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Research Article

# Experimental evidence on the syllabification of two-consonant clusters in Czech

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ABSTRACT

This study examines syllabification preferences of 30 speakers of Czech in two behavioural experiments using real disyllabic words with 61 intervocalic CC clusters as stimuli. The aim was to evaluate competing theoretical predictions about syllable boundaries in Czech. Participants synchronized individual syllables with metronome pulses in Experiment 1 (induced pause insertion) and produced syllables in reversed order in Experiment 2 (syllable reversal). Logistic regression analyses revealed significant effects of cluster sonority type, phonological length of the preceding vowel and word-edge phonotactics (also in relation to frequency of occurrence). Morphological structure of the items significantly influenced syllable boundary placement as well. The results of both experiments converge towards the effects found in previous studies on English and some other languages. However, ambisyllabic responses were virtually non-existent in pause insertion and relatively low (8%) in syllable reversal, which differs from the results on Germanic languages. Finally, the findings do not support strict onset maximization but rather indicate an onset-filling strategy.



## 1. Introduction

Syllabification has been investigated, both in metalinguistic judgments and in behavioural experiments, quite thoroughly over the years. We now possess data not only on English, which is arguably the best-researched language in this respect, but also on Dutch (Schiller, Meyer, & Levelt, 1997), German and Finnish (Berg & Niemi, 2000), Icelandic (Berg, 2001), French (Content, Kearns, & Frauenfelder, 2001; Goslin & Frauenfelder, 2001), Italian (Bertinetto, Caboara, Gaeta, & Agonigi, 1994), Russian (Côté & Kharlamov, 2011), Polish (Bertinetto, Scheuer, Dziubalska-Kołaczyk, & Agonigi, 2006), Irish (Ní Chiosáin, Welby, & Espesser, 2012), Hindi (Ohala, 1999) and even L2 English of Japanese speakers (Ishikawa, 2002). Derwing (1992) investigated English and four other languages: Arabic, Blackfoot, Korean and Swiss German. This is promising because we can survey the specific findings and generalize across a wide range of languages. However, even with such a representative sample of languages generalization might be less straightforward, since the studies are not directly comparable in terms of material and tasks (this will be attended to in more detail throughout the paper and in the General discussion).

The current study examines Czech, where the syllable has so far been examined in phonological and phonotactic descriptions only (e.g. Bičan, 2013; Kučera, 1961; Ludvíková, 1972). New results from Czech would contribute significantly to broadening and deepening the focus of the field, as the experiments present a good testing ground for various issues. For instance, one finding of the English studies is that syllables with a short, lax vowel (such as /ɛ ɐ ɒ/[1]) tend to attract consonants to the coda position (Eddington, Treiman, & Elzinga, 2013a, 2013b; Fallows, 1981; Treiman & Danis, 1988; Treiman & Zukowski, 1990). However, given that English lexical words do not end with such vowels, this might just reflect the English phonotactics. As there is no phonotactic constraint against short vowels word-finally in Czech, any tendency to avoid syllables ending with short vowels cannot reflect phonotactics, but may rather be related to universal characteristics, such as syllable weight.

Moreover, the current study can be of interest for the following reasons. First, a wide range of two-consonant clusters is

[1] The vowel /ɐ/ as in "cut" (traditionally transcribed as /ʌ/). The transcription employed here follows the conventions of the IPA.

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examined here, including morphologically complex forms, which are usually omitted from experiments. Second, the present analysis can draw on the availability of corpus frequency data provided by Šturm and Lukeš (2017), which will be useful because cluster word-edge frequency of occurrence might play an important role in syllabification behaviour. Third, two different methods are employed on the same material to see whether the results from one task (pause insertion) can be replicated in another (syllable reversal). If the two tasks converge, the conclusions drawn from this study might be more convincing.

### *1.1. Syllables and syllabification*

The articulatory basis of the syllable is related to the cyclic motion of the jaw and the alternation of open vocal tract shapes, associated with vowels, and strictures in the oral cavity, associated with consonants (Hála, 1956; MacNeilage, Davis, Kinney, & Matyear, 2000). Syllable nuclei are linked to peaks in acoustic sonority (i.e., relative intensity, see Parker, 2008), which facilitates speech perception and segmentation of the signal. Sonority relations between segment classes have been captured in phonology by the *sonority hierarchy* (Blevins, 1996; Clements, 1990; Goldsmith, 2011; Zec, 2007) and, by extension, by rules governing preferential segment ordering, such as the Syllable Contact Law or the Sonority Sequencing Generalization (see Blevins, 1996; Clements, 1990). These principles make specific predictions about syllable boundaries: since sonority is expected to rise towards the nucleus, an obstruent-sonorant intervocalic cluster (/pl/) would be assigned to the onset of the second syllable, whereas a sonorant-obstruent cluster (/lp/) would be divided between the two syllables (or assigned to the coda of the first syllable; however, in that case the second syllable would be onsetless, which is generally strongly disfavoured; Gordon, 2016, chap. 4; Prince & Smolensky, 2004).

The syllable as a distributional unit is associated especially with the domain of phonotactics. There are co-occurrence restrictions among segments so that, for instance, specific combinations of consonants cannot arise syllable-initially in one language (e.g., /tl/ in English), whereas a different language might allow it (/tl/ in Czech /tlɛskat/, “to clap hands”). Therefore, the absence of specific combinations is not always due to articulatory or perceptual reasons. Word-edge phonotactics is usually taken into account when substantiating assumptions about syllable boundaries (e.g. Fallows, 1981; Kahn, 1976; Ludvíková, 1972; Pulgram, 1970; Steriade, 1999). There is general agreement that words should be syllabified in such a way that phonotactic constraints of the given language are not violated (but authors may not agree on specifying which constraints are relevant).

Furthermore, language use seems to have significant effects at various levels of the linguistic structure, from morphology and syntax to phonological structures (Bybee, 2001). It has been demonstrated that intuitions of native speakers about the well-formedness of presented sound sequences are affected not only by the presence vs. absence of the given sequence in the language, but also by its frequency of occurrence (Hay, Pierrehumbert, & Beckman, 2004; Munson, 2001; Treiman, Kessler, Knewasser, Tincoff, & Bowman, 2000; Vitevitch, Luce, Charles-Luce, & Kemmerer, 1997). For instance, Vitevitch et al. (1997) used disyllabic nonsense words composed of English syllables differing in phonotactic probability. Of the four logical combinations (LL, HH, LH, HL, where L and H stands for low- and high-probability patterns, respectively), highest scores were assigned by the listeners to the HH nonwords, in contrast to LL items, which received lowest scores on the well-formedness evaluation scale. The other experimenters arrived at similar conclusions implying a strong correlation between well-formedness judgments and frequency of occurrence. Finally, the effect of phonotactics is reported in language development and psycholinguistic experiments as well (Bernard, 2015; McQueen, 1998; Skoruppa, Nevins, Gillard, & Rosen, 2015; Storkel, 2001).

However, phonotactics is not the only factor in locating syllable boundaries. In addition to the sonority sequencing mentioned above, morphological composition can play a significant role (Derwing, 1992), and phonological variables such as stress placement or segment type have also been shown to influence syllabification judgments (see Section 1.2 below). Focusing on Czech, it will be instructive to summarize the approach of Ludvíková (1972), who carried out a quantitative analysis of syllable types in Czech. In the description of her method she presents several criteria for syllable division of the Czech language:

1. syllable boundaries align with word boundaries;
2. if a word has a syllabic prefix, the syllable boundary aligns with the morpheme boundary;
3. single intervocalic consonants are aligned to the right, i.e. CV.CV;
4. intervocalic clusters are divided in agreement with the morphological structure; if there is no morpheme boundary, then a statistically more frequent solution – based on an inventory of word-initial onsets and word-final codas – is preferred.

In her view, morphological aspects prevail over phonotactics. However, it needs to be ascertained whether such a claim, reflecting Ludvíková’s intuition and theoretical stance, will be evidenced by experimental data (compare contrary results on English in Smith and Pitt, 1999).

By far the most widely invoked syllabification principle is the Maximum Onset Principle (Fallows, 1981; Hall, 2006; Kahn, 1976; Pulgram, 1970). Onset maximization becomes relevant with word-medial consonant clusters, as a single consonant is usually supposed to form an onset automatically (the Onset Principle or Onset Filling, see Hooper, 1972; Berg & Niemi, 2000; the ONSET constraint in Optimality Theory, see Prince & Smolensky, 2004). Thus onsetless syllables are not predicted to arise word-medially. The Maximum Onset Principle postulates that whenever possible, the onset should be preferred, i.e., maximized, by assigning the largest number of intervocalic consonants to the following vowel as an onset, rather than to the preceding vowel as a coda. Phonotactics acts as the restraining force here (or in some cases sonority relations, which are often indistinguishable). The English word “poster” would thus be syllabified as /pouə͡ʊ.stə/, but “pester” would result as /pɛs.tz/ since /ɛ/ does not occur word-finally. Although arguments in support of this principle can be provided from the domain of typology or speech acquisition (syllable onsets are preferred over syllable codas in general; Blevins, 1996;

Vihman, 1996), and we can find some support in the experimental literature (see Section 1.2), maximizing onsets is by no means a universal syllabification procedure. The question of onset maximization (in contrast simply to onset filling) represents one aspect that the current study aims to examine.

Another syllabification principle that was originally driven by theoretical considerations is ambisyllabicity (Blevins, 1996; Gussenhoven, 1986; Kahn, 1976). In this view, the boundary between two syllables is not clearly defined, but the intervening consonant can belong to both syllables simultaneously, functioning as coda of the first syllable and onset of the second. The advantage of such an approach is that for example "happy" will no longer violate the English phonotactic constraint against /æ/ syllable-finally, compared to an analysis with /p/ solely in the onset position. Nevertheless, ambisyllabicity is restricted to certain contexts, defined with respect to stress (Kahn, 1976). Compare the words "pity" (/ˈpɪtɪ/) and "platoon" (/pləˈtuːn/), where only the first /t/ can be considered ambisyllabic. Ambisyllabicity was investigated in syllabification experiments quite extensively; from recent publications see especially Elzinga and Eddington (2014). Although Czech researchers have not pursued this direction so far, ambisyllabicity appears to be a promising concept worth exploring.

### *1.2. Experimental investigation of syllable boundaries*

Since syllable boundaries have conventionally been derived from linguistic theory or from speakers' metalinguistic judgments, experimental verification of syllabification is clearly relevant. As shown below, substantial findings have been accumulated especially in psycholinguistic experiments that elicit data from participants' performance. The behaviour of speakers is controlled by the experimenter, and syllable boundaries are inferred from their performance in the task. (However, it is debatable whether such results reflect the online processing of speech, or the phonological structure of words; as noted for instance in Côté & Kharlamov, 2011, the phonological syllable is not necessarily identical to the speaker's syllable.)

A variety of tasks have been proposed and successfully used in experiments (see particularly a review in Côté & Kharlamov, 2011; Eddington & Cairns, 2015). In all cases, participants perform some kind of operation with words (both real and nonsense), and the term "syllable" is usually substituted with "part of the word". Fallows (1981) used a method of *syllable reduplication* for an experiment with children participants, in which the children repeated the presented words pronouncing the first (or second) part of the word twice. The response /pɪk pɪknɪk/ (or /pɪknɪknɪk/) to "picnic" would consequently suggest the syllabification /pɪk.nɪk/, while /pɪpɪknɪk/ (or /pɪknɪkknɪk/) would suggest /pɪ.knɪk/. A similar reasoning applies to other tasks as well. *Syllable repetition* involves producing solely the first (or second) part of the target word, which can be presented either auditorily (Goslin & Frauenfelder, 2001; Ní Chiosáin et al., 2012) or orthographically (Côté & Kharlamov, 2011). A *syllable permutation* task necessitates the participants to reverse the order of two syllable-sized chunks in the target word (Berg & Niemi, 2000; Content et al., 2001; Schiller et al., 1997; Treiman & Danis, 1988). In addition, Schiller et al. (1997) also used the method of *pause insertion*, where the participant's task is to divide the target word by pronouncing its first part and, after a short pause, the second part (more recently e.g. Goslin & Floccia, 2007). An alternative way is the approach of Content et al. (2001) who asked the participants to divide the words with a fragment of speech (e.g., "and then") instead of with silence. As Table 1 indicates, it is customary to combine several methods in one experiment, presumably because the comparison may help to identify task-specific effects.

Furthermore, syllable boundaries have been investigated in written tasks that elicit metalinguistic judgments (Eddington et al., 2013a, 2013b; Ishikawa, 2002; Treiman & Danis, 1988; Treiman & Zukowski, 1990; Treiman, Gross, & Cwikiel-Glavin, 1992). The participant typically chooses one of suggested syllabifications or divides the word with a slash at the appropriate place. However, it is clear that such responses are burdened with conscious operations performed by the

**Table 1**

Summary of selected studies in terms of participants' language and group, material used (words, words including bimorphemic words, nonwords), target sequence (single intervocalic consonant vs. clusters of consonants), task (REV = syllable reversal, DIV = syllable division, i.e., pause or slash insertion, REP = first or second syllable repetition), and whether stimuli were presented and syllabifications elicited orally (O) or in writing (W). Arranged according to language.

| Study | Language | Participants | Material | Target | Task | Prompt | Response |
|---|---|---|---|---|---|---|---|
| Eddington and Cairns (2015) | English | Adults | Words | Cluster | REV + DIV + REP | O + W | O + W |
| Eddington et al. (2013a, 2013b) | English | Adults | Words (incl. bimorph.) | C + cluster | DIV | W | W |
| Elzinga and Eddington (2014) | English | Adults | Words | C + cluster | REP | W | W |
| Fallows (1981) | English | Children | Words (incl. bimorph.) | C + cluster | RED | O | O |
| Ishikawa (2002) | English | L1 + L2 adults | Words + nonwords | C | DIV | O + W | O + W |
| Redford and Randall (2005) | English | Adults | Nonwords | Cluster | DIV | O | W |
| Treiman and Danis (1988) | English | Adults | Words | C | REV + DIV | O + W | O + W |
| Treiman and Zukowski (1990) | English | Adults | Words | Cluster | REP + RED | O | O + W |
| Treiman et al. (1992) | English | Adults | Nonwords | Cluster | REP + DIV | O | O + W |
| Treiman et al. (2002) | English | Adults + children | Words | C | REP | O | O |
| Derwing (1992) | English + 4 other | Adults | Words (incl. bimorph.) | C | DIV | O | W |
| Schiller et al. (1997) | Dutch | Adults | Words + nonwords | C + cluster | REV + REP | O | O |
| Content et al. (2001) | French | Adults | Words | C | REV + REP + DIV | O | O |
| Goslin and Floccia (2007) | French | Adults + children | Words (incl. bimorph.) | Cluster | DIV | O | O |
| Goslin and Frauenfelder (2001) | French | Adults | Nonwords | C + cluster | REP | O | O |
| Berg and Niemi (2000) | German + Finnish | Adults | Nonwords | Cluster | REV + RED | O | O |
| Ohala (1999) | Hindi | Adults | Words | Cluster | RED | O | O |
| Ní Chiosáin et al. (2012) | Irish | Adults | Words | C + cluster | REP | O | O |
| Bertinetto et al. (2006) | Polish | Adults | Words (incl. bimorph.) | Cluster | REV + REP | O | O |
| Côté and Kharlamov (2011) | Russian | Adults | Nonwords | C + cluster | DIV + REP + rating | W | O + W |

participant on the word before indicating the syllabification in the answer sheet, and with the participant's assumptions about the correctness of the solution, likely to be influenced by factors such as linguistic experience or orthographic effects (see Goslin & Frauenfelder, 2001, p. 421). It should be noted, however, that spelling knowledge may affect the syllabification outcome even in oral tasks (Goslin & Floccia, 2007; Treiman, Bowey, & Bourassa, 2002). Nevertheless, written and oral tasks may represent complementary methods provided that these reservations are taken into consideration.

An overview of 20 studies is provided in Table 1, where one can easily compare for instance the type of material or the experimental task used. Several studies examined single intervocalic consonants, which – despite the predictions of many theories – do not seem to be unequivocally syllabified as onsets (but compare Derwing, 1992; Goslin & Frauenfelder, 2001). A number of effects have been noted. First of all, syllabification is influenced by lexical stress in that participants prefer to assign the medial consonant to the preceding or following syllable depending on which one is stressed (Eddington et al., 2013a; Schiller et al., 1997; Treiman & Danis, 1988). Consequently, final stress on a disyllabic item favours a medial onset, whereas initial stress is associated with a higher proportion of closed syllables or with responses of the type /mən.lɛm/ (for reversed "lemon"), indicating ambisyllabicity. Secondly, both ambisyllabic and coda responses are typically more frequent after short/lax vowels than after long/tense vowels. At least in English and Dutch, this could to some degree be due to the phonological illegality of lax vowels in open syllables (Fallows, 1981; Schiller et al., 1997; Treiman & Danis, 1988; Treiman et al., 2002), but the same effect was found in Irish as well (Ní Chiosáin et al., 2012). Moreover, especially in stress-initial words, ambisyllabic responses tend to occur more often when spelled with a double letter, and sonorants are more closely associated with the preceding vowel than obstruents (Eddington et al., 2013a; Treiman & Danis, 1988). The last mentioned study and Derwing (1992) also found a significant effect of morphology, i.e., syllabification followed morphological boundaries when relevant.

Most of the results can be extended to word-medial clusters. For instance, Treiman and Zukowski (1990) and Eddington et al. (2013b) report the effect of stress, vowel length and sonority for English. Stressed syllables attract consonants, they tend to be closed when they include a short vowel, and clusters beginning with a sonorant consonant are especially likely to be divided between the syllables. Ní Chiosáin et al. (2012), studying Irish words, found an effect of phonological vowel length, but also of phonetic vowel duration (the shorter the vowel, the higher its probability of being closed); further, obstruent-liquid sequences tended to be syllabified as an onset, while fricative-plosive sequences were most often divided. Goslin and Frauenfelder (2001) investigated French syllabification; CC clusters were usually divided with the exception of obstruent-liquid sequences (/gr br gl/), and CCC clusters were treated either as C.CC (nasal + plosive + liquid) or CC.C (plosive + fricative + plosive). This confirms that syllabification is affected by the phonetic nature of the consonants in many languages (Bertinetto et al., 2006; Goslin & Floccia, 2007; Ohala, 1999).

Another important aspect is phonotactic legality of the cluster. Eddington et al. (2013b) claim that syllables are made to be as word-like as possible, following morphological boundaries and respecting phonotactic constraints (similarly Derwing & Eddington, 2014). Goslin and Frauenfelder (2001) found greatest agreement between the experimental results and theoretical models of French syllabification based on phonotactic legality. Treiman and Zukowski (1990) and Redford and Randall (2005) also reported that medial sequences formed by clusters that are illegal word-initially were virtually always split. Finally, Berg and Niemi (2000) investigated CC and CCC sequences in nonsense words, using German and Finnish speakers. As predicted based on the phonotactic structure of the two languages, German speakers tended to maximize the onset, whereas Finnish speakers demonstrated an onset-filling strategy (i.e., onsets have at least one consonant).

### *1.3. Basic description of Czech*

Czech is a Western Slavic language with approximately 10 million speakers. Since it has relatively few monosyllabic words (Bartoň, Cvrček, Čermák, Jelínek, & Petkevič, 2009), the problem of syllable division will arise quite frequently. One relevant feature of the Czech language is that, like in Finnish, stress is fixed to the first syllable of polysyllabic words, irrespective of morphological composition. Another feature is that Czech uses vowel length distinctively in the phonological system (therefore, /ˈpascɪ/ and /ˈpaːscɪ/ represent different words, "traps [noun]" and "to graze"), which is true for final positions as well (/ˈt͡sɛlɛ/ "(in) a cell" vs. /ˈt͡sɛlɛː/ "whole"). Finally, similarly to Polish, Czech has a complex syllabic structure with a rich inventory of consonant clusters (Bičan, 2013). It allows up to four consonants at the beginning of words (e.g., /ˈvzɦlɛːdno͡ut/ "to look up", /ˈskvj ɛliː/ "awesome") and up to three consonants at the end (/vojsk/ "of armies", /ˈkontɛkst/ "context"). Moreover, secondary sonority peaks are allowed word-initially, in words such as /mzda/ "salary" or /ˈlʒiːt͡sɛ/ "a spoon" (monosyllabic and disyllabic, respectively). Nevertheless, despite the complexity of permissible syllable shapes, the proportion of (C)CCC word-initial onsets and CC(C) word-final codas in spoken corpora is less than 3% (Šturm & Lukeš, 2017).

The segmental inventory of Czech is provided for example in Šimáčková, Podlipský and Chládková (2012). A note should be made about the raised alveolar trill /r̝/. It is an obstruent fricative sound, realized as a trilled fricative (usually no more than one trill of the tongue tip in casual speech). Phonologically functioning as one phoneme, it has nevertheless two phonetic realizations. The voiced variant [r̝] is the primary realization of the phoneme (e.g. [ˈmor̝ɛ] "the sea"), whereas the voiceless [r̝̊] appears only in progressive and regressive voicing assimilation contexts (e.g., [ˈtr̝̊iːmat] "to wield", [ˈmɲɛr̝̊tɛ] "measure [imperative]"). Another speech sound worth discussing is the voiced labiodental fricative /v/. It is normally considered a fricative in the Czech language, and as such it alternates with the voiceless /f/ in voicing assimilation (e.g. /ˈpolɛːvat/ "to pour" vs. /ˈpolɛːfka/ "a soup"). In contrast to /r̝/, the voicing counterparts are phonologically contrastive (e.g. /ˈzo͡ufat/ "to despair" vs. /ˈzo͡uvat/ "to take one's shoes off"). In continuous speech,

/v/ is realized as a fricative or an approximant. Moreover, although obstruents undergo voicing assimilation before other obstruents in Czech, /v/ is an exception to the rule as it does *not* trigger assimilation in the preceding obstruent, behaving like a sonorant in this respect for diachronic reasons (Lamprecht, Šlosar, & Bauer, 1986, p. 97). Therefore, we can have word pairs like /tvojɛ/ "your" vs. /dvojɛ/ "double, a pair of", which would not be possible if /v/ behaved consistently as a "true" obstruent. Consequently, I will employ two classifications of /v/ – namely obstruent (O) and sonorant (S) – depending on the context in which the sound appears. For the sake of clarity, the two will be differentiated in transcription as well (/v/ or /ʋ/).

### 1.4. Hypotheses

The two experiments presented in this study were prepared with the following hypotheses in mind:

(1) *Onsets will be maximized, unless other (phonotactic) criteria interfere.* This follows from the Maximum Onset and Legality principles (Pulgram, 1970). Therefore, two-consonant clusters will be syllabified, at least in part, as the onset of the following syllable, excluding VCC.V syllabification generally and VC.CV syllabification additionally in phonologically legal clusters.

(2) *Syllabification will not give rise to syllables that violate the ideal sonority profile*. This is based on cross-linguistic observation of syllables and the ordering of segments according to sonority classes (Clements, 1990; Parker, 2011). Therefore, sonorant-obstruent clusters will be divided, but obstruent-sonorant clusters not. The sonority scale used here is obstruents > sonorants > vowels (Zec, 1995).

(3) *Sequences that do not appear at word edges will not appear at syllable edges*. This is the legality principle, denoting that syllable division is constrained by word-edge phonotactics. The legality of sequences is evaluated against phonological descriptions of Czech and especially a recent large corpus study (Šturm & Lukeš, 2017).

(4) *Word-edge frequency of occurrence will affect syllabification*. This is an extension of the legality principle, refining the binary variable legal-illegal into a scale. High frequency clusters will be maximized more often than low frequency clusters.

(5) *Short vowels in the first syllable will attract a coda more often than long vowels*. This assumption stems from Germanic languages that frequently display a phonotactic constraint against stressed open syllables with lax vowels (Hammond, 1997) but, more importantly, is also expected for language-independent reasons, such as syllable weight or minimality requirements (Gordon, 2006).

(6) *Syllabification will follow morpheme boundaries*. Monomorphemic and polymorphemic words are expected to differ (Eddington et al., 2013a, but also Ludvíková, 1972 for Czech). If a medial cluster involves a morpheme boundary (preceding, intersecting or following the cluster), the morphological parse will influence syllable division.

(7) *Participants will differ in syllabification responses*. Speakers need not behave unanimously, possibly due to discovering the true aim of the experiment or having differing degrees of phonological awareness (Caravolas, Volín, & Hulme, 2005).

(8) *Syllable reversal will be associated with more ambisyllabic responses than pause insertion*. The results of the experiments may differ due to task-related reasons (Côté & Kharlamov, 2011; Derwing & Eddington, 2014; Eddington & Cairns, 2015). Most importantly, participants are required to handle test words in linear or reversed order.

Although formulated for CC clusters, the hypotheses could be extended to CCC(C) clusters as well. The material included only a small number of such complex clusters and was thus difficult to analyse statistically; a brief summary is given in Šturm (2017). Further, I do not investigate single intervocalic consonants, as there seems to be no contradictory evidence to the claim for Czech that these are assigned to the following syllable as an onset (Bičan, 2017; Kučera & Monroe, 1968; Ludvíková, 1972). Informal observations based on filler items of this study point in the same direction. Another possibility is that in post-stress contexts, intervocalic singletons could be ambisyllabic. (However, this interesting suggestion would require a separate study on single intervocalic consonants).

## 2. Pause-insertion experiment

This experiment uses a modified version of the classical pause-insertion task (e.g., Côté & Kharlamov, 2011; Schiller et al., 1997). Normally the participant is instructed to pronounce the first part of the target word, and after a short pause the second part. This simple pause insertion was refined by providing an external motivation to divide words into syllable-sized chunks – pauses between syllables were induced by a metronome with which the participants had to synchronize individual syllables. The motivation was to turn the participants' attention from syllable division to synchronization, which was presented as the topic of the research. In order to further conceal the aim of the experiment, short sentences were used as carrier phrases. Pause insertion was chosen because it is intuitive for the participants and well suited for the intended modification. The products of the task are sub-words, which can be compared to Experiment 2 eliciting whole-word responses.

### 2.1. Method

#### 2.1.1. Material

The two experiments were part of a single session and the same participants were employed. Therefore, the exact same words could not be compared across the two experiments, as the participants might notice the repeated measures design. Instead, each participant received two words that differed in one or two phonemes. Two parallel sets of 87 disyllabic Czech words with an intervocalic CC cluster were used as targets, which yielded 61 unique clusters. The two sets were matched for phonological and morphological variables (identical medial cluster, identical morphological structure, in the majority of cases also identical vocalic environment and size of the word-initial onset). For instance, the pairs /lamp-a/ "a lamp" vs. /ramp-a/ "a ramp" or /praː-dl-o/ "laundry" vs. /ʒraː-dl-o/ "food" are identical in all respects except for the initial consonants (as the hyphens indicate, the root is followed by the nominative inflectional ending /a/ in the first case, while it is followed by the derivational suffix /dl/ and the nominative inflectional ending /o/ in the other case). Moreover, the two words were similar in the frequency of occurrence; when more candidates for the target words were available, two with the closest token frequency were selected. Token frequencies were obtained from the Czech National Corpus ORAL2013 (Benešová, Křen, & Waclawičová, 2013), partly based on the analysis reported in Šturm and Lukeš (2017). As explained below, I did not use two fixed lists distributed to the participants, but instead assigned the target words from both lists randomly.

Short phrases were constructed from these words to be used as stimuli in the experiment. Each phrase contained two different target words (only one of the corresponding words could be used in a phrase, i.e., /lampa/ and /rampa/ could not appear together). The targets were preceded by 2–4 syllables and followed by 2–7 syllables (usually 3–5). Just as there were two sets of target words, there were two sets of target phrases: each phrase that contained target words like /lampa/ + /praːdlo/ was matched with a phrase that included /rampa/ + /ʒraːdlo/. The remaining portion of these matched phrases was as comparable as possible; whenever permitted by the grammatical and semantic structure, the surrounding words were identical in the matched sentences. The number of syllables was always equal, as was the number and distribution of stress groups. By way of example, the phrase *Zatajil bance loňské postihy* ("*He concealed last year's sanctions from the bank*") was matched with *Zatajil Hance koňské dostihy* ("*He concealed the horse races from Hanka*"); target words are underlined. The non-target words acted as fillers and are not analysed here. In addition, the material also included several distractor items in the target position (22 words with a CCC cluster and four words with a CCCC cluster) that are not analysed here. The complete list of the 100 phrases is provided in Appendix A (174 target words + 26 distractor words, yielding 200 words in total, i.e. two words per phrase).

*2.1.2. Stimuli preparation*

The sentences were read by a female native speaker of Czech (24 years old, a university student of phonetics). The recording took place in a sound-treated booth at the Institute of Phonetics, Charles University in Prague. The material was recorded on a condenser microphone at 32 kHz sampling rate and 16-bit quantization directly into a computer and saved as a WAV file. The speaker read each phrase from the list naturally, with a short break after each item. She was instructed to read slowly, without too much expressiveness and as consistently as possible, with falling intonation at the end of each phrase. In order to facilitate the similarity between the two variants, the matched pairs were presented together, separated from the following sentences by a double space. The speaker was asked to repeat any phrase that was considered inadequate by the experimenter (e.g., vowel centralizations, segment elisions, lengthening, creaky phonation, rising intonation etc.). After processing the recording, individual phrases were saved separately and normalized to 70 dB SPL in Praat (Boersma & Weenink, 2014).

Trials consisted of the speech material and metronome pulses. Each trial began with a 1000-ms silence, followed by the target phrase (approximately two seconds). After a 2000-ms pause, metronome pulses (recorded previously as audio) began to appear at the rate of 80 bpm, i.e. 750 ms apart. There were two lead-in pulses followed by $k + 2$ pulses, where $k$ denotes the number of syllables in the phrase. The whole trial item was concatenated and saved as one audio file.

*2.1.3. Participants and procedure*

30 speakers participated in the experiment (9 males, 21 females; mean age was 20.9 years). They were recruited from university classes and were compensated financially for their time and effort. Each participant was recorded individually. The purpose of the research was not revealed to the participants, being presented as an investigation of speech–metronome synchronization. Three other speakers had piloted the experiment, and their data were not analysed (but were checked for errors and bugs in the experimental design).

The familiarization phase consisted of five training phrases, exemplifying the types encountered later in the experiment (different sequences of medial consonants were used than in the target phrases). The experimenter sat along with the participant in the recording booth and provided feedback after each sentence. The instructions were provided in written form on a computer screen, supplemented by comments and practical demonstration by the experimenter. The participant's task was to (1) listen to a phrase from the loudspeakers, (2) wait for the metronome to start, and (3) recall the phrase and pronounce it to the metronome, synchronizing each syllable with one metronome beat. Specifically, the participants were instructed to articulate the syllables separately, with a pause – not with prolongation of the previous syllable – between the pulses. In a pre-test it was discovered that the suggestion "to speak like a robot" was helpful, so this was included in the instructions as well (characterized as clear, clipped, staccato speech). The pacing was intentionally swift in order to prevent the participants from thinking about the trials by keeping them occupied with the task. The training phase was crucial for correct mastering of the procedure. After all issues had been settled, the experimenter left the room. (For instance, some of the participants asked how they should divide the sentences into syllables; the answer always was that it did not matter – the important thing was to synchronize the syllables with the metronome. Every effort was made to veil the research in such terms, highlighting the synchronization aspect and deflecting the attention from word division).

Each participant received in total 50 phrases with the provision that any particular version prevents the speaker from receiving the matched version; in other words, once a particular phrase was assigned, the matched version could not be used. Across the 30 participants, each version was presented equally often; consequently, the aggregate data included 15 tokens of all "A" targets and 15 tokens of all "B" targets. The experiment was self-paced and consisted of five blocks of 10 phrases each, with short breaks (30 seconds) between the blocks. The stimuli were presented in DMDX, a software application for experiment design and control (Forster & Forster, 2003). The order of the ten phrases in each block was randomized for individual participants (with a provision that each block included at least one of the more complex distractor clusters), and the five blocks were also presented in random order. The duration of the experiment (excluding the training phase) was approximately 18 minutes. The whole session was recorded.

*2.1.4. Data extraction*

The recordings were examined in Praat both auditorily and visually (in the waveform and spectrogram) by the experimenter. It was not necessary to establish a panel of judges because the participants' reactions were unambiguous and, in addition, only the medial cluster was of interest. Each target word was labelled according to where the split between syllables occurred: the CC cluster could be divided as V.CCV, VC.CV or VCC.V. It was further necessary to establish a category of "ambisyllabic" responses for instances when a consonant was kept in the first syllable, but also repeated in the second syllable ($VC_1C_2$-pause-$C_2V$ or $VC_1$-pause-$C_1C_2V$). However, the syllabification VCC.V did not occur, and there were only four instances of ambisyllabic responses. In effect, the participants decided between VC.CV and V.CCV syllabifications, and only these responses were examined.

The category of errors comprised mispronunciations and other aborted or faulty responses. Segment substitutions were coded as errors only when they occurred on the target consonant cluster. The number of missing data was relatively low: only 33 tokens were discarded (1.3% of the data set). The maximum number of errors per speaker was four, and no target word yielded more than two errors. The statistical analyses of Experiment 1 were therefore based on the maximum of 2573 observations (87 target words per participant × 30 participants = 2610 observations, minus missing data and minus ambisyllabic responses).

*2.1.5. Statistical analysis*

As the response variable was effectively binary, mixed-effects logistic regression modelling was used to fit the data (VC.CV = 1, V.CCV = 0), which is considered more accurate than fitting percentages or proportions (Jaeger, 2008). Mixed-effects models employ both fixed effects (various factors that we observe) and random effects (sampled sets like speakers or target words). We should allow for both random intercepts and random slopes if we want to generalize the influence of fixed effects also to speakers/words not present in our sample. It is therefore recommended to use a structure of the relevant random effects including slopes at which the model still converges (Barr, Levy, Scheepers, & Tily, 2013).

The statistical analyses were performed in the R software (R Core Team, 2016) and the R package *lme4* (Bates, Mächler, Bolker, & Walker, 2015). The fixed effects included V1 LENGTH (short, long), SONORITY TYPE (obstruent-obstruent, obstruent-sonorant, sonorant-obstruent, sonorant-sonorant) and MORPHOLOGY (base, prefixed base, C-suffix, CC-suffix). In addition, the results of a phonotactic analysis from Šturm and Lukeš (2017) were used as basis for the factors ONSET FREQUENCY (log word-initial frequency of occurrence, both token and type) and LEGALITY (appearance of the cluster as a word-initial onset in Czech).[2] STRATEGY of the speaker was also considered, based on self-reported data in the post-test questionnaire; the factor was classified into four levels (no strategy, no strategy but aware of the aim, strategy to divide clusters, visualization strategy). Further, PARTICIPANT and WORD were entered as random effects. The inclusion of a predictor (or an interaction) in the model was justified by a significant increase in log-likelihood of models with and without the given predictor (or interaction) using a likelihood ratio test. The subsetting of the data varied due to imbalance of the clusters across categories. Section 2.2.1 reports the results based on 1980 responses, i.e. the whole data set after excluding words with long vowels and with the CC-suffix /dl/ (there was only one CC-suffix in words with a short V1). Section 2.2.2 narrows it down to 1272 responses by filtering out phonotactically illegal clusters. Section 2.2.3 focuses on the effect of vowel length, analysing 338 responses.

Effect plots were created using the packages *effects* (Fox, 2003) and *ggplot2* (Wickham, 2009); the mean value corresponds to the arithmetic mean, whiskers to 95% confidence intervals. Probabilities were calculated from the *glmer* model by the *effects* package, using type = "response" function; generally, the formula for converting logits to probability is $prob = \exp(logit)/(1 + \exp(logit))$.

*2.2. Results*

The data set included 174 distinct words (61 intervocalic CC clusters). The distribution of response patterns for individual clusters is provided in Appendix B, along with information about the phonological, morphological and phonotactic characteristics used in the analyses. Generally, the CC cluster was divided in 75% of the cases, and assigned to the onset of the following syllable in 25% of the cases. As was mentioned above, the speakers did not produce any CC codas in the first syllable, which would otherwise leave the next syllable onsetless. The task also yielded two cases where the first consonant of the cluster was ambisyllabic, and two where the second consonant was ambisyllabic; however, since these responses accounted for merely 0.16% of the data, the ambisyllabic category was omitted from the statistical analyses.

*2.2.1. Morphology, sonority and legality*

The analysed material comprised 134 unique words and 52 unique clusters (only short target vowels included). Overall, the medial cluster was divided in 83% of the cases and syllabified as onset in 17%. Basic item categories are shown in Table 2 (for individual clusters see Appendix B). Fig. 1 shows the

**Table 2**
Cluster characteristics and absolute (relative) number of the syllabifications V.CCV and VC.CV (O = obstruent, S = sonorant). The number of words in each category is given.

| Sonority | Morphology | Legality | .CC | C.C | .CC (%) | C.C (%) | Num of words |
|---|---|---|---|---|---|---|---|
| O-O | Base | Legal | 60 | 297 | 17 | 83 | 24 |
| O-O | Base | Illegal | 3 | 57 | 5 | 95 | 4 |
| O-O | Prefixed base | Legal | 29 | 60 | 33 | 67 | 6 |
| O-O | Prefixed base | Illegal | 10 | 19 | 34 | 66 | 2 |
| O-O | C-suffix | Legal | 17 | 162 | 9 | 91 | 12 |
| O-O | C-suffix | Illegal | 15 | 135 | 10 | 90 | 10 |
| O-S | Base | Legal | 57 | 104 | 35 | 65 | 11 |
| O-S | Prefixed base | Legal | 16 | 14 | 53 | 47 | 2 |
| O-S | C-suffix | Legal | 87 | 162 | 35 | 65 | 17 |
| O-S | C-suffix | Illegal | 18 | 11 | 62 | 38 | 2 |
| S-O | Base | Legal | 0 | 60 | 0 | 100 | 4 |
| S-O | Base | Illegal | 1 | 202 | 0 | 100 | 14 |
| S-O | Prefixed base | Legal | 7 | 53 | 12 | 88 | 4 |
| S-O | C-suffix | Legal | 0 | 30 | 0 | 100 | 2 |
| S-O | C-suffix | Illegal | 0 | 120 | 0 | 100 | 8 |
| S-S | Base | Legal | 0 | 30 | 0 | 100 | 2 |
| S-S | Base | Illegal | 0 | 87 | 0 | 100 | 6 |
| S-S | C-suffix | Legal | 10 | 17 | 37 | 63 | 2 |
| S-S | C-suffix | Illegal | 1 | 29 | 3 | 97 | 2 |

[2] Legality and frequency of the cluster were also defined in terms of word-final occurrence, but this did not turn out to be significant in the analyses (see Section 2.2). The frequency measurements were extracted from a corpus of approximately 40 000 word forms (equalling 88 million text occurrences), and the onset (coda) frequency was defined as relative initial (final) frequency of occurrence of the given cluster in word types (counting unique words) or in word tokens (counting all occurrences, cumulatively).

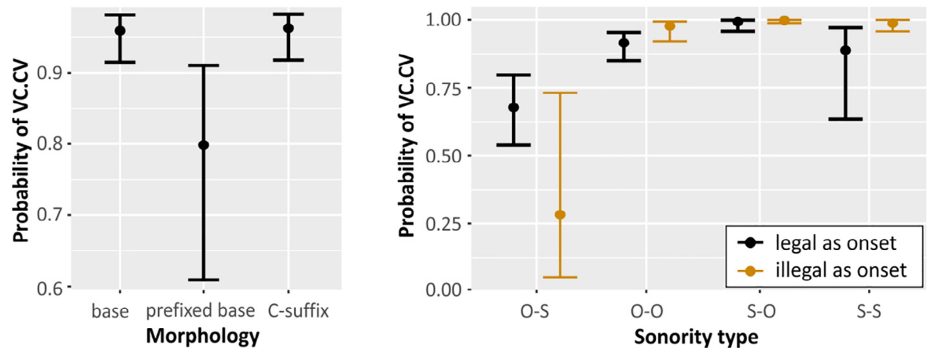


**Fig. 1.** The probability of VC.CV syllabification as a function of morphology (on the left) and sonority type and phonotactic legality (on the right). O = obstruent, S = sonorant.

**Table 3**
Regression coefficients of fixed effects in the logit model. The intercept corresponds to words with a legal O-O cluster that is part of the base (O = obstruent, S = sonorant).

| Fixed effect | Logit | St. Error | *z* | *p*-value |
|---|---|---|---|---|
| Intercept | 2.59 | 0.37 | – | – |
| MORPHOLOGY (prefixed base) | −1.77 | 0.46 | −3.88 | <0.001 |
| MORPHOLOGY (C-suffix) | 0.02 | 0.32 | 0.07 | 0.94 |
| SONORITY (O-S) | −1.69 | 0.36 | −4.71 | <0.001 |
| SONORITY (S-O) | 2.83 | 1.10 | 2.57 | <0.05 |
| SONORITY (S-S) | −0.36 | 0.82 | −0.44 | 0.66 |
| LEGALITY (illegal) | 1.30 | 0.58 | 2.22 | <0.05 |
| SONORITY (O-S) : LEGALITY (illegal) | −2.97 | 1.13 | −2.63 | <0.01 |
| SONORITY (S-O) : LEGALITY (illegal) | 0.53 | 1.44 | 0.37 | 0.71 |
| SONORITY (S-S) : LEGALITY (illegal) | 2.40 | 1.49 | 1.61 | 0.11 |

results of regression modelling (see below for details) on the probability scale, which is more intuitive than the logit values of the regression analysis. The plot on the left shows that prefixed clusters were associated with lower probability of VC.CV syllabification than base clusters, whereas C-suffix clusters did not differ significantly. With regard to sonority classes (Fig. 1 on the right), O-S clusters yielded the lowest probability of VC.CV syllabification, but the effect interacts with onset legality: O-O, S-O and S-S clusters that are illegal word-initially showed a significant increase in the probability of division compared to legal clusters (phonotactically illegal O-S clusters seem to be associated with lower probability of VC.CV syllabification, but the difference from legal clusters was not significant, $p = 0.09$).

The regression model was constructed by adding factors in the order of greatest improvement of its fit. SONORITY TYPE was added first ($\chi^2(3) = 52.8$, $p < 0.001$), then MORPHOLOGY ($\chi^2(2) = 17.8$, $p < 0.001$). There was no significant interaction between the factors. Adding phonotactic LEGALITY defined with respect to word onsets also significantly improved the model ($\chi^2(1) = 6.0$, $p < 0.05$), unlike word-final legality ($\chi^2(1) = 1.0$, $p = 0.30$), and it turned out to be in interaction with sonority ($\chi^2(3) = 11.7$, $p < 0.01$). STRATEGY was not a significant factor ($\chi^2(3) = 5.1$, $p = 0.16$).[3] The structure of random effects at which the model still converged included (0 + SONORITY TYPE + LEGALITY | SPEAKER) and (1 | WORD). Parameters of the final model are given in Table 3.

### 2.2.2. Frequency of occurrence

The data from the previous section include both legal and illegal clusters. Here I analyse the influence of the word-initial frequency of occurrence of the cluster (word-final frequency is not considered as there was no effect of word-final legality). After filtering out phonotactically illegal clusters, a new series of regression models was constructed with SONORITY TYPE, MORPHOLOGY and ONSET FREQUENCY. Sonority was a significant predictor ($\chi^2(3) = 27.7$, $p < 0.001$), as was morphological structure ($\chi^2(2) = 10.3$, $p < 0.01$). The relevant finding is that the frequency of occurrence of the cluster at word beginnings was a significant predictor as well, using both token ($\chi^2(1) = 4.4$, $p < 0.05$) and type frequency ($\chi^2(1) = 4.2$, $p < 0.05$). The probabilities of VC.CV syllabification are shown in Fig. 2; the graphs indicate that token and type frequency measures yield similar patterns.[4]

### 2.2.3. Vowel length

This section reports the results on the effect of vowel length (V1 length). Although the sample is relatively large, it is not balanced, partly because the attention was restricted to words occurring in a corpus of texts. Therefore, I identified six phonotactically legal clusters that differed in the length of the preceding vowel, whereas the morphological structure of the pair was identical (Table 4). In one pair, the clusters differed (/sn/ × /ʃn/) but were considered equal with respect to vowel length behaviour. The data comprise 23 unique words. A series of logistic mixed-effects models was created. Fig. 3 shows the probability of cluster division as a function of vowel length and sonority type. The probability of CV.VC syllabification was higher after a short than after a long vowel, but this effect was cancelled out in O-S clusters.

The inclusion of V1 LENGTH was significant ($\chi^2(1) = 8.4$, $p < 0.01$), as was the subsequent addition of SONORITY TYPE ($\chi^2(1) = 9.0$, $p < 0.01$). These two factors interacted significantly ($\chi^2(1) = 8.9$, $p < 0.01$). Adding MORPHOLOGY did not lead to a better fit of the model ($\chi^2(2) = 1.7$, $p = 0.43$). It was possible to use the full structure of random effects in the model (1 + V1 LENGTH*SONORITY TYPE | SPEAKER), which allows not only for individual sensitivity to the two factors, but to their

[3] Four participants tried to divide the words "in the middle", thus presumably splitting the clusters, and three visualized the words orthographically. The remaining 12 speakers that were aware of the goal claimed to divide the words intuitively, without conscious preparation. Finally, 11 speakers stated that they were not aware of the goal at all.

[4] It would also be interesting to examine cluster frequency in general (i.e., the frequency of occurrence of the given cluster irrespective of word position). However, the frequency data in Šturm and Lukeš (2017) provide information only about word beginnings and ends, omitting word-medial clusters, so this effect could not be investigated here.

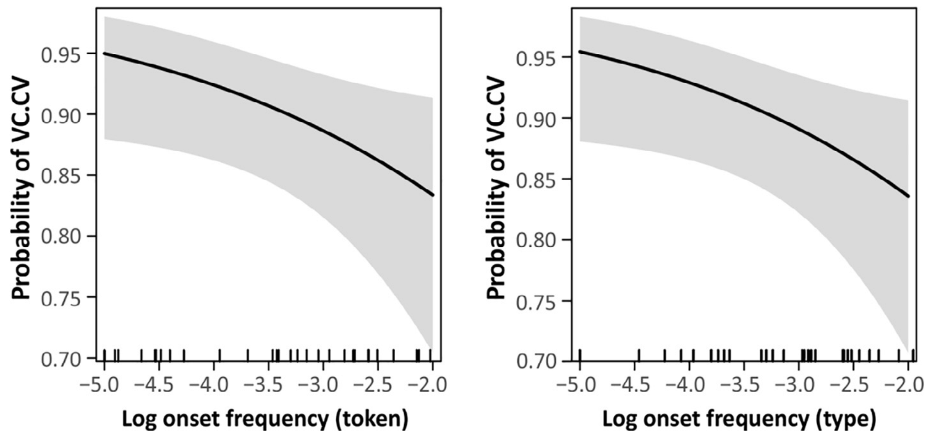


**Fig. 2.** The probability of VC.CV syllabification as a function of word-initial onset frequency of occurrence.

**Table 4**
Cluster characteristics and absolute (relative) number of the syllabifications V.CCV and VC.CV (O = obstruent, S = sonorant). The number of words in each category is given.

| Sonority | Cluster | V1 length | Morphology | .CC | C.C | .CC (%) | C.C (%) | Num of words |
|---|---|---|---|---|---|---|---|---|
| O-O | /st/ | Short | Base | 3 | 27 | 10 | 90 | 2 |
| O-O | /st/ | Long | Base | 17 | 13 | 57 | 43 | 2 |
| O-O | /ʃc/ | Short | Base | 5 | 24 | 17 | 83 | 2 |
| O-O | /ʃc/ | Long | Base | 15 | 15 | 50 | 50 | 2 |
| O-O | /sk/ | Short | Base | 8 | 22 | 27 | 73 | 2 |
| O-O | /sk/ | Long | Base | 6 | 8 | 43 | 57 | 1 |
| O-O | /tk/ | Short | C-suffix | 3 | 27 | 10 | 90 | 2 |
| O-O | /tk/ | Long | C-suffix | 17 | 13 | 57 | 43 | 2 |
| O-S | /dl/ | Short | CC-suffix | 19 | 10 | 66 | 34 | 2 |
| O-S | /dl/ | Long | CC-suffix | 17 | 13 | 57 | 43 | 2 |
| O-S | /ʃn/ | Short | C-suffix | 13 | 15 | 46 | 54 | 2 |
| O-S | /sn/ | Long | C-suffix | 15 | 13 | 54 | 46 | 2 |

interaction as well. The fixed-effect parameters of the final model are given in Table 5.

### 2.2.4. Individual clusters

It is possible that the classification of clusters into only four sonority groups is too coarse. Although the results for individual clusters are provided in Appendix B, I shall discuss them briefly in this section with the aid of graphs that show the mean percentage of VC.CV syllabification computed from individual words (Fig. 4). Fig. 4a and b capture clusters with a sonorant consonant as $C_1$. It is clear that both classes are relatively homogeneous and almost all clusters (except for /mɲ/ and /rv/) were unambiguously divided between the syllables. The cluster /mɲ/ is very frequent word-initially in Czech, which is not true for /rv/ (Šturm & Lukeš, 2017). The sequences of two obstruents (Fig. 4c) were also quite homogeneous: their syllabification was not as clearly defined as in the previous category, but it still oscillated around 80%. The outlying cluster /ps/ belongs – along with /br̩/ – to sequences with a rising sonority pattern,[5] but in contrast to /br̩/ it has somewhat higher frequency of occurrence word-initially, which might explain its greater resistance to splitting (in addition, /ps/ occurred after a prefix, namely /na/ and /za/, which also facilitates V.CCV). Finally, O-S clusters (Fig. 4d) were associated with the lowest homogeneity, even within the fricative and plosive subgroups. The cluster /bj/, which was unanimously preserved as an onset, has an ideal rising sonority pattern, with the greatest possible distance between the consonants. Nevertheless, its

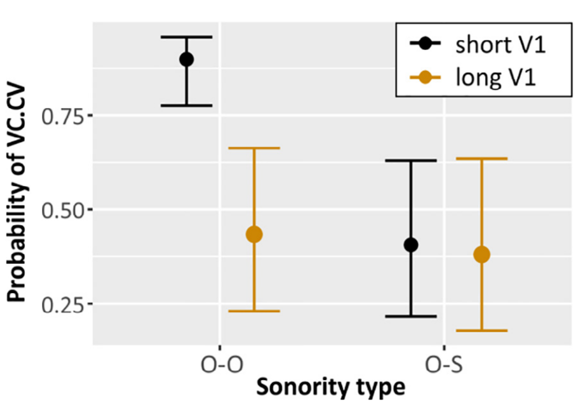


**Fig. 3.** The probability of VC.CV syllabification as a function of vowel length and sonority type (V1 = preceding vowel, O = obstruent, S = sonorant).

**Table 5**
Regression coefficients of fixed effects in the logit model. The intercept corresponds to words with an O-O cluster that are preceded by a long vowel (O = obstruent, S = sonorant).

| Fixed effect | Logit | St. Error | *z* | *p*-value |
|---|---|---|---|---|
| Intercept | −0.27 | 0.48 | – | – |
| V1 LENGTH (short) | 2.44 | 0.52 | 4.69 | <0.001 |
| SONORITY (O-S) | −0.22 | 0.52 | −0.43 | 0.67 |
| V1 LENGTH (short) : SONORITY (O-S) | −2.33 | 0.73 | −3.22 | <0.01 |

[5] The sonority scale referred to here is *oral stops* > *fricatives* > *nasals* > *liquids* > *glides* > *vowels* (Clements, 1990, p. 286).

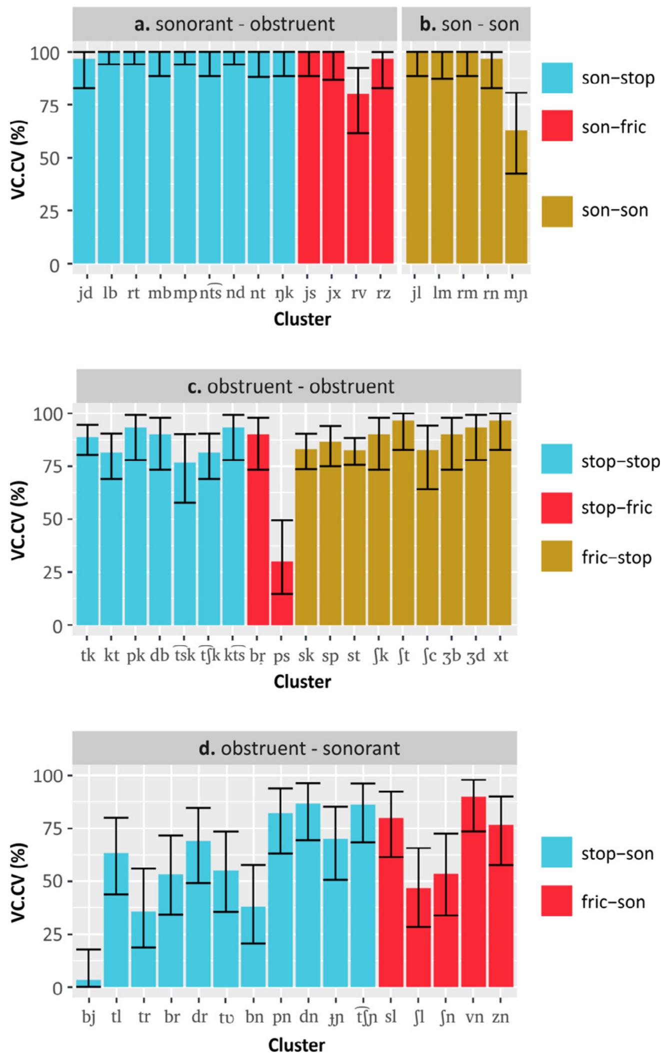


Fig. 4. The mean percentage of VC.CV syllabification according to sonority types (a–d) and individual clusters (son = sonorant, fric = fricative, stop = oral stop, i.e. plosive/affricate).

syllabification might quite as likely be due to an orthographic effect, as it was part of the words *sobě* ("to oneself") and *době* ("of some time"), which are spelled with a single letter and which undergo alternations of the type /doba/ ~ /dobjɛ/.

### 2.3. Discussion

Experiment 1 presented behavioural data elicited from 30 speakers of Czech using a modified method of pause insertion. As the responses were essentially binary in nature – either VC.CV or V.CCV – mixed-effects logistic regression modelling was employed for statistical evaluation. It may seem, on the surface, that the absence of VCC.V syllabification confirms the validity of the Maximum Onset Principle. However, splitting the cluster between two syllables, which was the globally preferred outcome of the experiment, was frequently associated with sequences that *do* occur at word beginnings (e.g., /rv/, /zn/, /ps/, /st/). The syllabification VC.CV would only be predicted by onset maximization if the cluster is illegal word-initially (e.g. /lb/ or /xt/). Therefore, we cannot invoke the principle of "onset maximization", since the data only indicate that the onset must be filled – the onset may (but does not have to) be maximal. A more accurate term would thus be "onset filling" (Berg & Niemi, 2000) or "obligatory onset".

On the whole, the results seem to indicate that the speakers tended to follow sorority relations in their production (sonority falling from the peak towards the syllable edges). When the cluster comprised a sonorant consonant as $C_1$, the cluster was divided between the two syllables in the majority of cases. In contrast, when sonorants occurred as $C_2$ in an obstruent-sonorant cluster (e.g., /tr/, /kn/, /sɲ/), the proportion of VC.CV responses decreased considerably. Thus, sonorant-stop and stop-sonorant clusters yielded completely different patterns. However, since in most cases the S-O cluster is at the same time phonotactically illegal word-initially, it is difficult to ascribe the syllabification outcome to sonority per se. The answer could be provided by words with a legal S-O sequence (e.g., /rt/ *berte* "take [imperative]", *kartu* "card") and words with an illegal cluster of a different sonority type (e.g., /xt/ *šachty* "shafts", /t͡sk/ *klacky* "sticks"). The former was syllabified as VC.CV by all speakers, and the latter yielded a similar outcome (VC.CV syllabification in more than 90% of the speakers). Thus, sonority and phonotactics may, to a certain extent, be independent factors. With regard to phonotactics, the results showed not only an effect of phonotactic legality (defined by the cluster's occurrence word-initially) but also a frequency effect in legal clusters: the probability of VC.CV syllabification was lower for high-frequency clusters.

Several items in the data (23 words) allowed us to investigate the effect of vowel length. The literature on syllabification reports both an opposition of short–long vowels (e.g. Treiman and Zukowski, 1990) and differences in phonetic duration (Ní Chiosáin et al., 2012). The probability of cluster division was indeed higher after a short vowel than after a long vowel, but surprisingly only in O-O clusters – there seemed to be no such effect in O-S clusters. These results might point out to an availability of a phonological analysis of syllabification where the sonority of a tautosyllabic cluster outranks weight requirements. Furthermore, although I do not possess data for S-O clusters, we can anticipate that the effect would not be marked, if any, as this is the category which approaches 100% cluster division rate. In any case, a larger data set would be necessary to investigate this effect further.

The morphological structure of the words should be considered as well. Unlike in most studies, which ignore morphology or use monomorphemic words, I included this factor in the analyses although it increases the imbalance of the sample. The intervocalic cluster could be part of the base (e.g., /naː-stup/ "boarding", which is prefixed, or /rɪsk-ɛm/ "with risk", non-prefixed), could be divided between the base and a C suffix (/bjɛʃ-tɛ/ "go [imperative]") or in a few cases it could form a CC suffix (/ʒraː-dl-o/ "food"); it should be noted that in all words the target cluster was located after the stressed syllable, as Czech prefixes attract stress from the root. On the whole it cannot be said that the presence of a morpheme boundary increases the probability of a syllable boundary. A significant effect was ascertained only for prefixed base clusters (after vowel-final prefixes /na/, /naː/, /do/, /vɪ/ etc.) – in these cases, the division rate was lower compared to unprefixed base clusters. An influence on syllabification was also associated with the CC suffixes /dl/ and /t͡ʃk/, which had a tendency to form the onset of the following syllable (however, they were most often preceded by a long vowel so it is unclear to what extent the effect is attributable to morphology). Finally, intervocalic clusters in which $C_2$ was part of a suffix and $C_1$ part of the base (/muʃ-kɪ/ “flies [diminutive]”) did not demonstrate any difference from clusters in which both $C_1$ and $C_2$ were part of the base morpheme (/rɪsk-ɛm/ “with risk”). It seems that the effect of CC and C suffixes is therefore not analogical.

## 3. Syllable-reversal experiment

A second experiment was prepared in order to determine whether the findings generalize to a different task, which must not necessarily be the case considering their different predispositions (see Côté and Kharlamov, 2011). Experiment 2 employs a syllable reversal (permutation) task (e.g., Berg & Niemi, 2000; Schiller et al., 1997), which differs from pause insertion for instance in that the result is a whole word and the operation is nonlinear. In this paradigm the participant is asked to reverse the order of two syllable-sized chunks in the target word, without explicitly referring to “syllables”. However, since the participants were the same participants as in Experiment 1, in which syllables had already been mentioned, the experimenter did not strictly adhere to this condition. If participants asked whether “part of the word” means “syllable”, the answer was positive.

### 3.1. Method

#### 3.1.1. Material and stimuli preparation

Two sets of 87 disyllabic Czech words with an intervocalic CC cluster were used as targets, identical to those of Experiment 1. However, there was no embedding in carrier sentences. The same speaker read the words in citation form under identical recording conditions and with similar instructions. The experimenter checked whether the production was as neutral as possible and consistent throughout, and the speaker corrected any words if necessary. The matched words were again presented together, separated from the surrounding words by a double space in the reading list. Individual words were then saved separately and normalized to 70 dB SPL in Praat (Boersma & Weenink, 2014).

#### 3.1.2. Participants and procedure

Experiment 2 was administered after a 5-minute break following Experiment 1. The same 30 speakers participated in the two experiments. Crucially, if the participant worked with a specific sentence in Experiment 1, the two target words from this sentence (e.g., /lampa/ “a lamp” and /postɛl/ “a bed”) could not appear in Experiment 2, being substituted here with the matched target words (/rampa/ “a ramp” and /kostɛl/ “a church”). Consequently, no participant received both corresponding words within one experiment, and no participant received the same target word across the two experiments.

The familiarization phase consisted of ten training words, exemplifying the types encountered later in the experiment (different sequences of medial consonants were used than in the target words). The experimenter sat along with the participant in the recording booth and provided feedback after each word. The instructions were provided in written form on a computer screen, supplemented by comments and practical demonstration by the experimenter. The experiment was introduced as “a word game” in which the participant’s task was to (1) listen to a word played from loudspeakers and (2) pronounce its “second part” followed by its “first part”. The result should be a new nonsense word, i.e., not two items separated by a pause; the new item was stressed on the first syllable, conforming to the Czech stress pattern. The participants were instructed to respond as quickly as possible; the expressions “spontaneous” and “intuitive” were used in describing the task. The pacing was swift and no corrections were demanded from the participants (they were told that errors were expected, and should not be a cause of worry). The time pressure and discouragement from self-monitoring were intended to distract the participants’ attention from syllable division. After all issues had been settled in the training phase, the experimenter left the room.

Individual trials involved the target word preceded by a 1000-ms silence. The experiment was self-paced (i.e., participants could stop between trials in case of need, but generally did not) and consisted of five blocks of 20 words each, with short breaks (30 seconds) between the blocks. There were 100 words in total per participant (87 targets + 13 distractors). The stimuli were presented in DMDX (Forster & Forster, 2003). The order of the 20 words in each block was randomized for individual participants, and the five blocks were also presented in random order. Due to the swift pacing the duration of the experiment was approximately 8 minutes (excluding training).

#### 3.1.3. Data extraction

The recordings were examined auditorily and visually in Praat by the experimenter. The medial CC cluster of each target word (e.g. /postɛl/ “a bed”) was labelled as one of the following:

- V.CCV = the production of /stɛl-po/;
- VC.CV = the production of /tɛl-pos/;
- VCC.V = the production of /ɛl-post/;
- V(.)C(.)CV = the production of /stɛl-pos/, where the first consonant was ambisyllabic (repeated in both syllables);
- VC(.)C(.)V = the production of /tɛl-post/, where the second consonant was ambisyllabic (repeated in both syllables).

Errors and other incomplete or faulty trials were discarded from analyses (195 tokens in total, i.e., 8% of the data set). The maximum number of errors per speaker was 15 (median = 6), and no target word yielded more than nine errors. Note that an increased error rate was expected given the relative difficulty of the task and that errors were not corrected during recording. The analyses of Experiment 2 were therefore based on the maximum of 2415 observations (87 target words per participant $\times$ 30 participants = 2610 observations, minus missing data).

#### 3.1.4. Statistical analysis

The statistics was analogical to Experiment 1, including the effects structure (see Section 2.1). However, since the results show an interaction of morphology and sonority in a factorial design that is not fully crossed, the sonority factor levels had to be conflated into three (O-O, O-S and S-O/S-S) so that each morphology level would co-occur with all sonority levels. Mixed-effects logistic regression models were constructed in the R software (R Core Team, 2016). The mean value in effect plots corresponds to the arithmetic mean, whiskers to 95% confidence intervals. Regression models yield logit values, whereas effect plots display probabilities.

The subsetting of the data again varied due to imbalance of the clusters across categories. Section 3.2.1 reports the results based on 1855 responses, i.e. the whole data set after excluding words with long vowels and with the CC-suffix /dl/. Section 3.2.2 narrows it down to 1022 responses by filtering out phonotactically illegal clusters. Section 3.2.3 focuses on the effect of vowel length, analysing 326 responses.

### 3.2. Results

The data set included 174 distinct words (61 intervocalic CC clusters). The distribution of response patterns for individual clusters is provided in Appendix B. Generally, the CC cluster was divided in 50% of the cases, and assigned to the onset of the following syllable in 42% of the cases. The speakers did not produce any CC codas in the first syllable. The task also yielded 189 ambisyllabic responses (overwhelmingly with C1 ambisyllabicity), accounting for 8% of the data.

#### 3.2.1. Morphology, sonority and legality

This section reports the results based on 134 words and 52 clusters (only short vowels included). The medial cluster was divided in 56% of the cases, syllabified as onset in 36% and considered as ambisyllabic in 9%. Basic item categories are shown in Table 6 (for individual clusters see Appendix B). In comparison with the previous experiment, there was a greater number of ambisyllabic responses, especially in the legal C-suffix cluster /mɲ/. A series of logistic mixed-effects models was created after excluding the ambisyllabic responses (see below for details). Fig. 5 shows the probability of VC.CV syllabification. It is clear that O-S clusters were associated with the lowest probability of cluster splitting, whereas clusters beginning with a sonorant (S-O/S-S) yielded the highest probability (this difference was most marked in the morphological categories of base and C-suffix clusters). O-O clusters were associated with intermediate probability of VC.CV syllabification. With regard to morphology, the clearest pattern was that prefixed clusters were more likely to be syllabified as onsets, and C-suffix clusters did not behave differently from base clusters except for the O-S sonority type, where the presence of a morphological boundary in the middle of the cluster led to a significant increase in the probability of VC.CV syllabification.

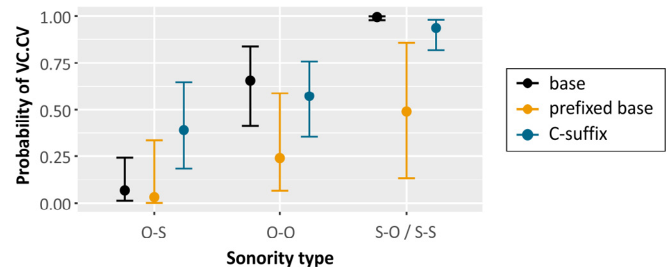


**Fig. 5.** The probability of VC.CV syllabification as a function of sonority type and morphological structure (O = obstruent, S = sonorant).

During the regression model construction, SONORITY TYPE ($\chi^2(2) = 34.7$, $p < 0.001$) was added first, then MORPHOLOGY ($\chi^2(2) = 18.3$, $p < 0.001$); there was significant interaction between them ($\chi^2(4) = 25.5$, $p < 0.001$). Adding LEGALITY did not improve the model further ($\chi^2(1) = 1.5$, $p = 0.22$ for onset legality, $\chi^2(1) = 0.06$, $p = 0.80$ for coda legality). STRATEGY was not a significant factor ($\chi^2(3) = 7.7$, $p = 0.06$). The random effects consisted of (1 | WORD) and (1 + SONORITY TYPE

**Table 7**
Regression coefficients of fixed effects in the logit model. The intercept corresponds to words with an O-O cluster that is part of the base (O = obstruent, S = sonorant).

| Fixed effect | Logit | St. Error | z | p-value |
|---|---|---|---|---|
| Intercept | 0.70 | 0.51 | – | – |
| SONORITY (O-S) | −3.36 | 0.70 | −4.81 | <0.001 |
| SONORITY (S-O/S-S) | 4.49 | 0.74 | 6.05 | <0.001 |
| MORPHOLOGY (prefixed base) | −1.86 | 0.73 | −2.54 | <0.05 |
| MORPHOLOGY (C-suffix) | −0.42 | 0.50 | −0.85 | 0.40 |
| SONORITY (O-S): MORPHOLOGY (pr. base) | 1.01 | 1.57 | 0.64 | 0.52 |
| SONORITY (O-S): MORPHOLOGY (C-suffix) | 2.63 | 0.85 | 3.11 | <0.01 |
| SONORITY (S-O/S-S) : MORPHOLOGY (pr. base) | −3.36 | 1.23 | −2.73 | <0.01 |
| SONORITY (S-O/S-S) : MORPHOLOGY (C-suffix) | −2.06 | 0.87 | −2.37 | <0.05 |

**Table 6**
Cluster characteristics and absolute (relative) number of the syllabifications V.CCV, VC.CV and ambisyllabic responses (O = obstruent, S = sonorant, A = total number of ambisyllabic responses, but the number in brackets indicates how many of those refer to the second consonant being ambisyllabic). The number of words in each category is given.

| Sonority | Morphology | Legality | .CC | C.C | A | .CC (%) | C.C (%) | A (%) | Num of words |
|---|---|---|---|---|---|---|---|---|---|
| O-O | Base | Legal | 135 | 177 | 30 (4) | 39 | 52 | 10 | 24 |
| O-O | Base | Illegal | 16 | 38 | 5 (0) | 27 | 64 | 8 | 4 |
| O-O | Prefixed base | Legal | 51 | 27 | 1 (0) | 65 | 34 | 1 | 6 |
| O-O | Prefixed base | Illegal | 17 | 12 | 0 (0) | 59 | 41 | 0 | 2 |
| O-O | C-suffix | Legal | 67 | 85 | 13 (0) | 41 | 52 | 9 | 12 |
| O-O | C-suffix | Illegal | 62 | 66 | 8 (0) | 46 | 49 | 6 | 10 |
| O-S | Base | Legal | 94 | 31 | 27 (0) | 62 | 20 | 17 | 11 |
| O-S | Prefixed base | Legal | 23 | 4 | 2 (0) | 79 | 14 | 7 | 2 |
| O-S | C-suffix | Legal | 112 | 95 | 26 (0) | 48 | 41 | 10 | 17 |
| O-S | C-suffix | Illegal | 13 | 7 | 1 (0) | 62 | 33 | 5 | 2 |
| S-O | Base | Legal | 3 | 50 | 2 (0) | 5 | 91 | 4 | 4 |
| S-O | Base | Illegal | 11 | 163 | 18 (7) | 6 | 85 | 9 | 14 |
| S-O | Prefixed base | Legal | 24 | 27 | 0 (0) | 47 | 53 | 0 | 4 |
| S-O | C-suffix | Legal | 3 | 23 | 3 (1) | 10 | 79 | 10 | 2 |
| S-O | C-suffix | Illegal | 9 | 100 | 6 (0) | 8 | 87 | 5 | 8 |
| S-S | Base | Legal | 1 | 27 | 2 (2) | 3 | 90 | 7 | 2 |
| S-S | Base | Illegal | 3 | 74 | 2 (1) | 4 | 94 | 3 | 6 |
| S-S | C-suffix | Legal | 12 | 1 | 16 (0) | 41 | 3 | 55 | 2 |
| S-S | C-suffix | Illegal | 2 | 26 | 2 (0) | 7 | 87 | 7 | 2 |

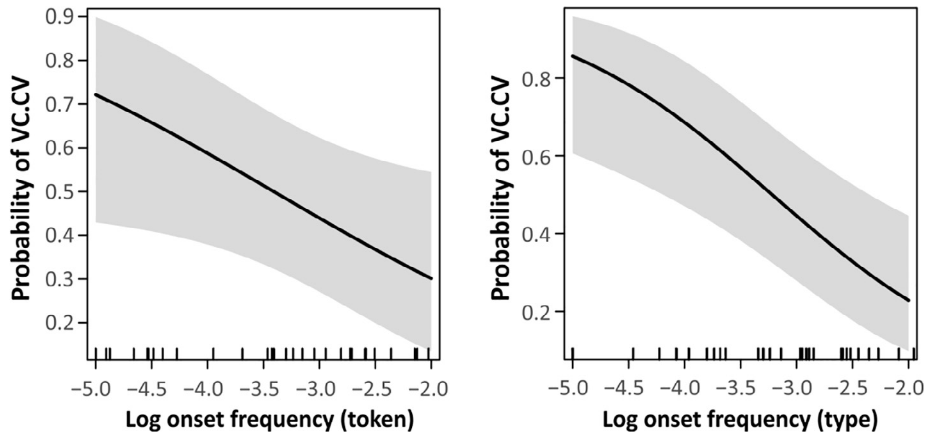


**Fig. 6.** The probability of VC.CV syllabification as a function of word-initial onset frequency of occurrence.

+ MORPHOLOGY | SPEAKER). The parameters of the final model are provided in Table 7.

### 3.2.2. Frequency of occurrence

The influence of the cluster's word-initial onset frequency was analysed after filtering out phonotactically illegal clusters. A new series of regression models was constructed with SONORITY TYPE, MORPHOLOGY and ONSET FREQUENCY. Adding both sonority and morphology led to a significantly better fit ($\chi^2(2) = 17.5$, $p < 0.001$ and $\chi^2(2) = 9.9$, $p < 0.01$, respectively). Their interaction reported above was confirmed for this subsample of legal clusters ($\chi^2(4) = 18.1$, $p < 0.01$). With regard to the onset frequency effect, both token and type measures increased the model's goodness-of-fit significantly ($\chi^2(1) = 4.3$, $p < 0.05$ and ($\chi^2(1) = 10.5$, $p < 0.01$, respectively), but note that type frequency was a somewhat better predictor of cluster splitting than token frequency. Fig. 6 shows that in both analyses the probability of VC.CV syllabification decreased with increasing onset frequency of the cluster.

### 3.2.3. Vowel length

I identified six phonotactically legal clusters that differed in the length of the preceding vowel, whereas the morphological structure of the pair was identical (Table 8, using the same subset as Experiment 1). The data comprised 23 unique words. The distribution of responses for the short vs. long condition suggests that short vowels tend to be associated with codas (VC.CV syllabification) more than long vowels, but the strength of the effect seems to vary with individual clusters. With regard to the ambisyllabic responses (6% of data), the proportions were equal or higher for the short vowel condition (with the exception of obstruent-nasal clusters).

A series of logistic mixed-effects models was created based on this data after excluding the ambisyllabic responses, focusing on the choice between cluster split (VC.CV) vs. cluster intactness (V.CCV). V1 LENGTH was a significant predictor ($\chi^2(1) = 6.3$, $p < 0.05$), but SONORITY TYPE did not lead to a significantly better fit of the model ($p = 0.30$), and there was no significant interaction between the two effects. Fig. 7 on the left shows the probability of cluster division as a function of vowel length. After long vowels the probability of VC.CV was lower compared to the short vowel condition. Furthermore, goodness-of-fit increased significantly after adding MORPHOLOGY to the model ($\chi^2(2) = 17.3$, $p < 0.001$); the interaction with vowel length was not significant ($p = 0.56$). As can be seen in Fig. 7 on the right, it was the CC-suffix condition (the cluster /dl/) that contributed to the significance of morphology, lowering the probability of VC.CV syllabification. The fixed-effect parameters of the final model are given in Table 9.

### 3.2.4. Individual clusters

Fig. 8 follows Fig. 4 of the first experiment, breaking the four sonority groups into smaller groups and ultimately into individual clusters. The S-O and S-S groups were again relatively homogeneous, characterized by a preference for VC.CV syllabification; however, three clusters differed: /rv/, which

**Table 8**
Cluster characteristics and absolute (relative) number of the syllabifications V.CCV, VC.CV and ambisyllabic responses (O = obstruent, S = sonorant, A = first consonant of the cluster ambisyllabic). The number of words in each category is given.

| Sonority | Cluster | V1 length | Morphology | .CC | C.C | A | .CC (%) | C.C (%) | A (%) | Num of words |
|---|---|---|---|---|---|---|---|---|---|---|
| O-O | /st/ | Short | Base | 13 | 16 | 1 | 43 | 53 | 3 | 2 |
| O-O | /st/ | Long | Base | 16 | 10 | 1 | 59 | 37 | 4 | 2 |
| O-O | /ʃc/ | Short | Base | 16 | 12 | 2 | 53 | 40 | 7 | 2 |
| O-O | /ʃc/ | Long | Base | 21 | 7 | 2 | 70 | 23 | 7 | 2 |
| O-O | /sk/ | Short | Base | 12 | 13 | 5 | 40 | 43 | 17 | 2 |
| O-O | /sk/ | Long | Base | 9 | 6 | 0 | 60 | 40 | 0 | 1 |
| O-O | /tk/ | Short | C-suffix | 15 | 8 | 0 | 65 | 35 | 0 | 2 |
| O-O | /tk/ | Long | C-suffix | 20 | 10 | 0 | 67 | 33 | 0 | 2 |
| O-S | /dl/ | Short | CC-suffix | 23 | 3 | 4 | 77 | 10 | 13 | 2 |
| O-S | /dl/ | Long | CC-suffix | 27 | 2 | 1 | 90 | 7 | 3 | 2 |
| O-S | /ʃn/ | Short | C-suffix | 2 | 20 | 1 | 9 | 87 | 4 | 2 |
| O-S | /sn/ | Long | C-suffix | 17 | 8 | 3 | 61 | 29 | 11 | 2 |

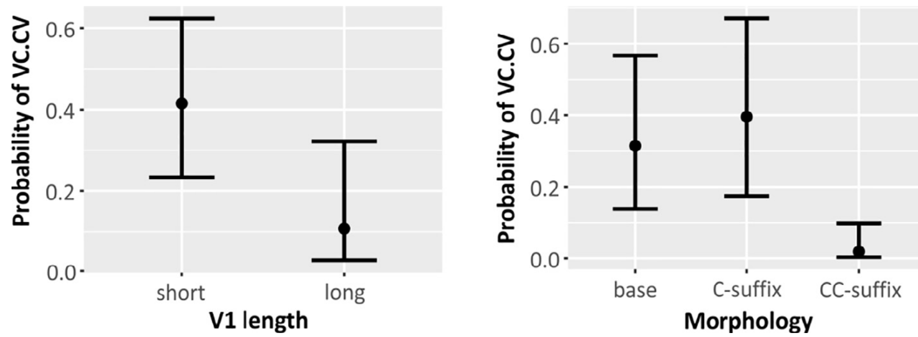


**Fig. 7.** The probability of VC.CV syllabification as a function of vowel length (left) and morphological structure (right); V1 = preceding vowel, O = obstruent, S = sonorant.

**Table 9**
Regression coefficients of fixed effects in the logit model. The intercept corresponds to base clusters that are preceded by a long vowel (O = obstruent, S = sonorant).

| Fixed effect | Logit | St. Error | *z* | *p*-value |
|---|---|---|---|---|
| Intercept | −1.66 | 0.73 | – | – |
| V1 LENGTH (short) | 1.77 | 0.61 | 2.88 | <0.01 |
| MORPHOLOGY (C-suffix) | 0.36 | 0.52 | 0.69 | 0.50 |
| MORPHOLOGY (CC-suffix) | −3.14 | 0.81 | −3.90 | <0.001 |

was preferentially syllabified as V.CCV, and /jd/ and /mɲ/, which elicited a substantial number of these responses. The new finding relates to the behaviour of /jd/, which was not an outlier in Experiment 1. Although untypical in sonority as an onset, the cluster /jd/ is phonotactically legal, being the initial part of the verb "to go" in some of its conjugations.[6] Actually, the cluster was part of the words /najdɛʃ/ ("you will find") and /zajdɛʃ/ ("you will go"), with the prefixes /na/ and /za/ before the root of "to go", so this might explain why speakers did not have difficulties starting the word with this cluster despite the untypical sonority pattern (/jdɛʃna/).

With regard to the O-O group we can state that most of the clusters were associated with more V.CCV responses compared to Experiment 1. A marked difference concerns the clusters /t͡sk/, /t͡ʃk/ and /br̝/. Surprisingly, the former two are phonotactically illegal, with only /br̝/ appearing at word beginnings. In addition, /ʒd/ was treated identically to Experiment 1, which paradoxically makes it an outlier here, as other fricative-stop clusters yielded lower proportions of VC.CV. Finally, O-S clusters also showed an increase in V.CCV syllabification generally but the cluster /ʃn/ was unambiguously syllabified as VC.CV (although in the first experiment it was balanced between the two options). In sum, the four sonority groups generally do not seem to behave differently across the two experiments, provided that we recognize an overall trend for an increase in V.CCV and ambisyllabic responses in the second experiment. The correlation between the number of VC.CV responses in Experiment 1 and 2, based on the categories in Appendix B, was highly significant ($r = 0.90$, $t = 15.05$, $p < 0.001$).

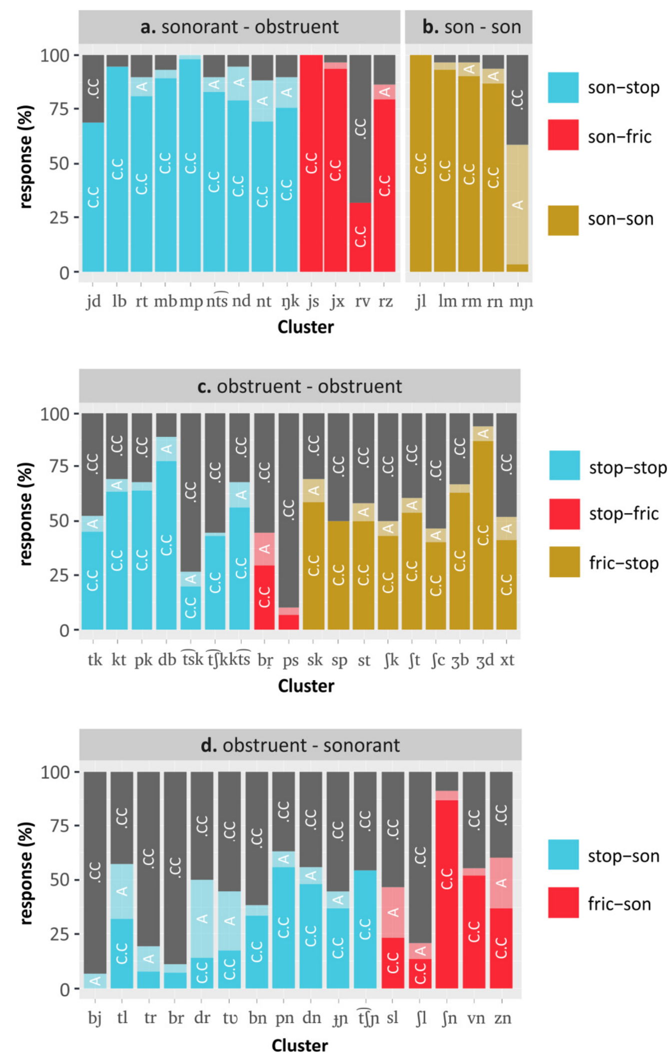


**Fig. 8.** The mean percentage of syllabification responses (full colour = VC.CV, light colour = ambisyllabic, grey = V.CCV) according to sonority types (a–d) and individual clusters (son = sonorant, fric = fricative, stop = oral stop, i.e. plosive/affricate).

### *3.3. Discussion*

Experiment 2 was set up to replicate Experiment 1 using the method of syllable reversal. The response patterns were more complex since the speakers produced also an appreciable number of ambisyllabic responses ($n = 195$, i.e., 8% of all valid responses; $n = 4$ in Experiment 1), generally of the V(.)C(.)CV type. This increase could be a consequence of the task: inserting a pause into a word on the one hand and syllable reversal on the other place very different demands on the speakers in terms of the linearity of manipulation with the word. It is proba-

[6] The /jd/ sequence is phonetically a true consonant cluster. Specifically, it is not a sequence of [ɪ] and [d]. Therefore, the Czech word /jdɛ/ "she goes" is monosyllabic and – unlike the disyllabic nonword /ɪdɛ/ – cannot begin with a glottal stop.

ble that reordering the syllables is cognitively more strenuous and speakers might be less aware of whether or not they have already produced the medial consonant. Despite this, the results still show a lower rate of ambisyllabic responses than most other studies (Berg & Niemi, 2000; Elzinga & Eddington, 2014; Fallows, 1981; Treiman & Danis, 1988). However, these examined other languages, which need not behave like Czech, and used different methods and often different material (single intervocalic consonants). Furthermore, the second experiment was associated with a higher number of V.CCV responses, where the cluster is preserved as an onset, which could also be a task-related consequence, especially since this increase was found across all categories.

Abstracting away from such differences, the results of both experiments point to similar conclusions. The manner-of-articulation characteristics of the medial cluster significantly predicted the outcome of syllable division in Experiment 2. Specifically, clusters with sonorant consonants in the first position were predominantly divided between the two syllables. In contrast, the participants demonstrated a preference for V.CCV syllabification concerning obstruent-sonorant clusters and no clear preference in the syllabification of obstruent-obstruent sequences (oscillating around 50% of VC.CV). As previously, clusters preceded by a short vowel were associated with a higher proportion of VC.CV responses compared to the long V1 condition. A third predictor – morphological structure – was also found to be statistically significant. However, although prefixed base clusters on the one hand and CC-suffix clusters on the other hand differed from the simple base clusters, there was no significant difference between base clusters and C-suffix clusters. The regression models further improved when word-edge phonotactics was taken into account, but only in terms of the onset frequency of occurrence of phonotactically legal clusters (more V.CCV responses with increasing word-initial frequency of the cluster). Interestingly, both token and type measures contributed significantly, although type frequency refined the precision of the model to a slightly larger extent than token frequency.

#### 4. General discussion

The current study investigated reactions of native speakers of Czech to real words with medial CC clusters. Previous syllabification experiments mostly examined English (e.g., Fallows, 1981 and especially the research of Rebecca Treiman and her colleagues), with several significant exceptions (Berg & Niemi, 2000; Bertinetto et al., 2006; Content et al., 2001; Côté & Kharlamov, 2011; Goslin & Floccia, 2007; Goslin & Frauenfelder, 2001; Ní Chiosáin et al., 2012; Ohala, 1999; Schiller et al., 1997). The languages in those studies vary considerably in their phonological and grammatical structure, such as the position and phonetic implementation of lexical stress, the distinctiveness of vowel length, the complexity of consonant sequences at word edges or the mean word length (in syllables). Czech is characterized by lexical stress fixed to the first syllable of polysyllabic words (including prefixed words, compare /ˈmazat/ “to grease [imperfective]” and /ˈnamazat/ “to grease [perfective]”), by distinctive vowel length (compare /ˈɦrabjɛ/ “earl” and /ˈɦraːbjɛ/ “rake”) and by a complex syllabic structure, allowing four-consonant word-initial onsets and three-consonant word-final codas and, moreover, allowing tautosyllabic S-O clusters word-initially (e.g. /ˈlʒɪt͡ʃka/ “teaspoon”). Moreover, Czech has a rich inflectional system (unlike English), and the use of real Czech words rather than nonsense words allowed us to investigate the role of morphological structure in syllabification.

In Section 1.4 eight hypotheses were formulated. According to Hypothesis 1, no onsetless syllables were predicted in the responses, and onset maximization was expected (Kahn, 1976; Pulgram, 1970; Zec, 2007). The results support the first part entirely, as all responses included at least one consonant in the onset of the second syllable. However, the onset was not unconditionally maximized: words were syllabified before the cluster only in 25% and 42% of responses (in Experiment 1 and 2, respectively). Interestingly, Šturm (2017) reports a similar result for CCC and CCCC clusters, where the most popular division was to leave one consonant in the coda of the first syllable and the remaining consonants in the onset of the second syllable. It might therefore be more appropriate to use the term “onset filling” (Berg & Niemi, 2000) rather than “onset maximization”. Alternatively, we would need to identify some relevant constraints that prevent onsets from being maximized.

One such constraint is suggested by Hypothesis 2. The liability of intervocalic clusters to be maximized could be influenced by the phonetic nature of the consonants. The Sonority Sequencing Principle (Clements, 1990) postulates that sonority should gradually rise from the first consonant in the onset to the nucleus, and fall or be level from the nucleus to the final consonant of the coda. Experimental studies of syllabification indicate that sonority might indeed play a significant role. For instance, Ní Chiosáin et al. (2012) found that CC onsets were more likely to arise with obstruent-liquid sequences, conforming to the ideal sonority contour, than with sibilant-stop sequences. Moreover, in control clusters with sonorant consonants as $C_1$, which do not occur word-initially in Irish, the sonorant consonant was in the vast majority of cases (94%) assigned to the first syllable as a coda. Similar effects of sonorants being more closely linked to the preceding vowel than obstruents were demonstrated even for single intervocalic consonants (e.g., Content et al., 2001; Treiman & Danis, 1988). The results of the current study agree with the reported literature. Sonorant-obstruent and sonorant-sonorant clusters were consistently divided between the two syllables, whereas divisions were less frequent with obstruent-obstruent clusters and obstruent-sonorant clusters. Although sonority does not solely determine syllabification, it seems to affect it to a large degree.

Syllabification preferences of speakers were further expected to differ depending on whether or not the cluster appears at word edges (Hypothesis 3). This approach of comparing medial clusters to non-medial clusters has a long tradition (e.g., Pulgram, 1970) and is often resorted to in interpreting results from different languages (see Treiman and Zukowski, 1990 for English, Berg and Niemi, 2000 for German and Finnish). The current study showed that the V.CCV responses, preserving the intervocalic cluster as an onset, comprised only 10% of observations in non-occurring clusters (22% in Experiment 2), but 33% of observations in clusters that are allowed word-initially (53% in Experiment 2). In the first experiment, onset legality was a significant predictor interacting with sonority (the legality effect showed only in O-O, S-O and S-S clusters). However, as Fallows (1981) points out, it is generally difficult to disentangle the effects of phonotactic and sonority constrains. Most of the clusters that did not appear at word onsets also violated the ideal sonority contours (e.g. /rk/). Such sequences were preferentially divided, in spite of being allowed word-finally (like in the word /ʃcɛrk/ "gravel"). This is in line with the finding that word-final phonotactics (coda legality) did not contribute significantly to the syllabification patterns.

Further, under Hypothesis 4, I examined the relation between the probability of VC.CV responses and the frequency of occurrence of the cluster in word-initial position (the frequencies were adopted from a corpus-based study of Šturm and Lukeš, 2017). In both experiments, high-frequency clusters were preserved as medial onsets more often than low-frequency clusters. This is in line with the results of Hay et al. (2004) and Treiman et al. (2000) on well-formedness judgments which reflect sensitivity to gradient phonotactics. Type frequency contributed strongly to the syllabification outcome in both experiments, although token frequency was also significant. This is in accord with the fact that especially type frequency is important for productivity of, for instance, morphological patterns (Bybee, 2001, p. 118ff.).

Hypothesis 5 relates to the phonological length of the preceding vowel. A number of studies have found that an intervocalic consonant is more likely to be assigned to the previous vowel if the vowel is short rather than long (Berg & Niemi, 2000; Derwing, 1992; Treiman & Danis, 1988). Obviously, the influence is not categorical, all-or-none; for instance, Berg and Niemi (2000) found that the proportion of coda responses increased after short vowels by 22% and 9% (for German and Finnish speakers, respectively). A similar difference of 20% appeared in Ní Chiosáin et al. (2012) for intervocalic C and CC stimuli. Since the primary focus was on examining a broad selection of clusters, the vowel length condition was not entirely controlled for, which was also necessitated by the fact that I used real Czech words and many short–long pairs could not be formed. However, despite the limited occurrence of long vowels in the material, the current results for Czech are in agreement with these findings, suggesting that the vowel length effect may represent a universal conditioning factor.

Crucially, there is an interesting relation between phonotactics and vowel length. The English lexicon is characterized by the absence of the so-called lax (short) vowels /ɛ æ ɐ ɒ/ from word-final position, and /ɪ ʊ/ being neutralized to [i u] (see Cruttenden, 2014, p. 261). Consequently, if speakers in a behavioural task produce syllabifications like /mɐs.tə/ vs. /mɑː.stə/, does it indicate an effect of vowel length (short syllables are closed by a coda consonant), or phonotactics (the form /mɐ.stə/, unlike /mɑː.stə/, would be considered illegal)? Czech is fortunately a language where vowel length is used distinctively and minimal pairs can occur even at word edges (e.g. /ˈvola/, "an ox [accusative]" vs. /ˈvolaː/, "he/she is calling"). Without a phonotactic constraint against short vowels word-finally, the preference for VC.CV division thus seems to stem from the nature of the vowel itself. For instance, phonological theory often describes the difference between short and long vowels as one of phonological weight, using either positions on a CV tier (Clements & Keyser, 1983) or the concept of moras (Broselow, 1996). In both approaches a syllable without a coda would be considered light if the vowel is short and heavy if it is long. As a result, syllabification preferences may be skewed towards heavy syllables, i.e. short vowels with a coda or long vowels (not necessarily with a coda). This might be reinforced further by lexical stress considering that Czech has initial stress, which has been shown to attract coda consonants to the first syllable (Eddington et al., 2013a, 2013b; Fallows, 1981).

Hypothesis 6 predicted that syllabification will be influenced by morphology. Usually, this aspect has not been considered in syllabification experiments. Researchers often use nonsense words, logically devoid of morphological boundaries, or intentionally refrain from investigating morphologically complex stimuli, opting for monomorphemic items. Derwing (1992) is an exception since he considered also bimorphemic stimuli such as "oily" (vs. monomorphemic "doily"). There was a strong preference to leave the root morpheme intact, dividing these words after the intervocalic consonant. More recently, Eddington et al. (2013b) analysed a large set of both monomorphemic and bimorphemic words, reporting that syllabifications in their written task coincided with morphological boundaries. Czech was expected to be of special interest because it has a rich inflectional system (concerning nouns, adjectives, verbs) in addition to derivative morphology.

However, the basic finding was not confirmed: a comparison of clusters that form a root morpheme with clusters that are composed of two morphemes did not reveal any significant difference (except for O-S clusters in Experiment 2, where C-suffixed words were more likely to be split than non-suffixed clusters). In contrast, prefixed words (with prefixes /vɪ/, /dɛ/, /rɛ/, /nɛ/, /do/, /na/, /za/, /po/ and /naː/, /zaː/) were associated with more V.CCV responses than non-prefixed base items (such as /postɛl/, where /po/ is part of the base). This result thus supports Kučera's (1961) and Ludvíková's (1972) theoretical prediction that prefixes are to be treated as separate entities. Kučera (1961, p. 66) distinguishes between prefixes, syllabic prepositions and compound words on the one hand, which are accompanied by phonological disjunctures such as the glottal stop in vowel-initial roots (e.g. [ˈbɛsʔopsaʒniː] "contentless"), and suffixes (both inflectional and derivational) on the other hand, which do not show any special phonological status. The results appear to be in agreement with this assumption, with the exception of CC-suffixes (derivational /dl/ and /t͡ʃk/), which remained undivided more often than items with C-suffixes or items without a suffix. However, the material was unbalanced with respect to morphology and this variable was often confounded with other factors (phonotactics, vowel length) so it is difficult to draw any firm conclusions from the current data.

The two experiments belong to a group of experimentation techniques commonly used in psycholinguistic research. Syllabification is inferred indirectly through the performance of participants in a behavioural task, such as pause insertion and syllable reversal. Although it is not unlikely that the participants will discover the underlying aim of the experiment, namely syllabification, the scope for metalinguistic reasoning during the task is clearly smaller than in introspection or in written tasks that ask for syllable division explicitly. Moreover, the design of the experiments attempted to reduce these aspects as much as possible. This was the primary motivation for modifying the pause insertion technique through providing metronome pulses to induce syllable division externally – the participants were led to believe that the experiment aimed to investigate speech–metronome synchronization patterns. The second experiment (syllable reversal) was conducted under time pressure conditions, demanding fast, spontaneous responses. Despite these precautions, the majority of the participants reported becoming aware of the experimental goal in the second, syllable reversal experiment, but only seven admitted to have developed a strategy for syllable division throughout the session. Moreover, it was not possible to discover a systematic shift associated with a certain strategy, and the information about the reported strategy of the speakers did not significantly improve the model. Therefore, we may conclude (cf. Hypothesis 7) that with great likelihood the syllabification behaviour of the participants was not substantially affected by their awareness of the goal or by their approach to performing the task.

Finally, the impact of the experimental task should also be considered (Hypothesis 8). Differences in results between researchers may well be caused by non-compatible methods, employing different tasks (e.g., syllable repetition vs. syllable permutation) or different types of stimuli (genuine words vs. nonsense words). Those studies that used genuine words (Content et al., 2001; Ní Chiosáin et al., 2012; Schiller et al., 1997) typically eliminated morphology from the variables, using only monomorphemic words. Notable exceptions are for instance Derwing (1992) or Eddington, et al. (2013b), who included bimorphemic English words as well (compare also Smith & Pitt, 1999). Oral tasks are undoubtedly better in terms of ecological validity than written tasks in investigating speech behaviour. Focusing on such issues, Côté and Kharlamov (2011) provide an instructive comparison of five methods using the same stimuli. For instance, tasks that require participants to produce only part of the word are more susceptible to interfering factors than tasks necessitating manipulation with the whole word. Also, various tasks may also have differing predispositions to responses that assign consonants to both syllables (such responses are usually interpreted as indicating ambisyllabicity). Given these findings it is clear that we must proceed with extreme caution in interpretation (but Eddington and Cairns, 2015 offer a more favourable aspect on this issue).

A comparison of Experiment 1 and 2 reveals the last mentioned effect clearly: there were virtually no ambisyllabic responses in pause insertion, but a significant amount appeared in syllable reversal. In contrast to dividing words by pauses, the permutation task is by its very nature more ready to generate repetition of the same consonant in both syllables. At the same time, Experiment 2 was on the whole associated with more V.CCV responses, which could also be a consequence of the task. Specifically, speakers might have had a strategy to parse the word at a point which gives rise to a maximally allowed word-initial sequence because the resulting form is a new nonword (e.g. /ˈpostɛl/ “a bed” reversed as /ˈstɛlpo/). It should be noted that the participants sometimes produced even sequences that are not found word-initially (e.g., the form /ˈmpara/ for /ˈrampa/ “a ramp”), suggesting a task-specific effect. Experiment 1 only parsed the word at some point, maintaining the order of segments and producing subword sequences. These, in contrast, might be subject to some minimality constraints, attracting coda consonants due to initial stress and/or syllable weight.[7] Therefore, it is still necessary to examine the behaviour of Czech participants in other syllabification tasks, including written tasks. Also, a greater control over experimental items is needed to estimate the relative size of the individual effects on response patterns.

## 5. Conclusions

The present study aimed to examine syllabification preferences of Czech speakers on a broader variety of material than is typical in similar behavioural experiments, including also morphologically complex forms. In total, 61 intervocalic two-consonant clusters were analysed with respect to a number of phonological and morphological factors, and two different tasks were employed (pause insertion and syllable reversal). Despite some task-related differences in the outcomes, the two experiments strongly support the role of sonority in online syllabification tasks, further mediated by the effects of vowel length, phonotactics and morphology. On a more general level, the *maximum onset principle* is often proposed by theories of syllabification (e.g., Goldsmith, 2011; Pulgram, 1970; Zec, 2007), and often adopted by academics without critical consideration. The principle was supported insofar that onsets are maximized unless blocked by phonological and phonetic constraints, such as phonotactics or especially sonority type. Moreover, even items with a greater preference for preservation of the intervocalic cluster were not associated with unanimous onset maximization by the speakers. There was also a significant effect of phonotactic probability defined with respect to the cluster's word-initial frequency of occurrence. On the whole, it appears that syllabification responses are probabilistic rather than categorical, which corresponds well with what we know about language behaviour and cognition in general.

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## Appendix C. Supplementary data

[7] Durational measurements of the recorded responses would be interesting in this respect. However, any phonetic lengthening due to a minimality constraint would be confounded with final lengthening (Wightman, Shattuck-Hufnagel, Ostendorf, & Price, 1992; Byrd, Krivokapić, & Lee, 2006). Furthermore, the possible effect of forced timing on the production in Experiment 1 complicates the analysis; for instance, the fact that syllables can be longer due to task-related reasons might also interfere with the vowel length effect. Nevertheless, I believe that the contribution of the design towards a lower metacognitive load is beneficial to the experiment and outweighs the more artificial character of the task.

**Appendix A**

List of carrier sentences for Experiment 1. Target words are transcribed in IPA and English translation of the sentences is provided.

| | | |
|---|---|---|
| 1a | V poslední /dobjɛ vi:skum/ narůstá | *Research has proliferated lately* |
| 1b | Akorát /sobjɛ pru:skum/ zakázal | *He banned himself from doing research* |
| 2a | Proto /bjɛʃtɛ vdubnu/ k lékaři | *Therefore visit a doctor in April* |
| 2b | Proto /lɛʃtɛ vbubnu/ do šesti | *Therefore lie in the barrel until 6o'clock* |
| 3a | Bohužel /jɪsta: ʒɛbra/ máte zlomená | *Unfortunately, some of your ribs are broken* |
| 3b | Bohužel /t͡ʃɪsta: zɛbra/ není k vidění | *Unfortunately, a clean zebra is not to be seen* |
| 4a | Velice /dobr̝ɛ la:fku/ opravil | *He repaired the footbridge very well* |
| 4b | Té vaší /kobr̝ɛ da:fku/ nezvýšil | *He didn't increase the dosage for your cobra* |
| 5a | Rozjetá /rolba kla͡tskɪ/ zničila | *The moving snowcat destroyed the sticks* |
| 5b | Včerejší /volba pla͡tskɪ/ zničila | *Yesterday's choice destroyed the badges* |
| 6a | Obdržel /bɛ:t͡ʃko lɛk͡tsɛ/ dvacáté | *He received the "B" of Lecture 20* |
| 6b | Obdržel /t͡sɛ:t͡ʃko sɛk͡tsɛ/ dvacáté | *He received the "C" of Section 20* |
| 7a | Musíš /pr̝̊i:ʃcɛ di:xno͡ut/ s nadšením | *Next time you have to breathe keenly* |
| 7b | Musíš /kli:ʃcɛ pi:xno͡ut/ s nadšením | *You have to poke the tick keenly* |
| 8a | Po celou /va:lku bomba/ nevydržela | *The bomb didn't survive the entire war* |
| 8b | Takovou /da:lku komba/ nevydržela | *The combos didn't survive such a long trip* |
| 9a | Třeba se /jɛdno͡u dot͡ʃka:m/ honoráře | *Maybe I will get the royalties one day* |
| 9b | S touhletou /bɛdno͡u pot͡ʃka:m/ na Tomáše | *I will wait for Tomáš with this box* |
| 10a | Poslední /rot͡ʃɲi:k katka/ nezvládla | *Katka didn't make the last grade* |
| 10b | Špinavý /not͡ʃɲi:k matka/ nezvládla | *Mother couldn't handle the dirty potty* |
| 11a | Zatajil /bant͡sɛ/ loňské postihy | *He concealed last year's sanctions from the bank* |
| 11b | Zatajil /ɦant͡sɛ/ koňské dostihy | *He concealed the horse races from Hanka* |
| 12a | Vepřové /sa:dlo/ uschne v kuchyni | *Pork grease will dry out in the kitchen* |
| 12b | Natřené /pa:dlo/ oschne v kuchyni | *The painted paddle will dry off in the kitchen* |
| 13a | Odsunul /pr̝̊ɛɟɲi: t͡ʃot͡ʃkɪ/ na stranu | *He pushed the front lenses aside* |
| 13b | Odsunul /fʃɛɟɲi: kot͡ʃkɪ/ na stranu | *He pushed the ordinary cats aside* |
| 14a | Co dělá ta /bodra:/ sestra za oponou? | *What is the jolly nurse doing behind the curtain?* |
| 14b | Co dělá ta /modra:/ kostra za oponou? | *What is the blue skeleton doing behind the curtain?* |
| 15a | Tahle /ɦudba/ Irsko neviděla | *This music hasn't seen Ireland* |
| 15b | Tahle /xodba/ Norsko neviděla | *This hall hasn't seen Norway* |
| 16b | Tohle je /za:klad ʒra:dla/ pro Irenu | *This is the food basis for Irena* |
| 17a | Po ránu /zaspal pɛjsɛk/ devět hodin | *The little dog slept in for 9 hours in the morning* |
| 17b | Po ránu /naspal rɛjsɛk/ devět hodin | *The shrew slept for 9 hours in the morning* |
| 18a | Ani /dɛʃcɛ frontɪ/ neodradily | *Even the rains didn't discourage the queues* |
| 18b | Ani /klɛʃcɛ ʃpuntɪ/ neodstranily | *Even pliers didn't remove the plugs* |
| 19a | Tajným /faktɛm/ Polsko zničili | *They destroyed Poland by a secret fact* |
| 19b | Tajným /paktɛm/ Ralsko zničili | *They destroyed Ralsko by a secret pact* |
| 20a | Poslední /branku zapsal/ červeně | *He wrote the last goal in red* |
| 20b | Poslední /blanku napsal/ červeně | *He wrote the last Blanka in red* |
| 21a | To byl zas /marni: na:stup/ na okrese | *That was a vain entry in the region again* |
| 21b | To byl zas /t͡ʃɛrni: za:stup/ na okrese | *That was a black crowd in the region again* |
| 22a | Prosím vás, /bɛrtɛ ko͡uskɪ/ postupně | *Take the bits one by one, please* |
| 22b | Prosím vás, /ʒɛrtɛ ɦo͡uskɪ/ potichu | *Eat the bun quietly, please* |
| 23a | V těhle /tɛmpɛx/ mantra nejede | *Mantra isn't popular in these tempos* |
| 23b | V těhle /kɛmpɛx/ tantra nejede | *Tantra isn't popular in these camps* |
| 24a | Na konci /br̝ɛzna bapka/ zmizela | *The old woman disappeared at the end of March* |
| 24b | V dubnu či /br̝ɛznu ʒapka/ zmizela | *The little frog disappeared in April or March* |
| 25a | Získal jsi /trapni: dɛspɛkt/ odpadlíka | *You acquired the awkward contempt of a renegade* |
| 25b | Získal jsi /kʊapni: rɛspɛkt/ odpadlíka | *You acquired the hasty respect of a renegade* |
| 26a | Vybral si funkční /da:sɲɛ/ od Magora Jirouse | *He chose functional gums from Magor Jirous* |
| 26b | Vybral si punkční /ba:sɲɛ/ od Magora Jirouse | *He chose puncture poems from Magor Jirous* |
| 27a | S úderem /blɛsku zarval/ Petra do zelí | *He put Peter into cabbage with a stroke of lightening* |
| 27b | Úderem /trɛsku narval/ mezi kameny | *He squashed the codfish between the rocks* |
| 28a | Nakonec /vɪʃlo gɛsto/ ukvapeně | *In the end the gesture came out prematurely* |
| 28b | Nakonec /nɛʃlo cɛsto/ okořenit | *In the end it was impossible to spice the dough* |
| 29a | Tím svým /rɪskɛm la:tku/ poničil | *He damaged the fabric by risking* |
| 29b | Tys chtěl /zɪskɛm pa:tku/ prorazit | *You wanted to break through by gaining Friday* |

(*continued on next page*)

**Appendix A** (*continued*)

| | | |
|---|---|---|
| 30a | Nebezpečné /daːrkɪ/ mužstvo odmítlo | *The team refused the dangerous gifts* |
| 30b | Nebezpečné /paːrkɪ/ družstvo odmítlo | *The association refused the dangerous sausages* |
| 31a | Nebude funkce /puʃkɪ/ zbytečná? | *Won't the rifle function be useless?* |
| 31b | Nebude punkce /muʃkɪ/ zbytečná? | *Won't the small fly's puncture be useless?* |
| 32a | Představoval dánský komplex továren | *He was introducing the Danish factory complex* |
| 32b | Představoval pánský komplet na strečink | *He was introducing men's stretching suit* |
| 33a | Zpoza /ʃaxtɪ/ rajské sklidili | *They harvested the tomatoes from behind the pit* |
| 33b | Škrábal /nɛxtɪ/ krajské břídily | *He scratched the regional bunglers with nails* |
| 34a | Dojala ho /pustaː malba/ dětí | *A bleak children's painting moved him* |
| 34b | Dojala nás /ɦustaː palba/ dětí | *Dense children's gunfire moved us* |
| 35a | Rozdává /lɛvnɛː rundɪ/ pro všechny | *He is giving away cheap rounds for everyone* |
| 35b | Rozdává /pɛvnɛː bundɪ/ pro všechny | *He is giving away firm jackets for everyone* |
| 36a | Skoro /kaʒdaː ʃpɛjlɛ/ váží víc | *Nearly every skewer weighs more* |
| 36b | Skoro /kaʒdɛː brɛjlɛ/ váží víc | *Nearly every pair of glasses weighs more* |
| 37a | Jejich /rɛktor kɛjxaː/ při obřadu | *Their rector sneezes during the ceremony* |
| 37b | Jejich /vɛktor dɛjxaː/ jako živý | *Their vector breathes as if alive* |
| 38a | Svoji /farmu jɛmɲɛ/ zavlažila | *She mildly watered her farm* |
| 38b | Svého /ʃarmu tɛmɲɛ/ využívá | *He maliciously uses his charm* |
| 39a | Žlutým /svɛtrɛm/ pejska obalila | *She wrapped the dog with a yellow sweater* |
| 39b | Prudkým /vjɛtrɛm/ rejska povalila | *She tumbled the shrew by gusty wind* |
| 40a | Drahou /dlaʒbu t͡sɛsta/ nepotřebuje | *The road doesn't need expensive paving* |
| 40b | Drahou /raʒbu vɛsta/ nepotřebuje | *The vest doesn't need expensive embossing* |
| 41a | V podstatě /zajdɛʃ miːstɪ/ jinam | *Basically you will go elsewhere sometimes* |
| 41b | V podstatě /najdɛʃ piːstɪ/ jinde | *Basically you will find the pistons elsewhere* |
| 42a | Na zahradě /kɪtka bɪdlo/ obrostla | *A flower grew over the pole in the garden* |
| 42b | Na zahradě /bɪtka t͡ʃɪdlo/ zničila | *A fight destroyed the sensor in the garden* |
| 43a | Lenčino /vratkɛː ɦɛslo/ zjistil hned | *He figured out Lenka's weak password immediately* |
| 43b | Lenčino /ɦlatkɛː vɛslo/ pustil pryč | *He dropped Lenka's smooth oar down* |
| 44a | Babička /mɛtla fandu/ koštětem | *Grandma swept Fanda with a broom* |
| 44b | Babička /t͡ʃɛtla bandu/ rošťáků | *Grandma read a gang of rascals* |
| 45a | Musíš /sfo͡ukno͡ut straʃniː/ dým | *You have to blow away the terrible smoke* |
| 45b | Musíš /sko͡ukno͡ut smɲɛʃniː/ film | *You have to watch a ridiculous movie* |
| 46a | Rozbitá /rampa kostɛl/ znesvětí | *A broken ramp will desecrate the church* |
| 46b | Rozbitá /lampa postɛl/ spálila | *A broken lamp burned the bed down* |
| 47a | Železná /dɛska ɦɛlmu/ rozbila | *An iron board broke the helmet* |
| 47b | Železná /maska ʃɛlmu/ děsila | *An iron mask scared the predator* |
| 48a | Falešná /t͡ʃaːrka burzu/ rozhodila | *A fake comma confused the stock market* |
| 48b | Minulá /vaːrka kurzu/ uškodila | *The last batch did a harm to the course* |
| 49a | Rozhodně /spaːsno͡u kartu/ nezahazuj | *Definitely don't throw away the redemption card* |
| 49b | Rozhodně /kraːsno͡u partu/ nezahazuj | *Definitely don't throw away the beautiful bunch* |
| 50a | Hrozivou /laːsku pɪtʋa/ ukazuje | *The autopsy points towards a scary love story* |
| 50b | Na správném /paːsku bɪtʋa/ přeci stojí | *The battle boils down to the correct belt* |

**Appendix B**

Number of responses in Experiment 1 and Experiment 2 to target clusters with a short vowel in the first syllable, supplemented with relevant phonological and morphological characteristics (A = ambisyllabic, O = obstruent, S = sonorant).

| Cluster | Sonority | Morphology | Legality | Exp. 1 | | Exp. 2 | | |
|---|---|---|---|---|---|---|---|---|
| | | | | .CC | C.C | .CC | C.C | A |
| /sk/ | O-O | base | legal | 15 | 74 | 26 | 50 | 9 |
| /sp/ | O-O | prefixed base | legal | 8 | 51 | 25 | 25 | 0 |
| /st/ | O-O | base | legal | 26 | 124 | 62 | 74 | 12 |
| /ʃk/ | O-O | C-suffix | legal | 3 | 27 | 15 | 13 | 2 |
| /ʃt/ | O-O | C-suffix | legal | 1 | 29 | 11 | 15 | 2 |
| /ʃc/ | O-O | base | legal | 5 | 24 | 16 | 12 | 2 |
| /xt/ | O-O | base | illegal | 1 | 29 | 14 | 12 | 3 |
| /ʒb/ | O-O | C-suffix | illegal | 3 | 27 | 9 | 17 | 1 |
| /ʒd/ | O-O | base | illegal | 2 | 28 | 2 | 26 | 2 |
| /br̝/ | O-O | base | legal | 3 | 27 | 15 | 8 | 4 |

**Appendix B** (*continued*)

| Cluster | Sonority | Morphology | Legality | Exp. 1 | | Exp. 2 | | |
|---|---|---|---|---|---|---|---|---|
| | | | | .CC | C.C | .CC | C.C | A |
| /ps/ | O-O | prefixed base | legal | 21 | 9 | 26 | 2 | 1 |
| /t͡sk/ | O-O | C-suffix | illegal | 7 | 23 | 22 | 6 | 2 |
| /t͡ʃk/ | O-O | C-suffix | illegal | 1 | 29 | 15 | 13 | 1 |
| /t͡ʃk/ | O-O | prefixed base | illegal | 10 | 19 | 17 | 12 | 0 |
| /db/ | O-O | C-suffix | legal | 3 | 27 | 3 | 21 | 3 |
| /kt͡s/ | O-O | C-suffix | illegal | 2 | 28 | 8 | 14 | 3 |
| /kt/ | O-O | base | legal | 11 | 48 | 16 | 33 | 3 |
| /pk/ | O-O | C-suffix | illegal | 2 | 28 | 8 | 16 | 1 |
| /tk/ | O-O | C-suffix | legal | 10 | 79 | 38 | 36 | 6 |
| /tʋ/ | O-S | C-suffix | legal | 7 | 8 | 9 | 2 | 4 |
| /tʋ/ | O-S | base | legal | 6 | 8 | 7 | 3 | 4 |
| /sl/ | O-S | base | legal | 6 | 24 | 16 | 7 | 7 |
| /ʃl/ | O-S | prefixed base | legal | 16 | 14 | 23 | 4 | 2 |
| /ʃn/ | O-S | C-suffix | legal | 13 | 15 | 2 | 20 | 1 |
| /vn/ | O-S | C-suffix | legal | 3 | 27 | 13 | 15 | 1 |
| /zn/ | O-S | C-suffix | legal | 7 | 23 | 12 | 11 | 7 |
| /bj/ | O-S | C-suffix | legal | 28 | 1 | 28 | 0 | 2 |
| /bn/ | O-S | C-suffix | illegal | 18 | 11 | 13 | 7 | 1 |
| /br/ | O-S | base | legal | 14 | 16 | 24 | 2 | 1 |
| /t͡ʃɲ/ | O-S | C-suffix | legal | 4 | 25 | 11 | 13 | 0 |
| /dn/ | O-S | base | legal | 4 | 26 | 12 | 13 | 2 |
| /ɟɲ/ | O-S | C-suffix | legal | 9 | 21 | 15 | 10 | 2 |
| /dr/ | O-S | base | legal | 9 | 20 | 14 | 4 | 10 |
| /pn/ | O-S | C-suffix | legal | 5 | 23 | 10 | 15 | 2 |
| /tl/ | O-S | C-suffix | legal | 11 | 19 | 12 | 9 | 7 |
| /tr/ | O-S | base | legal | 18 | 10 | 21 | 2 | 3 |
| /js/ | S-O | base | legal | 0 | 30 | 0 | 26 | 0 |
| /jx/ | S-O | base | illegal | 0 | 26 | 1 | 28 | 1 |
| /rv/ | S-O | prefixed base | legal | 6 | 24 | 15 | 7 | 0 |
| /rz/ | S-O | base | illegal | 1 | 29 | 4 | 23 | 2 |
| /jd/ | S-O | prefixed base | legal | 1 | 29 | 9 | 20 | 0 |
| /lb/ | S-O | C-suffix | illegal | 0 | 60 | 3 | 54 | 0 |
| /mb/ | S-O | base | illegal | 0 | 30 | 2 | 25 | 1 |
| /mp/ | S-O | base | illegal | 0 | 59 | 0 | 49 | 1 |
| /nt͡s/ | S-O | C-suffix | illegal | 0 | 30 | 3 | 24 | 2 |
| /nd/ | S-O | base | illegal | 0 | 59 | 3 | 45 | 9 |
| /nk/ | S-O | C-suffix | illegal | 0 | 30 | 3 | 22 | 4 |
| /nt/ | S-O | base | illegal | 0 | 29 | 3 | 18 | 5 |
| /rt/ | S-O | C-suffix | legal | 0 | 30 | 3 | 23 | 3 |
| /rt/ | S-O | base | legal | 0 | 30 | 3 | 24 | 2 |
| /jl/ | S-S | base | illegal | 0 | 30 | 0 | 23 | 0 |
| /lm/ | S-S | base | illegal | 0 | 27 | 1 | 26 | 1 |
| /mɲ/ | S-S | C-suffix | legal | 10 | 17 | 12 | 1 | 16 |
| /rm/ | S-S | base | legal | 0 | 30 | 1 | 27 | 2 |
| /rn/ | S-S | C-suffix | illegal | 1 | 29 | 2 | 26 | 2 |

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