IS THERE A GENERAL MOTOR BASIS FOR FINAL LENGTHENING?

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ABSTRACT

Phrase-final lengthening is a proposed speech universal, also found in music performance, and is reported in animal communication, e.g. birdsong. In this paper, we ask whether there is a general motor basis for these behaviors.

We recorded the finger movements of five participants as they traced groups of zigzags on paper. Results show that participants reliably signalled groupings by pausing or finger lifting between groups, but did not slow down their group-final movements. Some participants (but not all) showed slower group initial movements.

These results suggest that we may need to look elsewhere for an explanation for the temporal prolongation of final movements observed in speech.

Keywords: Final lengthening, prosody, motor control.

1. INTRODUCTION

1.1. Grouping in speech

A large body of research on many different languages shows that sounds in spoken utterances are grouped into a hierarchy of constituents. These groupings are signaled by a variety of phonetic correlates, including intonation, pause, final lengthening, initial strengthening, and voice quality modifications (breathiness, glottalization). Level in the prosodic hierarchy is indicated by the type and magnitude of correlates (cf. [12]). For example, higher –level constituent boundaries are more likely to be signaled by intonation and pausing, and constituent-final lengthening is greater at higher levels. Some correlates are language (variety) specific, e.g. Finnish breathy endings, whereas others, such as pause and final lengthening, appear to be universal. The focus of this paper is on final lengthening, and our research aims at determining why this correlate in particular is universal. To begin to address this issue, we ask whether there is a general motor basis for this phenomenon.

1.2. Final lengthening in speech

Final lengthening in speech occurs in all languages studied to date, including "quantity" languages that use duration to signal differences among word forms (e.g. Dinka, [11], and Finnish, [8]). It is primarily localized on the rhyme of the constituent-final syllable, although it can occur earlier, e.g. on a pre-final primary stressed syllable ([13]). The magnitude of final lengthening depends on a variety of factors, including 1) the level in the constituent hierarchy, with more lengthening at higher levels [16], and 2) on the role of duration in signaling other aspects of grammar (e.g. final lengthening can be restricted on short quantity segments in some quantity languages, [8]).

Studies of the articulatory control of final lengthening have shown that it is due to a set of strategies, including final nucleus steady state lengthening, and to the slowing of the final movements, either from a V to C in a final VC ([5] for normal and fast rates), or from a final V to a constituent-initial C ([2]).

Although greater spatial displacements can occur in final position, and no doubt contribute to final lengthening via the well-documented effect of distance on duration ([6]), these spatial effects are material-, rate-, and speaker-specific ([5], [2], [1]), and generally take a back seat to the robust and reliable temporal effects.

1.3. Final lengthening in sign language, music, and animal communication

If there is a general motor basis for final lengthening, it would be expected to occur in sign language as well as in other modes of behavior that involve the production of groups of elements. Available studies report that this occurs, but because kinematic studies of sign language are rare, it is difficult to know whether constituent-final behaviour in sign is analogous to constituent-final behaviour in speech. Miller, cited in [4], reports that in Quebec Sign Language, some signs are realized with greater amplitude movements, e.g. a full circle sentence-finally instead of an arc, and are consequently longer. Dutch Sign Language uses a variety of strategies to signal the ends of phrases, including longer final sign holds, repetition of final signs, additional phrase-edge signs, as well as additional simultaneous signs [4]. However, Crasborn et al. [4] note that, in the absence of kinematic data, it is unclear whether final movements can be slowed, as they often are in spoken languages. Tyrone et al. [15] present data from a kinematic study of final lengthening in ASL, and find longer duration sign holds and longer sign release movements in final position. However, the case that they illustrate involves greater spatial displacement as well as a slight increase in duration (with no apparent decrease in movement velocity). Thus it remains unclear whether final movements can be slowed in the absence of spatial changes in ASL, as they can be in speech.

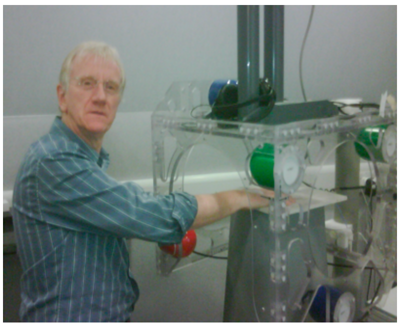
Final lengthening has been observed in musical phrases (references cited in [10]) and has been reported in animal communication, e.g. birdsong (e.g. [13]) and insects (references cited in [3]). These findings suggest that there might be a general motor basis for the final lengthening that is observed in speech. The experiments reported here test this hypothesis in the kinematics of human participants who traced groups of zigzag patterns manually.

2. METHOD

We address the possible motor basis of final lengthening in speech through a study of the kinematics of finger movements in a non-speech motor grouping task. Five participants were asked to trace groups of zigzags printed on paper cards; these consisted of either two groups of three zigzags, or three groups of two zigzags (more details below).

Movements of a sensor attached to each participant's index fingernail were tracked using a magnetometer normally used for studying speech articulation (Carstens AG500). Figure 1 shows the experimental setup, where the participant's hand moves on a horizontal plane within the articulometer.

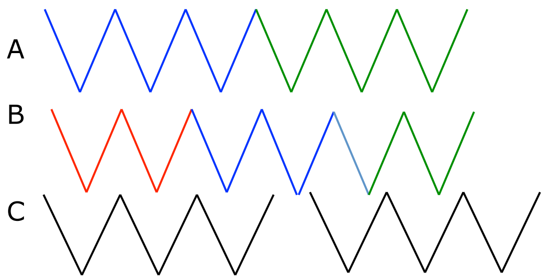
Figure 1: Illustration of the experimental setup



To create the materials, we systematically manipulated:

- Space [Grouping indicated by a Space between groups (Space), vs. indicated by colours (NoSpace)],
- N-Groups [two groups of 3 zigzags vs. three groups of 2 zigzags],
- LR-RL [Tracing from Left-to-right vs. Right-to-Left],
- Down-Up zigzags vs. Up-Down zigzags

Figure 2: Example Materials: A. Two groups of 3 down-up zigzags with NoSpace; B. Three groups of 2 down-up zigzags with NoSpace C. Two groups of 3 down-up zigzags with Space.



These manipulations yielded 16 separate tasks, where a task was e.g. RL_two groups of 3 up-down zags, NoSpace; LR_three groups of 2 down-up zags, Space, etc.

A subset of materials were used in an additional "For Communication condition"; 1) NoSpace Down-Up zigzags with three groups of 2, and 2) NoSpace Down-Up zigzags with two groups of 3. In this condition, participants were asked to carry out the task so that a viewer seeing the movements of their tracing could detect the grouping.

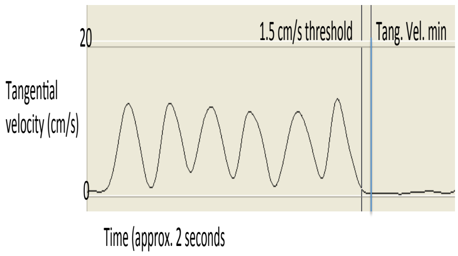
In the NoSpace tasks, participants were instructed not to lift their fingers between groups, so as to encourage the use of grouping strategies different from the finger lifting that was required in the Space tasks.

Each trial included 3 repetitions of a task. Three repetitions of each trial were randomized within each block, where blocks consisted of 1) the No-Communication block (performed first), and 2) the Communication condition (performed last, to avoid biasing the participant's behavior in the No-Communication block). There were normally 9 repetitions of each task (e.g. RL three groups of 2 – Up-Down zags_Space) for analysis, but in some instances, there were more, due to requested repetitions, and in some instances there were fewer, primarily due to position estimation difficulties.

Movement trajectories of sensors taped to each participant's index fingernail were derived from the signal amplitudes recorded from the sensors using a [xxx] procedure detailed in [7]. The data were smoothed using a 40 ms triangular window when taking the first derivative of each dimension (x, y, z), and were smoothed again using the same procedure when computing the tangential velocity.

The 12 strokes in each zigzag group repetition were segmented based on 2 separate onset/offset criteria: 1) tangential velocity minima, and 2) a 1.5 cm/s threshold criterion. This second criterion was adopted because (especially before pause, when movement velocities were close to zero) movement onsets and offsets were difficult to identify using the Minimum Velocity criterion, cf. Figure 3).

Figure 3: Illustration of the two criteria for determining movement offsets.



The following kinematic measures were extracted from the data for each stroke, most of these served as Dependent Variables in our statistical analyses:

- DurationTV (Minimum Tangential Velocity criterion)
- Duration1.5 (1.5 cm/s Tangential Velocity threshold criterion, if TV minimum is lower)
- Peak Tangential Velocity (cm/s)
- Time of Peak Tangential Velocity (not reported here)
- Distance in cm
- Tangential Velocity at stroke onset/offset tangential velocity minimum

By-subject repeated measures ANOVAs were used for statistical analysis.

Independent variables were Space (Space vs. NoSpace, LR-RL (tracing Left-to-right vs. right-to-left), N-Groups (Two groups of 3 vs. Three groups of 2), and Up-Down stroke (Up vs. Down stroke), and Final-NonFinal (Final vs. Non-Final stroke).

3. RESULTS

3.1. Same pattern of results for the Communication and No Communication conditions

The subset of data that was common across Communication and No Communication conditions largely showed the same pattern of grouping results for both conditions. Crucially, neither condition showed any evidence of slowing in group-final position. We therefore present results for the No Communication conditions only.

3.2. Final shortening overall, final lengthening limited to repetition-internal No-Space conditions

The overall result is one of final shortening (mean shortening 8 ms, 3%, $F(1,4) = 16.42$), due primarily to final shortening in the Space condition (17 ms, 7%); shortening in the NoSpace condition was negligible (1 ms, .4%).

However, if we exclude the repetition-final groups from the analysis, we see that many No-Space conditions show a small amount of final lengthening (10 ms, 3.6% on average), whereas the Space conditions show final shortening (18 ms, 7% on average), cf. stroke 6 vs. 1-5 in Figures 4 and 5. These findings are supported by a significant interaction of Final vs. Non-Final stroke with Space ($F(1,4) = 24.60$, $p < .01$), an interaction of Final vs. Non-final stroke with Space, LR-RL, and Up-Down stroke ($F(1,4) = 14.02$, $p < .05$), and an interaction of Final vs. Non-final stroke with Space, N-Groups, LR-RL, and Up-Down stroke ($F(1,4) = 9.57$, $p < .05$). All of these showed final lengthening in the NoSpace conditions, and final shortening in the Space conditions.

Figure 4: Durations of the 12 strokes in the Two- groups of 3, NoSpace, NoCommunication condition. The patterned bars are group-Final.

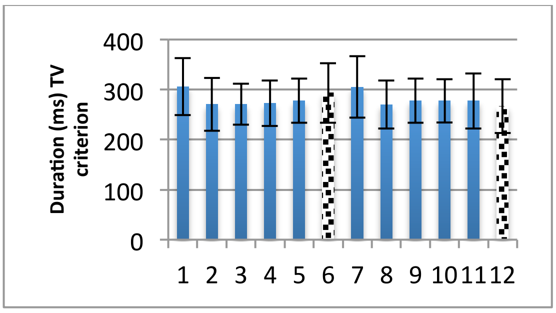
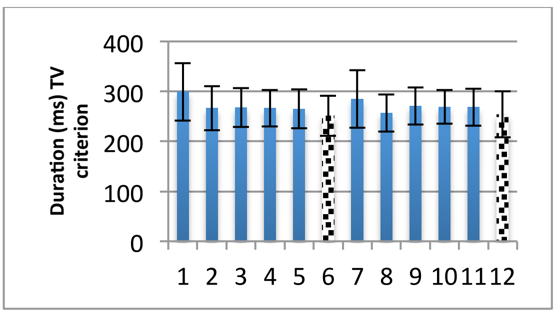


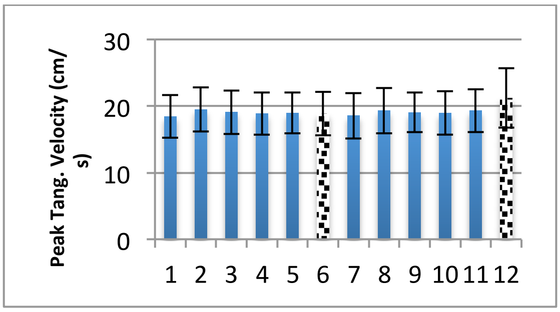
Figure 5: Durations of the 12 strokes in the Two- groups of 3, Space, NoCommunication condition. The patterned bars are group-Final.



3.3. No Final Slowing

The overall result for Final strokes vs. Non-Final strokes is one of final speeding up ($F(1,4) = 10.06$, $p < .05$; finals 1.06 cm/s faster than non-finals).
If we exclude the repetition-final groups, the main effect of Final vs. nonFinal is still significant ($F(1,4) = 11.97$, $p < .05$), but there is a significant Space X Final-NonFinal interaction ($F(1,4) = 12.306$, $p < .05$). In the NoSpace condition, Finals have peak velocities that are .08 cm/s faster than nonFinals. In the Space condition, the speeding up is more marked: Finals have peak velocities that are 1.1 cm/s faster.

Figure 6: Peak tangential velocities of the 12 strokes in the Two- groups of 3, NoSpace, NoCommunication condition. The patterned bars are group-Final.



Analyses of Distance show that observed differences in tangential velocity are not likely to be due to differences in distance (all effects observed for Tangential Velocity were not significant for Distance), cf. [9].

3.4. Final Pause in NoSpace conditions

Final lengthening in NoSpace conditions is not due to final slowing (see evidence above), but is rather due to pausing (reaching a lower, near-zero, minimum velocity at the end of movement) in the NoSpace conditions. This is supported by the disappearance of final lengthening when the 1.5 cm/s threshold criterion is used to define movement offsets, indicating that a lower end-point velocity is reached later in these NoSpace conditions. Accordingly, analyses of Stroke-end Minimum Tangential Velocity for non-repetition-final groups, show a significant Space X Final-NonFinal interaction ($F(1,4) = 26.11$, $p < .01$, Final strokes min TV: 1.64 cm/s; non-Final minTV: 3.06 cm/s). In the Space conditions, Final stroke minTV were faster than non-Final min TV: (Final strokes min TV: 3.38 cm/s; Non-Final strokes minTV: 3.17 cm/s).

Figure 7: Stroke-offset minimum tangential Velocities of the 12 strokes in the Two- groups of 3, NoSpace, NoCommunication condition. The patterned bars are group-Final

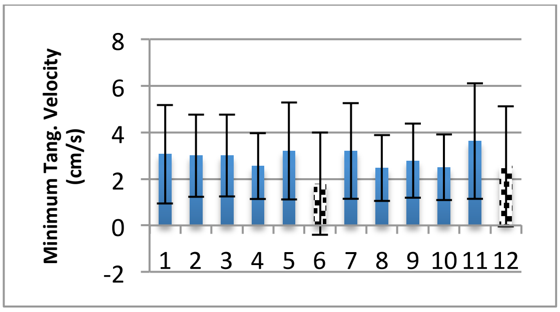
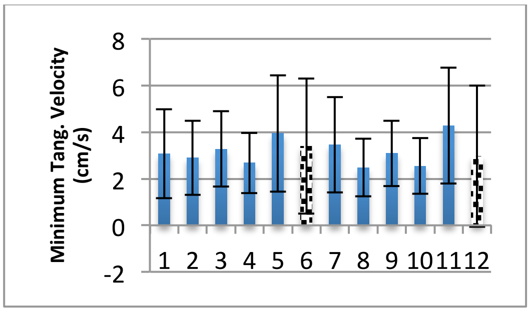


Figure 8: Stroke-offset minimum tangential velocities of the 12 strokes in the Two- groups of 3, Space, NoCommunication condition. The patterned bars are group-Final.



3.5. Initial Lengthening + slowing for some participants

Additional analyses suggest that some participants reliably lengthen and slow initial strokes compared to other strokes. Space prevents us from detailing these results here.

3.6. Conclusions

We found no evidence for group-final slowing in our experiment. What looks like it might be a very small amount of final lengthening in the non-repetition-final groups in the NoSpace conditions, is not due to final slowing, but rather to pausing after the final stroke.

In our experiment, grouping was indicated by:

1) Final speeding up and finger lifting for Space conditions
2) Final pause for NoSpace conditions
3) Initial lengthening and slowing for some participants

We found no general motor basis for final lengthening in our experiment. It is therefore worth asking whether final lengthening is a characteristic of grouping in the acoustic/auditory modalities.

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