How measures of gestural overlap relate to dynamics:
Evidence from German and English word-initial stop-lateral clusters

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ABSTRACT

In data from English and German clusters (C1C2), we examine if and how the stiffness of C1 opening and C2 closing movements (the two relevant movements in the C1-to-C2 transition) modulate overlap, using four overlap measures. Results show a variegated picture where different overlap measures do or do not depend on the stiffness parameters. We seek explanations for this patterning that lead to a better understanding of the relation between the plethora of overlap measures used in the literature and the dynamics of the gestures whose overlap is at issue.

Keywords: stiffness, overlap, consonant clusters

1. INTRODUCTION

Studies on inter-segmental coordination have amassed substantial evidence for the cross-linguistic patterning of consonant clusters (e.g., among others, [1]-[23], [25]-[27]). By and large, the approach has been to document patterns of overlap between segments and study the dependence of various overlap measures on the segmental composition of the cluster (stiffness of the component gestures, place of articulation and so on). There has been little to no consensus on what measures to use in characterizing patterns of overlap and in cases where different measures are used within the same study why some measures show dependence on the conditioning factors studied and other overlap measures do not. Here, we seek to address this latter issue by studying the dependence of four different measures of overlap on the conditioning factors of the stiffness of the two relevant movements in the C1-to-C2 transition, C1 opening stiffness and C2 closing stiffness. Whereas the role of the latter parameter in modulating overlap has been studied by Roon et al. [23] and Du and Gafos [10], that of the C1 opening movement remains so far unexplored. Yet, it is intuitively clear that this parameter should play some role in modulating overlap in C1C2 clusters: C1 opening stiffness controls temporal properties of the C1 opening movement which is co-extensive with the transition between C1 and C2, and thus any measure concerning their overlap. Moreover, in terms of overlap measures, while both Roon et al. [23] and Du and Gafos [10] used different quantifications of overlap, their measures were by no means extensive, especially when concerning the transition period between the C1 and C2 gestures. In particular, the interval between the plateaus of C1 and C2, often referred to as the inter-plateau interval (IPI), was absent in the aforementioned two works even though this interval is often used in the literature as an index of overlap (e.g., among others, [1], [12], [21], [26]). Hence, the current study extends this line of research by examining the role of also C1 opening stiffness in modulating overlap and includes IPI as one of the indices of overlap. It will be shown, first, that, similarly to C2 closing stiffness, C1 opening stiffness significantly contributes to modulating overlap, at least for some of the measures of overlap. The dependence of the overlap measures on the conditioning parameters (stiffness of C1 opening and stiffness of C2 closing movement) in our results shows a variegated picture: two overlap measures are modulated by only one stiffness parameter, one measure is modulated by both stiffness parameters, and another measure is not modulated by either of the two stiffness parameters. This patterning sets up the stage for the question we take up here in the Discussion section, namely, why some overlap measures are and other are not modulated by the dynamical parameter of stiffness of the two gestures whose overlap is at issue.

2. METHODS AND DATA

Electromagnetic articulography (EMA) data from three adult German native speakers and three adult American English native speakers were analyzed. The data were collected using the Carstens AG501 at the authors' institution. No participants reported any hearing or speech problems. The experimental procedures were approved by the Ethics Committee at the authors' institution.

The corpus was comprised of German and English word-initial stop-lateral clusters in which C1 was /p, k/ and C2 was /l/. Stimulus words were the lexical items *Plage*, *Klage* for German and *plight*, *played*, *pledge*, *plead*, *climb*, *clip*, *clean* for English.

German (/English) participants produced ten (/eight) repetitions of each stimulus in a carrier phrase. Overall, a total of 151 German and 156 English tokens went into data analysis.

Gestural landmarks in the C1C2 clusters were identified using the Matlab-based software Mview developed at Haskins Laboratories by Mark Tiede. Stiffness was computed by dividing the peak velocity of the C1 opening or C2 closing movement by the amplitude of that movement, following Roon et al. [23] and Du and Gafos [10].

Overlap in the C1C2 stop-lateral clusters was quantified by four different temporal intervals, each delineated by one landmark from C1 (release, offset) and one from C2 (onset, target). The resulting four intervals are listed in Table 1 and schematized by braces in Figure 1. All four overlap measures were computed by subtracting the C1 landmark timestamp from the C2 landmark timestamp.

Overlap measure	Landmarks delineating the interval corresponding to each overlap measure
1	C1 release to C2 onset
2	C1 release to C2 target (IPI)
3	C1 offset to C2 onset
4	C1 offset to C2 target

Table 1: The four overlap measures used in the present work with their delineating landmarks.

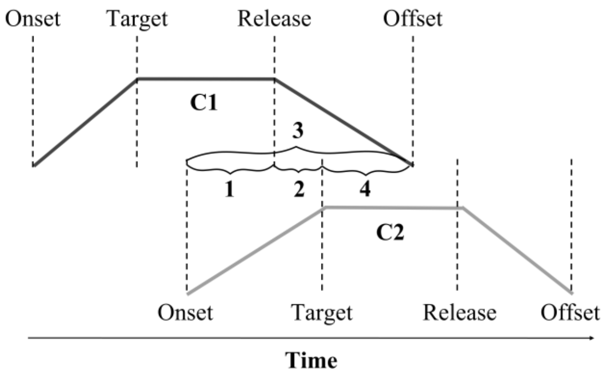

Figure 1: Schematic representation of C1 and C2 gestures with temporal landmarks indicated by vertical dashed lines. The four overlap measures (1, 2, 3, 4) listed in Table 2 are labelled by the horizontal curly brackets.

Linear mixed effects models were fitted to the data to assess relations between the two stiffness parameters (C1 opening stiffness and C2 closing stiffness) and the four overlap measures using the lme4 package in R [24]. C1 opening stiffness (continuous), C2 closing stiffness (continuous), cluster (categorical, levels: /pl/, /kl/) and language (categorical, levels: German, English) were modelled as independent variables with interactions among all possible combinations (C1 opening stiffness × C2 closing stiffness × cluster × language). Each of the four overlap measures was modelled as the dependent variable, thus yielding four models. Random intercepts by subject were also included. All models were assessed using the ANOVA function in the R stats package.

3. RESULTS

We begin with descriptive characterizations of the relations between the four overlap measures (y-axis) and C1 opening stiffness (x-axis) in Figure 2. Figure 3 shows the same for C2 closing stiffness (x-axis). A linear regression line was fitted for each cluster within each language across all speakers.

C1 opening stiffness seems positively related to overlap 3 and 4 (Fig. 2C, 2D) across languages and clusters, while its relation with the other two overlap measures (Fig. 2A, 2B) seems ambivalent, if at all existent. C2 closing stiffness appears to be positively related to overlap 1 and 3 (Fig. 3A, 3C), but less so with the other two overlap measures (Fig. 3B, 3D).

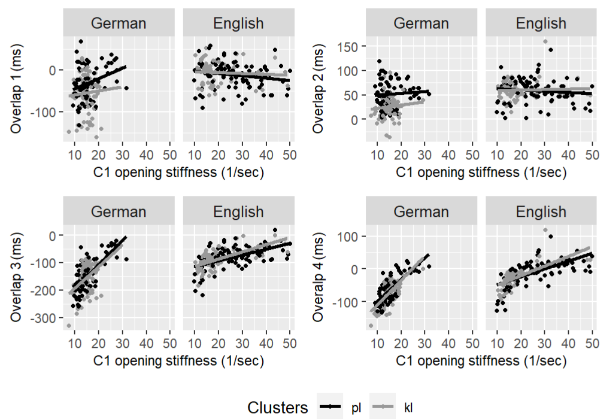

Figure 2: Relations between C1 opening stiffness and the four overlap measures (A: overlap 1, B: overlap 2, C: overlap 3, D: overlap 4). Linear regression lines were fitted across speakers for each cluster in each language.

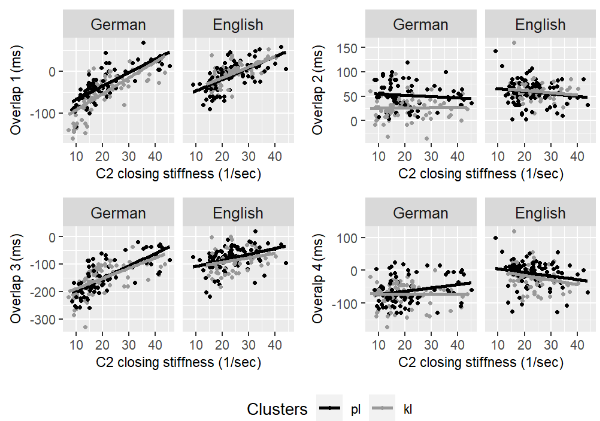

Figure 3: Relations between C2 closing stiffness and the four overlap measures (A: overlap 1, B: overlap 2, C: overlap 3, D: overlap 4). Linear regression lines were fitted across speakers for each cluster in each language.

Statistical results confirm the above observations: for overlap 1 (Fig. 2A and Fig. 3A), only the main effect of C2 closing stiffness was significant ($p < 0.0001$, F-value = 39.35); the effect of C1 opening stiffness was not significant ($p = 0.81$, F-value = 0.06). When overlap was indexed by IPI (overlap 2, Fig. 2B and Fig. 3B), neither the main effect of C1 opening nor that of C2 closing stiffness was significant (C1: $p = 0.36$, F-value = 0.84; C2: $p = 0.44$, t-value = 0.61); for overlap 3 (Fig. 2C and Fig. 3C), both main effects were significant (C1: $p < 0.001$, F-value = 39.12; C2: $p < 0.001$, F-value = 38.12); and finally, for overlap 4 (Fig. 2D and Fig. 3D), only the main effect of C1 opening stiffness showed significance ($p < 0.001$, F-value = 53.42) but not that of C2 closing stiffness ($p = 0.12$, F-value = 2.42). Overall, overlap 1 and 4) are modulated by C2 closing and C1 opening stiffness respectively, overlap 3 is modulated by both stiffnesses, and overlap 2 (IPI) is not modulated by either C1 opening or C2 closing stiffness.

4. DISCUSSION

An examination of the dependence between our four overlap measures on our conditioning parameters (stiffness of the C1 opening and stiffness of the C2 closing movement) gives rise to a variegated picture: two overlap measures are modulated by only one stiffness parameter, one measure is modulated by both stiffness parameters, and another measure is not modulated by either of the two stiffness parameters. This patterning of how overlap measures may or may not be modulated by the dynamics of the two most relevant movements in the transition between C1 and C2 invites explanation.

We begin by recalling the basic reason why stiffness relates to interval duration and hence why overlap measures, which delineate intervals of different durations, should in principle depend on stiffness: stiffness controls the durational properties of a movement – stiffness is the reciprocal of time; recall that stiffness is computed as Velocity v divided by Amplitude A, in which v bears the unit of mm/s and A the unit of mm; hence stiffness has the unit of 1/s (or the reciprocal of time). Thus, the more coextensive (contemporaneous) the movement controlled by the stiffness parameter with the overlap measure in question, the stronger the relation between the two. Note now that, in Figure 1, the different overlap measures are coextensive to different degrees with the two relevant movements (C1 opening, C2 closing) in the C1-to-C2 transition. For instance, overlap 1 is in its entirety coextensive with C2 closing, but not with C1 opening (the latter is so because overlap 1 ends at C1 release whereas C1 opening movement starts at that landmark). More precisely, note that overlap 1 is exclusively coextensive with C2 closing, because during the lifetime of that interval, C1 opening movement is not unfolding). We submit that it is this notion of exclusive coextensiveness that contributes to understanding of how the relations between the four overlap measures and the two stiffnesses play out.

To give a quantitative expression of this thesis, we calculated the percentage of exclusive coextensiveness (PEC) for each overlap measure with the two relevant movements. A PEC value is a property of a pair of an overlap measure (overlap 1, 2, 3, 4) and a movement (C1 opening, C2 closing) and is computed as the proportion of that movement that coextends (is contemporaneous with) the interval delineated by the overlap measure, under the exclusiveness condition that the other movement must not be unfolding at the same time during that interval. For example, in Figure 1, to calculate the PEC for overlap measure 1 with the C2 closing movement, we divide the duration of the interval delineated by overlap 1 by the duration of the C2 closing movement (no C1 opening movement is unfolding during the lifetime of overlap measure 1). Similarly, for the PEC of overlap 3 with the C1 opening movement, we divide the duration of the interval delineated by overlap 4 by the C1 opening movement duration. The results are shown in Figure 4. Overlap 1 and 4 show exclusive coextensiveness predominantly with the C2 closing and C1 opening movement respectively, and thus they are modulated by either C2 closing stiffness or C1 opening stiffness individually but not both at the same time. Only overlap 3 shows considerable coextensive portions with both the C2 closing and the C1 opening movement. Therefore, it is predicted to be the only measure modulated by both stiffnesses; this prediction is borne out in our statistical results in §3.

Moreover, language differences can also be seen in Figure 4, as PEC in each of the eight overlap-movement pair for German is larger than for English; that is, for example, PEC for overlap 1 with C2 closing in German /kl/ is higher than in English /kl/. These PEC differences mesh well with the model fits in §3. In each of the four models, whenever there are significant effects of stiffness, the interaction between these effects and language is statistically significant as well ($p < 0.001$). For instance, even though C1 offset to C2 onset (overlap 3) is modulated by both stiffness terms in German and English, the relations in German are significantly stronger than those in English. This can also be read off from the differences in the regression slopes between German and English in Figure 2C and 3C; the German clusters always have a steeper slope than their English counterparts. The same observation can be made for overlap 1 (Figure 2A and 3A) and 4 (Figure 2D and 3D): here too, the German clusters have steeper regression line slopes than those in English, likewise confirmed by the model fits, wherein interactions between language and the main effects of stiffnesses are significant.

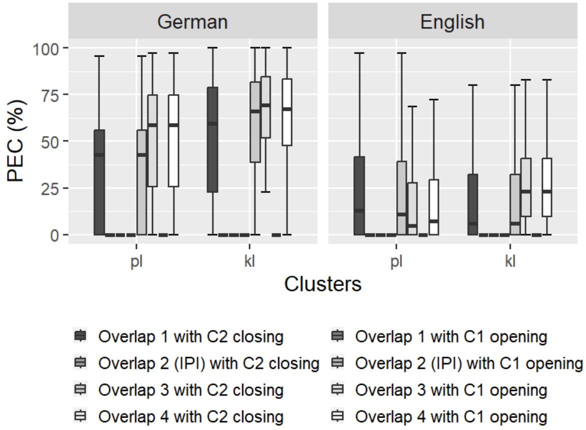

Figure 4: Percentage of exclusive coextensiveness (PEC) for each pair of overlap measure and C1 opening / C2 closing movement across languages and clusters.

Finally, what remains to be explained is why overlap 2 (IPI) is not modulated by either of the two stiffness parameters. As shown in Figure 4, within each cluster type from each language, overlap 2 (IPI) always shows the least PEC with both C1 opening and C2 closing movement. To illustrate more concretely, let us use the schema in Figure 1 to compare overlap 2 (IPI) to overlap 1: it can be seen that IPI exhibits the least amount of exclusive coextensiveness with the C1 opening and C2 closing movements. In fact, during the interval delineated by IPI, the two movements unfold at the same time. Therefore, assessing the relation between (the duration of) IPI and any one of the two stiffness parameters is contaminated by any effects the other stiffness parameter may have on the duration of the same interval (because movement controlled by the other stiffness unfolds at the same time).

Another (non-exclusive to the previous) way to make sense of IPI's lack of relation with the stiffness parameters in our data can be sought from the perspective of variability. In absolute duration terms, IPI is a relatively short interval as depicted in Figure 5, which shows distributions of the overlap measures. Perhaps, then, because IPI is a short interval, its variability, relative to other overlap measures, is limited to such an extent that assessing the relation of its duration and the value of any of the two stiffness parameters becomes infeasible (assessing the nature of a relation between two parameters is possible only if both parameters vary).

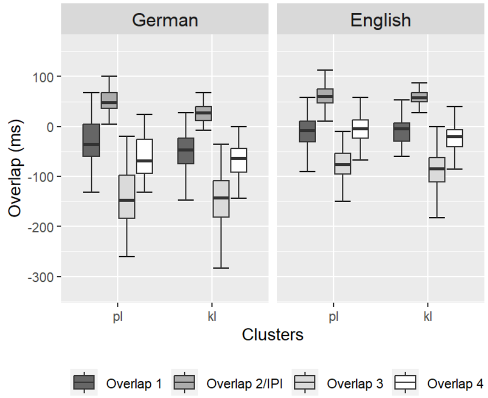

Figure 5: Distributions of the four overlap measures by cluster across German and English. Note that IPI is the interval: 'C1 release to C2 target'.

To compare variability across overlap measures, we used the standard deviation for each overlap measure (because some of our measures take negative values, it is not appropriate to use their means in comparing coefficients of variance, as opposed to standard deviations, of these measures). The results are displayed in Table 2. Both across and within each language, IPI is the least variable interval. Hence, it seems that an appeal to extent of variability may also contribute to the lack of a relation between IPI and the two stiffnesses.

Overlap measure	SD (across languages)	SD (German)	SD (English)
1	41.211	44.616	29.353
2 (IPI)	27.096	27.463	22.586
3	59.471	57.900	39.657
4	47.283	39.808	38.643

Table 2: SD(s) of the four overlap measures across languages and within German and English.

5. CONCLUSION

We investigated the effects of C1 opening and C2 closing stiffness on temporal overlap in English and German word-initial stop-lateral clusters (C1C2), using four overlap measures. Results show that the various overlap measures were not uniformly modulated by the stiffness parameters. Analyses indicate that the extent to which any given overlap measure was modulated by the stiffness parameters is related to the variability of the interval and the degree to which that overlap measure is coextensive with the two movements whose stiffness parameters are under scrutiny. Our results constitute a first step towards a better understanding of the relation between the plethora of overlap measures used in the literature and the dynamics of the gestures whose overlap is at issue.

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