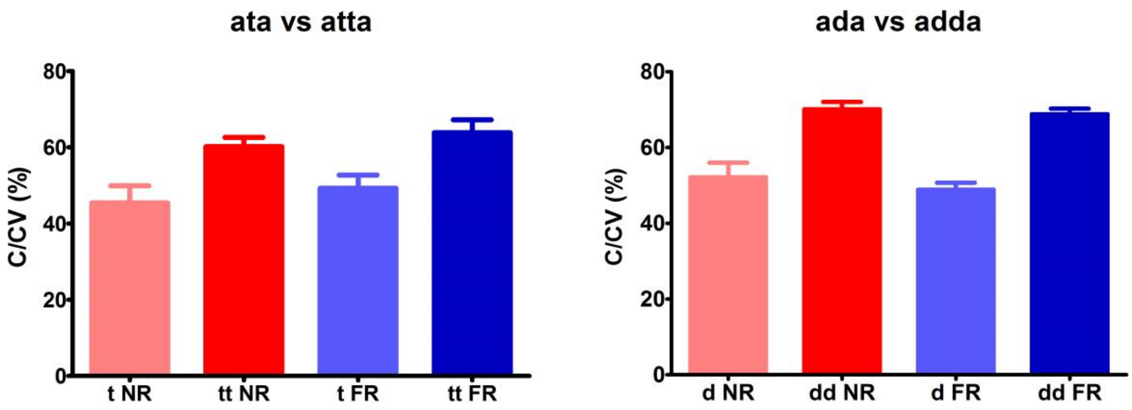

Figure 3**:** Relative values C/CV of /t/ *vs.* /tt/ (left) and /k/ *vs.* /kk/ (right) in fast and normal speaking rates in intervocalic positions. See text for details.

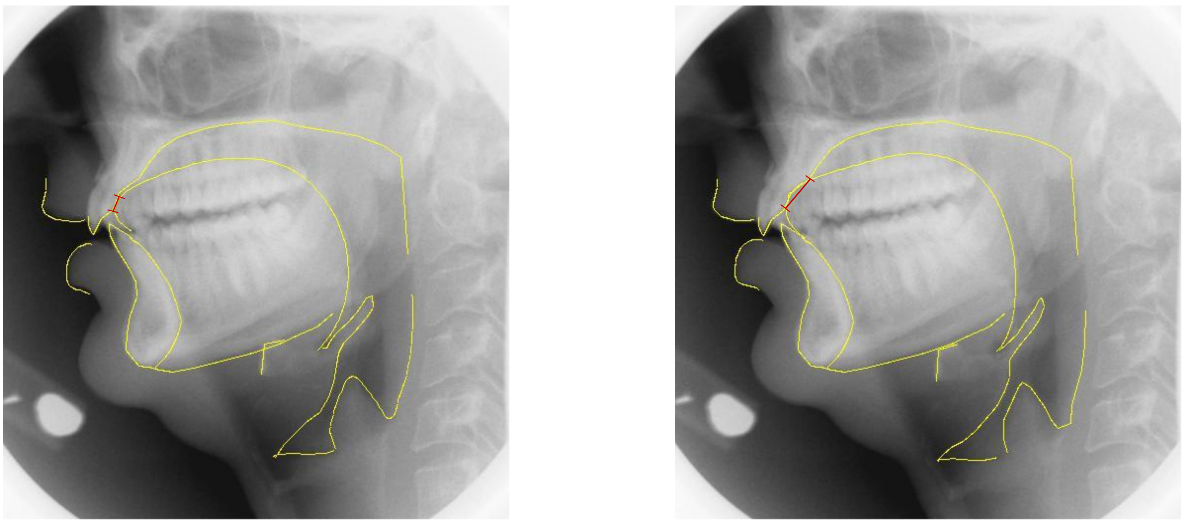

Figure 4**:** Contact extent of /t/ (left = 5 mm) and /tt/ (right = 11 mm); speaker F

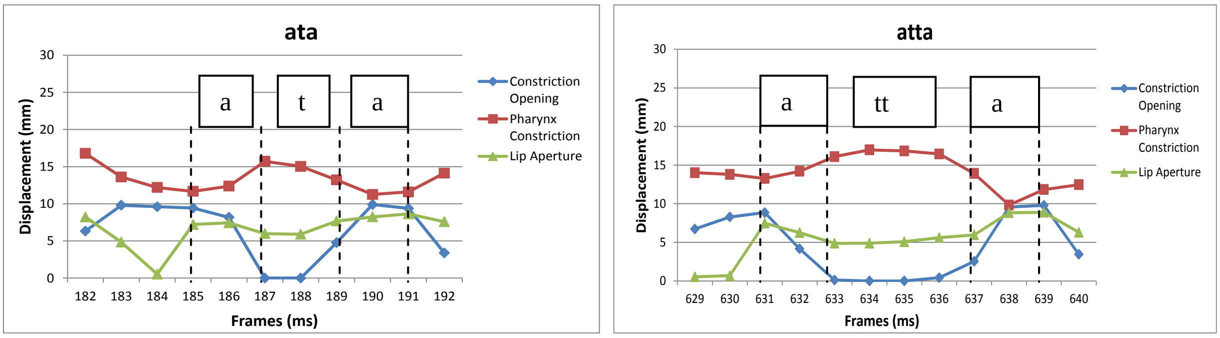

Figure 5: Trajectory of three articulatory parameters (constriction opening, pharynx constriction and lip aperture) of /ata/ (left) and /atta/ (right); speaker F.

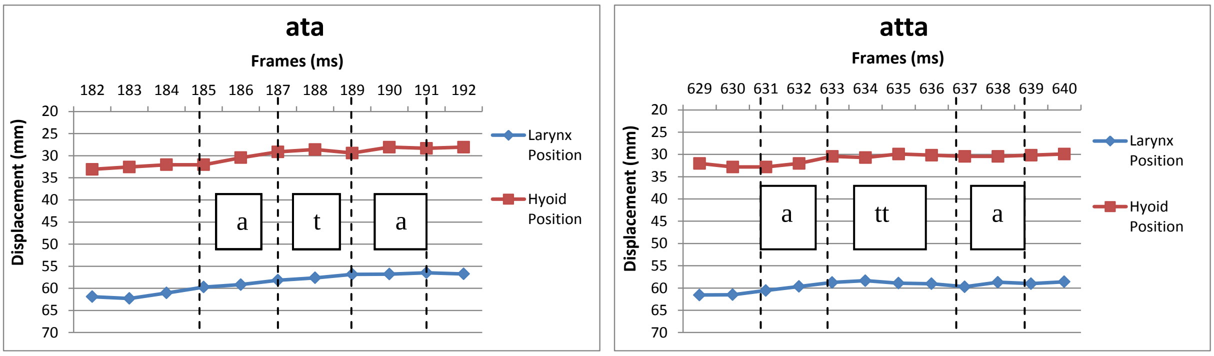

Figure 6: Trajectory of two articulatory parameters (larynx position and hyoid bone position) of /ata/ (left) and /atta/ (right); speaker F.