Syllable segmentation: Are humans consistent?

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Abstract

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SYLLABLE SEGMENTATION: ARE HUMANS CONSISTENT?
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ABSTRACT
A problem frequently encountered in studies of syllable boundary placement is that of inconsistency, that is, variation in subject responses when syllabifying given consonant clusters. In this empirical study we examine the degree and range of this variation, and the impact of pre- and post consonant cluster vowels on syllable boundary placement. Analysis showed high levels of syllable boundary variation between different cluster types, as well as a marked difference in the perception of syllable onsets and offsets. Syllable boundary movement due to the contextual of vowels was also found, due to both vowel type and aperture. We believe that these results point to a wider approach to syllabification than that traditionally held, involving interactions between vowels and the consonant cluster in the process of syllable onset detection.

1. INTRODUCTION
Considered as the smallest pronounceable unit, a popular choice for the ‘primary perceptual unit’, and now used as an acoustic representation for robust speech recognition, the syllable is of importance across a wide spectrum of speech research fields. However, whilst the syllable is a commonly used concept, our knowledge of it’s role in perception is incomplete. One problem frequently encountered in the use of the syllable is segmentation inconsistency, even in French, a syllable-timed language with what is thought of as having a relatively clear syllable structure.

In previous empirical studies of syllable perception [1,2] we sought to study how closely human syllabification performance matches that of a variety of syllable boundary placement models. Whilst these investigations found that the Dell [3] and Laporte [4] models of syllabification showed high categorial agreement with both adult and pre-literate child syllable boundary placement, they could not explain significant levels of variation found in participants’ syllable boundary placement. Because these models utilise rules based upon the phonotactic regularities of intervocalic consonant clusters, any within consonant cluster variation is treated as noise. However, we hypothesise that such variation is not due to random effect, but is a part of human syllable boundary placement, and should be included in any complete model of syllable perception.

Therefore the first aim of this paper is to examine the consistency of listener’s syllable boundary placement in French over a wide range of possible consonant clusters and singletons. Thus we hope to discover the degree of variation in syllable boundary placement, and which types of cluster are most prone to variability.

Our second aim is to discover the possible effect of the syllable nucleus on upon syllable boundary placement. Usually overlooked in models of syllabification, the effects of both the pre- and proceeding consonant cluster vowels will be examined, as to whether they serve as cue to segmentation.

In this way we hope to build a more complete picture of the variability in syllable boundary placement with a view to possible implications for theories of both syllabification and syllable perception.

2. EXPERIMENT 1
The purpose of this perception experiment is to discover the consistency of the participants’ syllable boundary placement over a wide range of possible intervocalic consonant clusters/singletons. To avoid lexical influences [5] only non-word stimuli were used in this experiment.

2.1 Method
2.1.1 Stimuli
Using a selection of phonotactically legal intervocalic consonant singleton/cluster types found from an analysis of the BDLEX lexicon, a list of stimuli were generated with between 1 and 3 intervocalic consonants. In order to create a bi-syllabic non-word, a random selection of vowels was placed at the start and end of each token (forming VCV, VCCV, and VCCCV stimuli) taken from either /u/, /i/, /a/, or /y/ (vowels thought not to affect syllable segmentation). Stimuli were organised using robust feature classes Nasal (N), Fricative (F), Liquid (L), and Plosive (P) into four singleton, 16 double (e.g. FN), and 3 triple consonant categories (e.g. PFP). Those categories contained between 1 and 3 different clusters with 6 tokens per category. This organisation of stimuli resulted in 138 tokens, with 58 clusters/singletons, and 23 feature categories, with an additional 20 tokens for training.
2.1.2 Procedure
Participants were asked to repeat either the first or second part of the bi-syllabic stimuli as quickly as possible. Experimental stimuli were arranged into 3 blocks, each of which was presented under two conditions, that is, the repetition of either the first syllable (offset detection) or second syllable (onset detection) of the stimuli. Stimuli order for each block was randomised for each presentation. Stimuli in each block were presented on a continuous basis, one every two seconds without pause until the end of the block, where participants were invited to take a short pause. The experimental condition alternated on each successive block, with blocks ordered such that block repetitions (for the 1st and 2nd condition) were never adjacent to each other. At the start of the experiment, two short training blocks of 10 stimuli were presented, one for each experimental condition.

2.1.3 Participants
All 22 participants were students of the Université de Genève and were native speakers of French with no known hearing defects. They received course credits for their participation.

2.2 Results
One of the clearest results from the experiment was the difference in syllable boundary placement consistency between the onset and offset conditions. As can be seen in Figure 1, the percentage of participant responses for the preferred boundary placement, that is the segmentation given by the majority of participants, are far higher for condition 2 than condition 1 for the majority of feature categories. In order to test this observation a repeated ANOVA was conducted using subject's responses from double consonant stimuli as the dependent variable. There were two within subjects factors: condition (1 and 2), and cluster type (41 modalities). There was an overall main effect of cluster type (F(40,800)=40.6, p<.01), that could be found on both condition 1 (F(40,800)=14.22, p<.01) and condition 2 (F(40,800)=37.2, p<.01). This effect was found to be stronger on condition 2 than 1, as attested by the interaction between condition and cluster type (F(40,800)=5.07, p<.01). The main effect of condition was also found to be significant across all cluster types (F(1,20) = 13.95 p<.01).

These results suggest that the repetition of the second syllable of the stimuli maybe the more reliable measure of human syllabification. This assumption is also supported by findings of syllable boundary placement using single intervocalic consonant stimuli. These results are of particular interest because diverse models of syllabification, including the ‘obligatory onset principle’ [6], are unanimous in their placement of the syllable boundary in the /V.CV/ position. The fact that over 99% of subjects agree with this placement for the second condition, whilst up to 40% disagree for the first also suggest that results of the second condition give a more accurate measure of syllabification.

Similar differences in consistency between the repetition of the first and second parts of stimuli were also found in an unspeeded study of syllable boundary placement [7]. In this study such effects are cited as evidence against the boundary view of syllable segmentation. Instead, an ‘onset hypothesis’ is suggested in which distinct operations are used to detect syllable onsets and offsets, with the former providing reference points for segmentation and lexical access.

3. EXPERIMENT 2
The purpose of the second experiment is to examine the effects on syllable boundary placement of changes in an intervocalic consonant cluster/singleton's preceding vowel. One well-known influence of the vowel is the effect of aperture, that is, if a syllable's nucleus vowel is open then the syllable will be closed (it will have a coda), whereas if the vowel is closed the syllable will be open (no coda). If this is the case, could we expect changes in the aperture of an intervocalic consonant cluster/singleton's preceding vowel to affect syllable boundary placement, that is, if we changed a closed vowel to an open would the syllable boundary move to the left, and vice versa? Our aims in this experiment are to investigate the hypothesis of aperture, as well as changes in syllable boundary placement due to different...
types of preceding vowel, and whether these effects are general or specific to particular types of consonant cluster.

3.1 Method
3.1.1 Stimuli
Stimuli were generated using a subset of consonant clusters/singletons used in Experiment 1. Consonant cluster/singletons used in this experiment composed of one cluster/singleton for each N, F, L, P, LPL, and PFP robust feature classes (in order to maintain a similar balance of stimuli as found in Experiment 1) and two clusters for PL, PF, FL, FP, and LN classes. Each of these consonant clusters/singletons were appended to each mid-vowel with open/closed counterparts (/o//), these consonant clusters/singletons were appended to clusters for PL, PF, FL, FP, and LN classes. Each of these consonant clusters/singletons were appended to each mid-vowel with open/closed counterparts (/ol/o/, /el/e/, and /al/a/), final vowels were selected from those used in Experiment 1 with open/closed agreement between the first and second vowel. This organisation resulted in similar stimuli to those used in Experiment 1, with 6 tokens resulting from each of the 26 consonant clusters/singletons.

3.1.2 Procedure
The stimuli for this experiment were presented in the same manner as Experiment 1.

3.1.3 Participants
Nineteen participants, details as Experiment 1.

3.2 Results
As with Experiment 1 a repeated measure ANOVA was conducted using subject’s responses from double consonant stimuli as the dependant variable. There were four within subject factors examined: condition (1 and 2), vowel type (three types, /æ/ /æ/, /e/), vowel aperture (two modalities, open or closed), and cluster type (ten types).

Analysis showed a main effect of cluster type on syllabification responses (F(9,162)=30.2, p<.01), found to be stronger in condition 2 than 1 (F(9,162)=7.26, p<.01). This effect is similar to that found in the previous experiment, agreement was also found with subject’s preferred boundary placement for each consonant cluster tested in both experiments.

An investigation of the influences of vowel type showed a main effect (F(2,36)=20.89, p<.01), this being stronger in condition 1 than in 2 (F(2,36)=8.9, p<.01). This effect was found to be dependent upon the type of cluster (interaction between cluster and vowel types: F(18,324)=2.62, p<.01) for both conditions 1 & 2 (interaction between condition, cluster type and vowel type: F(18,324)=1.2), and was not found to differ according to aperture (F(2,36)<1).

In addition to the influences of vowel type a main effect of vowel aperture was also found (F(1,18)=8.04, p = 0.011). This influence resulted in a movement in syllable boundary placement to the left with open vowels, and to the right with closed vowels. This effect was found in both conditions (interaction of condition and aperture: F(1,18)<1), all cluster types (F(9,162)<1), and all vowel types (F(2,36)<1).

Summarising the effects of the preceding vowel on syllable boundary placement, it seems that the hypothesis about the influence of vowel aperture was correct, open vowels do attract closed syllables, and vice versa. An additional effect of vowel type was also found, however this effect is relative to each consonant cluster, some combinations moving the syllable boundary to the left, others to the right.

4. EXPERIMENT 3
Experiment 3 expands upon the ideas of Experiment 2 in investigating the effects and interactions which take place between pre- and post consonant cluster singleton vowels.

4.1 Method
4.1.1 Stimuli
Taking a subset of the stimuli used in Experiment 2, those based upon consonant clusters/singletons /n/ (F), /lm/ (LN), /lt/ (FP), /ps/ (PF), /gl/ (PL), and /kst/ (PFP), were recombined with a number of different vowels in the post consonant cluster singleton vowel position. Because of the effects of vowel to vowel coarticulation between the pre- vowel (1) and post consonant vowels (vowel 2) not all combinations of vowels can be used in generating the experimental stimuli. Therefore those combinations used in Experiment 3 are /ol/ /o/ /æ/ /æ/ for vowel 1 combined with /el/ /e/ /al/ /a/ for vowel 2. This organisation gives 16 different vowel 1 & 2 contexts for each consonant cluster singleton used in the experiment, resulting in 96 tokens.

4.1.2 Procedure
The stimuli for this experiment were presented in the same manner as Experiment 1.

4.1.3 Participants
Eighteen participants, details as Experiment 1.

4.2 Results
As before a repeated measure ANOVA was conducted using subject’s responses from double consonant stimuli as the dependant variable. There were five within subjects factors examined: condition (1 and 2), vowel 1 type (two types, /æ/ /æ/, /o/ /o/), vowel 1 aperture (two modalities, open or closed), cluster type (four types) and second vowel type (four types, /æ/ /æ/ /æ/ /æ/).

Differing from both Experiments 1 & 2 no main effect of the cluster type was found (F(3,51)<1) on syllabification responses (F(3,51)<1). This change is obvious in the treatment of the preferred boundary placement for the /gl/ cluster, whilst syllabified /gl/ in the previous experiments the preferred boundary placement for this cluster in this experiment was /gl/.
the same as the other double consonant cluster stimuli tested in this experiment. It is not known why subjects have changed their behaviour for this experiment, however it is suggested that large reduction in consonant cluster variation for this experiment compared to the others may have played a role.

Analysis of vowel 1 type shows that main effect and interactions are similar to Experiment 2 differing only in that there was no interaction between vowel type and cluster type (F(3,51)<1). Examining the effect of vowel 1 aperture only a marginal effect was found (F(1,17)=3.46, p=.08) with boundary movement the same as found in Experiment 2. The reason for this change is that vowel 1 aperture now interacts significantly with cluster type (F(3,51)=3.08, p=.035), in both conditions 1 & 2 (F(3,51)=1.17) and across all vowel types (F(3,51)<1). This meant that whilst /ps/ and /ft/ clusters showed a boundary movement to the right for open preceding vowels, the other two clusters exhibited the opposite behaviour.

A main effect was also found for vowel 2 type (F(3,51)=15.5, p<.01), shown to be stronger on condition 2 than 1 (F(3,51)=3.49, p=.022). However, this effect is mainly due to the /ø/ vowel. This effect was not shown to interact with cluster type (F(9,153)=1.26), first vowel type (F(3,51)=1.52), or the aperture of the first vowel (F(3,51)=1.5).

In order to analyse the effect of second vowel aperture a separate analysis is required because of the four vowels used in vowel 2 only two were paired by aperture (/ø/). If only those two are considered in the ANOVA as the second vowel type, then no main effect (F(1,17)<1) was found, whatever the condition (F(1,17)=1.19), the first vowel type (F(1,17)=2.08), or the cluster type (F(3,51)<1). However, an interaction between aperture of the first vowel and aperture of the second vowel was discovered (F(1,17)=4.73, p=.044). This behaviour means that when the first vowel is open, opening the second vowel moves the syllable boundary to the right. If the first vowel is closed, opening the second vowel moves the syllable boundary to the left.

5. CONCLUSION
Over the course of experiments covered in this paper we investigated a number of different sources of variability in human syllable boundary placement. The first source of variability, that of the consonant cluster singleton type, is considered by most models of syllabification as the defining function in syllable boundary placement. Results from both experiments 1 and 2 showed a main effect of cluster type on syllable boundary placement, supporting this view. However, as can be seen from Figure 1 the percentage of agreement in syllable boundary placement for each cluster type is not constant. Some cluster classes exhibit very high levels of variability, whilst for others variability is low.

An examination of another possible source of variability, that of vowel context, discovered that both pre- and post cluster vowels had significant effects on syllable boundary placement. In Experiment 2 both vowel aperture and type were found to produce movements in syllable boundary placement. Whilst problems encountered in Experiment 3 made direct comparison with Experiment 2 difficult due to the removal of the effect of consonant cluster, we can see the continued influence of vowel 1 type as well as main effects from vowel 2 and interactions between the aperture of vowels 1 & 2.

It is also interesting to note that differences in the consistency of syllable boundary placement due to condition, reflecting behaviour of onset and offset detection, observed in Experiment 1 & 2 can also be seen in the experimental manipulation of vowel type. Whilst both vowel 1 and vowel 2 were influential in both conditions vowel 1 had greater effect in offset detection than onset, whereas the difference for vowel 2 was the opposite.

In conclusion it seems, if taken from the traditional phonological viewpoint used by most models of syllabification, that the high levels of within consonant cluster variability found in these experiments reflect inconsistent human syllable boundary placement. However, we believe that our experiments suggest a wider approach to syllabification which takes account of the complex interplay between consonant cluster and both adjoining vowels in the detection of syllable onsets. By taking all of these factors into account behaviour which once seemed highly variable and inconsistent would become less so, therefore more predictable.

6. REFERENCES

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