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On the locus of the syllable frequency effect in speech production

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Abstract

The observation of a syllable frequency effect in naming latencies has been an argument in favor of a functional role of stored syllables in speech production. Accordingly, various theoretical models postulate that a repository of syllable representations is accessed during phonetic encoding. However, the direct empirical evidence for locating the syllable frequency effect at this level, rather than at the phonological or motor programming levels, is scarce. To investigate the origin of this effect, we conducted six experiments involving immediate and delayed production, with or without an interfering task (articulatory suppression). Previous evidence from psycholinguistic and short-term memory studies allows the working hypothesis that this interfering task disrupts phonetic processing, while leaving phonological encoding relatively intact. Experiments 1 and 3 showed a syllable frequency effect in immediate pseudo-word production and picture naming, respectively. Experiments 2 and 4 required delayed naming (participants produced the items after a short delay, upon presentation of a response cue). The delay was or was not filled with articulatory suppression. The syllable frequency effect was not observed in standard delayed naming. By contrast, it was observed when the delay was filled with articulatory suppression. The effects for words and pseudo-words were highly similar. This pattern of results is interpreted as evidence that syllable frequency affects the stage of phonetic encoding. This interpretation is consistent with the previously postulated hypothesis that phonetic encoding involves the retrieval of syllable sized representations.

Keywords: Language production; Speech; Naming; Phonology; Syllable frequency

Introduction

When a speaker has a message that (s)he intends to communicate, (s)he needs to go through a number of processing stages. First of all, (s)he needs to retrieve the words that express the intended message, a process known as lexical selection. Then, (s)he needs to retrieve the relevant linguistic properties of these words in order to construct the form of the utterance (s)he intends to produce. The form representations will finally drive the motor processes of articulation. In this article, we are interested in the processing stages that follow lexical selection. We investigate the processing status of the syllable, a sub-lexical linguistic unit that participates in the

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phonological make-up of words. The syllable is a fundamental unit in most phonological theories, although its exact definition as well as many details of its psychological representation are still controversial.

Two main issues have been investigated with respect to the processing of syllables. The first issue concerns the processing level(s) at which syllabic information is represented. The second (related) issue is whether syllables are represented and retrieved from a mental store or, alternatively, whether they are computed on-line. We discuss these two issues in turn.

Levels of processing involving syllable representations

Current models of speech production postulate distinct phonological and phonetic levels of processing. The level of phonological encoding involves the processing of phonological representations (e.g., the segments, the metrical frame of the words, etc). The level of phonetic encoding constitutes the interface between phonological encoding and articulation. During this encoding, the articulatory plan that will be used to output the word is built-up and stored. Depending on the theoretical models, syllabic information in various forms has been postulated to be present either at the phonological or at the phonetic level (see review in Costa, Alario, & Sebastián-Gallés, in press).

Some models have postulated that, at the phonological level, syllabic information is stored in terms of the abstract syllabic structure (or "CV-structure"; Dell, 1988; Sevald, Dell, & Cole, 1995). This hypothesis was motivated by the observation of syllabic constraints on phonological slips-of-the-tongue (Shattuck-Hufnagel, 1979) and by the observation of syllabic-structure priming effects in psycholinguistic studies (Costa & Sebastian-Gallés, 1998; Ferrand & Segui, 1998; Meijer, 1996; Sevald et al., 1995). Notice that earlier versions of these models (e.g., Dell, 1986) postulated stored syllable units at the phonological level. These syllabic units, also referred to as "chunks", are made up of the structure *and* the segmental content of the syllable (e.g., the phonological syllables /ba/, /pa/, /bil/, etc.). The original hypothesis of syllabic chunks at the phonological level was abandoned to accommodate the fact that, in languages like English, phonological slips-of-the-tongue rarely involve syllables (although see Chen, 2000, for evidence of syllabic slips-of-the-tongue in Mandarin Chinese). In short then, the phonological level of these models involves a CV-structured frame. Depending on cross-linguistic factors, it might also involve wholly specified phonological syllabic chunks.

An alternative view holds that no syllabic representations are retrieved at the phonological level (Levelt, Roelofs, & Meyer, 1999). In this hypothesis, the metrical frame stores the word's length in syllables and in some cases, the lexical stress position, but not the CV-structure of the word. According to this view, syllable chunk representations (in the form of articulatory plans) are only retrieved during the later stage of phonetic encoding. A primary motivation for this set of hypothesis is the pervasiveness of resyllabification in connected speech production (in a sequence like *cher ami* -"dear friend"-, the syllabic structure of the surface form [ʃɛ.ra.mi] - CV.CV.CV - is different from that of the individual forms [ʃɛr] – CVC - plus [ami] - V.CV -). It is argued that the sensitivity of syllabification to phonological context requires that syllables are not stored at the phonological level. A further argument against the presence of syllabic information in the phonological metrical frame comes from a contrastive pattern of syllabic effects in two psycholinguistic paradigms. The failure to demonstrate reliable syllable priming in the classic picture-word priming paradigm (Schiller, 1998; Schiller, Costa, & Colomé, 2002), contrasts with the syllable structure effect reported in the implicit priming (or form-preparation) paradigm (Cholin, Schiller, & Levelt, 2004). In the former paradigm, participants are not asked to produce the prime whose syllabic structure is manipulated. In the latter paradigm, the manipulation of syllable structure concerns the sets of items that are actually produced. It has been argued that the (syllable insensitive) picture-word priming paradigm taps into phonological processes whereas the (syllable sensitive) form-preparation paradigm taps into later encoding processes such as phonetic processing (see Cholin et al., 2004, for details on this rationale).

Retrieval vs. computation of syllable representations

A second (related) question concerning the representation and processing of syllables is whether syllabic information is retrieved or computed online. In those models that postulate detailed syllabic structure information in the metrical frames, syllable information is retrieved during phonological encoding and combined with the segments to form syllabic chunks. Generally, these models do not make explicit assumptions about how syllables are computed or represented at the later stage of phonetic encoding.

By contrast, in those models that postulate no syllabic structure information in the metrical frames, no syllabic information is retrieved at the phonological level; rather phonological syllables are constructed on-line following general syllabification rules. Only after that, syllabic representations (in the form of articulation plans which specify both the content and the structure of the syllable) are retrieved from a mental *syllabary* that is accessed during phonetic encoding. In this view, the syllabary (Crompton, 1982) is a store containing a chunk representation for each syllable of the language (in some versions, the very low frequency syllables are not represented in the store).

The hypothesis that content syllables are explicitly represented as chunks and retrieved from a mental syllabary has been tested by investigating whether or not speech production performance is sensitive to syllable frequency. Syllable frequency is defined as the frequency of occurrence of content-specified syllable sized units (i.e., syllabic chunks such as /ba/, /pa/, /bil/, etc). The following rationale, introduced by Levelt and Wheeldon (1994), has been used. It is commonly observed that the retrieval of linguistic representational units is sensitive to the frequency with which they are used. Representations that are used more often are easier to activate and retrieve than representations that are used less often (Oldfield & Wingfield, 1965). If syllables are explicitly represented in a mental store, their retrieval can be expected to be sensitive to this parameter. By contrast, if syllable frequency does not affect performance, then it is possible that syllables are not stored but rather constructed or encoded each time they are needed.

Empirical evidence for the syllable frequency effect

A few studies have provided empirical evidence showing a syllable frequency effect on production latencies.

The effect has been reported in a pseudo-word production task conducted in Dutch by Cholin, Levelt, and Schiller (2006). In this paradigm, participants learned to associate pseudo-words with arbitrarily specified positions on the computer screen. When one of the positions in the screen was cued, participants produced the associated pseudo-word as fast as possible. The frequency of the syllables composing the pseudo-words to be produced was manipulated. A syllable frequency effect was observed with monosyllabic pseudo-words and with disyllabic pseudo-words for which the frequency of the first syllable was manipulated. The authors interpreted these findings on the basis of the model described earlier (Levelt et al., 1999). They argued that the frequency effect was an indication that high and low frequency syllables have different retrieval times from a mental syllabary. This interpretation, which excludes the phonological level as a possible locus of the effect, hinges on the fact that the materials in the two syllable frequency conditions were matched on their phonological properties (e.g., CV structure, phoneme frequency and bi-phones). Notice however that in this paradigm it is not clear a priori what linguistic representation (e.g., phonological, phonetic, or other) participants have learned to associate with the visual cue in order to produce their responses. In fact, performance in this association paradigm is also sensitive to frequency manipulations which are thought to affect other levels of linguistic processing (e.g., lexical frequency, which is thought to affect the lexical or phonological level; Cholin et al., 2006; see also Levelt & Wheeldon, 1994, for a similar paradigm).

A facilitatory effect of syllable frequency has been reported in Spanish by Perea and Carreiras (1998). These authors observed the effect in a standard word reading task (where the frequency of the first syllable of the word was manipulated), and in a series of pseudo-word naming experiments (Carreiras & Perea, 2004). Interestingly, in a word recognition task such as lexical decision, syllable frequency had a reversed "inhibitory" effect (i.e., worst performance for items with higher syllabic frequency; Perea & Carreiras, 1998). The details of the interpretation of this inhibitory effect are beyond the scope of this article. We can mention that the contrast between effect directions in naming and lexical decision was taken as an indication that the facilitatory effect observed in naming involves the speech production stages of reading, rather than recognition (see Conrad & Jacobs, 2004, and Perea & Carreiras, 1998, for details on this rationale). The data reported in these studies, however, do not allow teasing apart a phonological or a phonetic locus for the effect within the production system. This is because reading aloud requires both phonological and phonetic processing, so the effect of syllable frequency could be due to processes happening at either of these stages. This indeterminacy on the locus of the effect is acknowledged by the authors (Carreiras & Perea, 2004) when they present two possible interpretations for their findings: one in terms of retrieval of syllable representations during phonological encoding (as in Ferrand, Segui, & Grainger, 1996) and one involving retrieval of syllable representations from a phonetic syllabary (as in Levelt et al., 1999).

Evidence for the effect of the frequency of syllables on picture naming latencies also comes from regression (non-factorial) designs. Alario et al. (2004) conducted a French picture naming experiment of a large collection of pictures (over 300 items) in order to assess the effects of various pre-lexical and lexical variables. A post hoc multiple regression re-analysis of this data was conducted on bi-syllabic words, with the inclusion of the syllable frequency variable as well as other phonological variables (e.g., phoneme frequency). This re-analysis showed a significant effect of syllable frequency on immediate picture naming latencies. Similarly, Brand, Rey, Peereman, and Spieler (2001) found syllable frequency effects in multiple regression analysis of the naming times of 700 bi-syllabic words by two groups of French and English speakers.

Finally, some neuro-linguistic studies provide evidence for syllable frequency effects in brain-damaged speakers. Aichert and Ziegler (2004) reported that speakers with apraxia of speech produced more errors when they repeated words composed of low (vs. high) frequency syllables. The effect was attributed to an impairment affecting the mental syllabary in Levelt et al.'s model (1999), given the standard association between apraxia of speech and deficits of phonetic encoding (Code, 1998; Darley, Aronson, & Brown, 1975; Varley & Whiteside, 2001). However, syllable frequency also affects the production of aphasic subjects who do not present apraxia of speech and whose impairment is thought to be located at the stage of phonological encoding. A syllable frequency effect has been reported on accuracy and errors in several aphasic subjects with phonological encoding disorders (Laganaro, 2005) and in a distributional analysis of a jargon-aphasic's neologistic utterances (Stenneken, Hofman, & Jacobs, 2005). Laganaro (2005) discusses two possible explanations for the syllable frequency effect observed in these patients. The first explanation postulates that the syllable frequency effect would occur because of an impaired access to stored *phonological* syllables. The second explanation postulates a deficient retrieval of the less frequent *phonetic* syllables due to an underspecified or incomplete phonological input.

The evidence we have reviewed supports the view that syllables are represented as functional units in the speech production system. In current theoretical models, this effect has been preferentially ascribed to the retrieval of syllable representations from the syllabary. However, none of the studies we have reviewed directly addresses the question of the processing level affected by syllable frequency. Psycholinguistic studies do not provide direct empirical tests for identifying precisely the level (or levels) of processing that are affected by the manipulation of this variable. Neuro-linguistic studies have reported syllable frequency effects with aphasic speakers whose impairment affects the level of phonetic encoding (subjects with apraxia of speech), and with aphasic speakers whose impairment affects an earlier stage (the phonological patients and the jargon patient).

What needs to be empirically clarified, then, is whether the impact of syllable frequency on naming performance affects the stage of phonological encoding or the stage of phonetic encoding. To this alternative, one may add a third hypothesis that has not been considered in the preceding discussion, nor in previous investigations of this effect. The frequency of the syllables could also affect the motor processes that occur after phonetic encoding. This third hypothesis is based on the assumption that the articulation of a given syllable involves a rather invariant motor plan. The very late process of unpacking and execution of this (previously retrieved) articulatory plan could be affected by the frequency with which the motor program is used, and therefore by the frequency of the syllable (Adams, 1987; Levelt, 1989, p. 421).

Delayed naming and the articulatory suppression task

To clarify the locus of the syllable frequency effect we devised an investigation based on the delayed production of words and pseudo-words. In delayed production, the speeded response to a stimulus is not given immediately upon appearance of the target but rather when a subsequent cue is presented. It has been argued that the delay preceding the cue allows participants to retrieve and prepare their response, or part of their response. Manipulations of the characteristics of the delay (e.g., its duration, the requirement to perform an interfering task, etc.) influence the amount of preparation that can be achieved by participants. Interpreting the effects of these manipulations allows distinguishing between processing levels. For example, the delayed naming paradigm has been extensively used in attempts to discriminate between input and output loci for the *lexical* frequency effect in visual word processing. (e.g., Balota & Chumbley, 1985; Barry, Hirsh, Johnston, & Williams, 2001; Goldinger, Azuma, Abramson, & Jain, 1997; Monsell, Doyle, & Haggard, 1989. See Savage, Bradley, & Forster, 1990, for a methodological assessment of the delayed naming task and an interpretation of previous seemingly contradictory results).

In the experiments reported below, we manipulated the amount of preparation participants could achieve by using articulatory suppression. In this interfering task, participants are asked to repeatedly sub-articulate a given syllable (e.g., "ba") during the preparation delay that precedes the delayed naming response. Articulatory suppression is commonly used in research on short-term memory (Baddeley, 1986), as well as in some psycholinguistic experiments (e.g., references above). As we discuss below, its effects appear to be interpretable in terms of a differential disruption of the phonological and the articulatory levels of processing. Although the memory demands of delayed naming are minimal (only one item is processed in each trial and the delays are relatively short), we will base part of our working model of delayed naming on the rationale used in memory studies (on the relationship between the components of short-term memory and those of speech production (see Martin & Gupta, 2004; Martin & Saffran, 1997; Martin, Lesch, & Bartha, 1999).

Models of short-term memory postulate that the rapid memorization of verbal material (e.g., pseudo-words or lists of words; Baddeley, 1986) involves two major components: the short-term phonological store and an articulatory rehearsal process. The phonological store is a device that maintains memory traces for no more than 1 or 2 s. It is thought to involve phonological information because it is sensitive to the phonological make up of words (e.g., the phonological similarity effect, where lists of phonologically similar words are remembered worse than lists of phonologically dissimilar words, Baddeley, Lewis, & Vallar, 1984; Logie, Della Sala, Laiacona, Chalmers, & Wynn, 1996). Articulatory rehearsal is the process by which the content of the phonological store is refreshed so that it can be maintained for longer periods than allowed by its natural decay rate. Various lines of evidence indicate that the rehearsal process involves components of the speech production system, most notably sub-articulation. For example, memorization performance is sensitive to the actual duration of the items being remembered, and not just their segmental length (Mueller, Seymour, Kieras, & Meyer, 2003).

Within this theoretical model, the interpretation of several effects produced by the interfering articulatory suppression task suggests that the disruption it produces leaves the phonological level relatively intact. The first line of evidence comes from the interaction between articulatory suppression and the phonological similarity effect cited above. The presence of this effect is taken here as a signature of the involvement of the phonological buffer in the memorization process. The critical observations under articulatory suppression are that: (a) the phonological similarity effect disappears if the items to be remembered are presented visually but (b) the effect is still observed if the items to be remembered are presented auditorily (Baddeley et al., 1984; Levy, 1971). It has been argued (e.g., Baddeley, 1986) that the absence of phonological effect with visual presentation reflects the interference produced by articulatory suppression on the process of transforming the visual input into phonological material that can be stored in the buffer. By contrast, in the auditory modality, the items to be remembered are thought to have direct access to the phonological store. Therefore disruption by articulatory suppression cannot occur. What is important for our rationale, then, is that according to this interpretation, articulatory suppression does not disrupt phonological buffering per se.

Second, converging evidence comes from neuropsychological observations made on patients with apraxia of speech, a disorder of articulatory motor planning that has been localized at the level of phonetic encoding (see previous discussion and Code, 1998; Darley et al., 1975; Varley & Whiteside, 2001). When tested in short-term memory tasks, these patients show a pattern of performance that is similar to that of normal speakers under articulatory suppression. In other words, the patients show the phonological similarity effect with auditory, but not with visual materials (Vallar & Cappa, 1987; Waters, Rochon, & Caplan, 1992; but see Martin, Blosson, Yaffee, & Wetzel, 1995). This observation indicates that the effect articulatory suppression has on healthy speakers is similar to the acquired disorder affecting phonetic and articulatory planning processing in patients with apraxia of speech. Furthermore, in contrast to speakers with apraxia of speech, patients with an impaired control of speech musculature but normal speech planning (i.e., dysarthrics) have normal short-term memory performance (Baddeley & Wilson, 1985). This shows that it is indeed phonetic planning and not motor execution which is recruited in the rehearsal/memorization process.

Finally, the third line of evidence for relatively preserved phonological processing under articulatory suppression comes from psycholinguistic experiments (Laganaro, Fougeron, & Schwitter, submitted; Wheeldon & Levelt, 1995). In these studies, participants were asked to silently monitor the presence of a phonological property (e.g., a pre-specified phoneme, word-length, etc.) in the words they retrieved during a silent translation or a silent picture-naming task. The concurrent performance of articulatory suppression had only a minor impact on detection times. Furthermore, the pattern of results (e.g., phoneme position effects, i.e., increasing reaction time from "left to right" position in the word) was comparable in the presence or absence of articulatory suppression. This was taken as evidence that participants were indeed monitoring a phonological representation, a process that was not significantly disrupted by the concurrent articulatory suppression.

These three lines of evidence suggest that performing the articulatory suppression task leaves phonological processing relatively intact (see Wheeldon & Levelt, 1995, for a similar interpretation). At the same time, articulatory suppression requires the overt articulation of a syllable. Therefore, it presumably recruits phonetic encoding to a much larger extent than it affects phonological processes. This conclusion allows the following rationale. Immediate naming requires phonological and phonetic processing, as well as motor execution. Finding a syllable frequency effect in this task provides the baseline for investigating the locus of the effect with the delayed naming instruction. When participants are asked to produce items in a delayed fashion, without interfering task, they should be able to prepare their response. If sufficient time is provided for this preparation, the response will be readily available in the short-term memory system by the time the cue is presented. This means that the syllable units required for responding, whether they are phonological or phonetic, will have been retrieved prior to cue presentation and response triggering. Consequently, if the syllable frequency effect originates at the phonological or the phonetic levels of processing, it should not be observed. By contrast, if the syllable frequency effect originates at the peripheral level of motor plan unpacking and triggering, which occurs at the time the cue is presented, then the effect should be observed.

When the delay period is filled with articulatory suppression, the encoding/buffering of response representations at the phonetic level should be impeded, while the encoding/buffering of phonological information should remain relatively intact. Of course, without the support of the rehearsal, phonological information should undergo its natural decay. Assuming that the delay is not long enough to produce this natural decay, phonological information should be readily available at the point in time the response cue is presented. Phonetic information, on the other hand, should not be available. Consequently, if the syllable frequency effect is tied to the retrieval of phonological information, it should not be observed in delayed naming with articulatory suppression. If, alternatively, the effect is tied to the retrieval of phonetic information or the unpacking of articulatory motor programs, then it should be observed in this task.

In short then, under the assumption that articulatory suppression disrupts significantly more phonetic than phonological processes, the three possible loci of the syllable frequency effect make three different predictions in the delayed naming task. If the effect originates at the phonological level, it should not be observed in delayed naming, neither with articulatory suppression nor without it. If the effect originates at the phonetic level, it should be observed in delayed naming with articulatory suppression but not without it. Finally, if the effect is due to the peripheral processes of triggering motor execution it should be observed in both delayed naming conditions.

The current study

We conducted four experiments that used immediate and delayed naming with or without interfering tasks. Pseudo-words have been used in previous investigations of the syllable frequency effect, partly for reasons of material selection. We used words and pseudo-words materials. Using pseudo-words allows the comparison with previous studies and an exhaustive control of the relevant variables. Contrasting words and pseudo-words provides information about the role of long-term lexical knowledge in producing the pattern of results. Finding similar effects for words and pseudo-words will ensure that the effects are indeed tied to the buffering system, and not to long-term lexical knowledge.

We first test the effect of syllable frequency on naming latencies in a standard immediate production task with words and pseudo-words. We then ask another group of participants to name the same items in delayed conditions. Two instructions were used. In some experiments, participants saw a target stimulus for 1 s and then waited for the cue that would trigger their speech response. In the other experiments, participants also saw a stimulus for one second; however, in this case they were asked to produce repeatedly the syllable /ba/ in the time between the disappearance of the stimulus and the appearance of the response cue. The previous discussion indicates that the interfering articulatory suppression task should modulate the occurrence of the syllable frequency effect according to its locus in the system. Experiments 1 and 2 involved pseudo-word naming. Experiments 3 and 4 involved picture naming. The latter also included a manipulation of the availability of response words (an age-of-acquisition manipulation) to control for lexical access time (see details below).

Experiment 1: Immediate pseudo-word naming

The aim of this experiment was to evaluate the effect of syllable frequency on pseudo-word production in French. We used an immediate naming task with bi-syllabic pseudo-words composed either of high or low frequency syllables. We were not directly interested in determining whether the first or the second syllable of a word are processed before speech articulation onset (Carreiras & Perea, 2004), therefore we manipulated the frequency of both syllables. The pseudo-words were matched on a number of relevant psycholinguistic variables, as described below.

Method

Participants

A total of 38 native French speakers participated in the experiment. They were all psychology students at the University of Geneva.

Materials

We created 40 bi-syllabic pseudo-words. Twenty of them were composed of two low frequency syllables and 20 others were composed of two high frequency syllables. We considered a syllable to be of low frequency when its frequency was below 150 occurrences per million and to be of high frequency when it was above 1000 per million in the database BRULEX (Content, Mousty, & Radeau, 1990) syllabified in Goslin & Frauenfelder (2000). High and low syllable frequency pseudo-words were matched pair-wise on their first phoneme and on the CV structure of both syllables. Phoneme frequency was also balanced between conditions, with no significant phoneme frequency difference between the two groups [$t(38) = 1.6$, $p = .11$]. An orthographic transcription was found for each pseudo-word by using the most frequent French phoneme-to-grapheme conversion while controlling for the number of graphemes across the two syllable frequency groups. The average number of graphemes was 6.5 for high syllable frequency pseudo-words and 6.6 for low syllable frequency pseudo-words [$t(38) < 1$]. A summary of the properties of the pseudo-words is presented in Table 1. A complete list is presented in the Appendix A.

To test for the ease of recognition of these experimental pseudo-words, we conducted an identification experiment. We selected 40 bi-syllabic nouns (lexical frequency between 20 and 50 occurrences per million in the LEXIQUE database, New, Pallier, Ferrand, & Matos, 2001) that were matched in terms of syllabic

Table 1
Characteristics of the pseudo-words (Experiments 1 and 2)

	Mean syllable frequency (per million)	Mean phoneme frequency (per million)	Mean *N* of graphemes
High frequency syllables	3274	242,115	6.5
Low frequency syllable	97	183,914	6.6

structure with the pseudo-words. The words and the pseudo-words were tested with a standard lexical decision procedure. Fifteen participants were asked to decide as quickly as possible whether the letter strings that were visually presented on a computer screen corresponded to a French word or not. Mean decision latencies were 34 ms *slower* for pseudo-words composed of high frequency syllables than for pseudo-words composed of low frequency syllables [high frequency syllables: 625 ms; low frequency syllables: 592 ms; $t_1(14) = 3.54$, $p < .01$; $t_2(38) = 2.01$, $p < .05$; $\min F'(1\text{–}52) = 3.05$, $p = 0.09$]. This result replicates previous observations of an inhibitory effect of syllable frequency in lexical decision, which have been interpreted in terms of competition among word units within the framework of an interactive activation model (see Conrad & Jacobs, 2004 and Perea & Carreiras, 1998, for detailed discussion and interpretations). Importantly for us, this pre-test shows that any benefit found for pseudo-words with high frequency syllables in the naming tasks will not be attributable to the recognition stages which are common to naming and lexical decision.

Procedure

Participants were tested individually in a quiet room. First, they were familiarized with the pseudo-words. They were asked to read them once, without time pressure. Then the experiment started. In each experimental trial, a "+" sign appeared in the middle of the screen for 500 ms, immediately followed by the pseudo-word. Participants were asked to name the pseudo-word as fast as possible, as soon as it appeared on the screen. The item remained visible until the voice key was triggered, or a timeout of 2000 ms was reached, whichever came first. The experiment began with six warm-up training trials, repeated if necessary; then the experimental pseudo-words were presented in a random order that was different for each participant.

Participants were seated in front of the computer screen and wore a head-mounted microphone. The experiment was controlled by the software DmDX (Forster & Forster, 2003). Naming latencies (time between onset of target display and onset of acoustically detectable speech) were measured. The spoken responses were digitized and recorded for later reference if necessary.

Results

Incorrect responses, as well as responses starting with noise or technical recording errors leading to an incorrect RT, were excluded (194 trials overall; 12.8% of the data). Reaction times were considered as outliers, also excluded from further treatment, when they were below 300 ms or when they were more than 3 standard deviations away from the mean of each participant (17 outliers; 1.1% of the data). The error distributions were similar for pseudo-words composed of high and low frequency syllables with respectively 79% and 83% of phonological errors, 12% of false starts or incomplete production as well as 8% and 5% of technical recording errors. A summary of the data for this experiment is shown in Table 2.

Paired bilateral Student *t*-tests showed that responses were both faster [$t_1(37) = 4.69$, $p < .01$; $t_2(38) = 2.06$, $p < .05$; $\min F'(1\text{–}52) = 3.55$, $p = .065$] and more accurate [$t_1(37) = 4.23$, $p < .01$; $t_2(38) = 2.41$, $p = .02$; $\min F'(1\text{–}60) = 4.38$, $p = .04$] for pseudo-words with high-frequency syllables than for pseudo-words with low frequency syllables.

Discussion

This experiment showed an effect of syllable frequency in speeded pseudo-word naming. Pseudo-words with high frequency syllables were produced faster than pseudo-words with low frequency syllables, replicating the observations reported by Carreiras & Perea (2004) in a different language. The comparison with the lexical decision pre-test allows locating this effect in the speech production component of the naming task, rather than in the recognition processes. However, the immediate production paradigm does not allow disentangling several possible interpretations

Table 2
Mean naming latencies (in milliseconds), standard deviations and error rates in Experiment 1: Immediate pseudo-word naming

	Immediate pseudo-word naming		
	M	St-Dev	% err
Low frequency syllables	713	182	17.4
High frequency syllables	666	152	8.2
Effect	46		9.2
95% Confidence interval	20		4.4

M, mean; St-Dev, standard deviation; % err, error rate; confidence intervals calculated around the differences between condition averages using the pooled estimate of the variance for the two data sub-sets involved in the comparison; all data by participants, same significance by items.

for the syllable frequency effect. As discussed in Introduction, faster processing for pseudo-words with syllables of high frequency could be occurring during phonological encoding, during phonetic encoding, or during motor program unpacking and triggering. In order to assess the nature of the syllable frequency effect, we conducted the next experiment. Experiment 2 used a delayed naming task with and without articulatory suppression. Participants were presented with the same pseudo-words than in Experiment 1. They were asked to name them not at the moment they appear on the screen but later, when a visual cue was presented. This experiment had two conditions. The first one was a standard delayed production task. The second condition was a delayed production with articulatory suppression: participants had to articulate the syllable /ba/ repeatedly after the presentation of the stimulus, while they waited for the cue.

Experiment 2: Delayed pseudo-word naming without and with articulatory supression

Method

Participants

A total of 40 native speakers of French volunteered for this experiment. None of them participated in Experiment 1. They were drawn from the same population than previously. Twenty of these participants performed the condition without interfering task and the other 20 performed the condition with interfering task.

Materials

The materials were those used in Experiment 1.

Procedure

The procedure for the condition without interfering task was similar to that of Experiment 1, except that participants were asked to name the pseudo-words in a delayed fashion. An experimental trial had the following structure: first, a "+" sign was presented for 500 ms, then the pseudo-word was presented for 1000 ms, followed by a blank screen for (randomly) 1000 or 2000 ms, and finally a response cue (question mark). A variable delay was used so that participants could not anticipate precisely the moment in time where the cue will appear. The short delay was chosen on the basis of the experiments of Savage et al. (1990). These authors showed that preparation of response was complete for delays above 800 ms (as indicated by the absence of lexical frequency effect at this delay in their study; see Savage et al., 1990, for details). The long delay was chosen to be shorter than estimations of natural decay rate from the phonological buffer without articulatory rehearsal (Baddeley, 2003).

Participants were asked to pronounce the pseudo-word as soon as the response cue appeared on the screen and not earlier. The cue remained on the screen until the voice key was triggered or until a timeout of 2000 ms was reached, whichever came first. The experiment began with six warm-up training trials, repeated if necessary.

The procedure for the condition with interfering task was similar to that of the previous condition, except for the following points. After the pseudo-word disappeared, the screen was not blank. Rather, the instruction "ba-ba…" appeared on the screen for 1000 or 2000 ms. It was then replaced by the response cue (question mark). Participants were asked to repeatedly articulate the syllable /ba/ for the time the instruction remained on the screen. Importantly, articulatory suppression did not start during the presentation of the target pseudo-word on the screen. This was done to allow the conversion of orthographic information into a phonological representation during target presentation (1000 ms). When the response cue appeared participants had to name aloud the previously presented pseudo-word as fast as possible.

Results

Reaction times were considered as outliers when they were below 150 ms or when they were more than 3 standard deviations away from the mean of each participant. Without articulatory suppression, participants produced 31 errors overall (3.9% of the data) and there were 20 outliers (2.5% of the data). With articulatory suppression, participants produced errors on 181 trials overall (21.5% of the data) and there were 54 outliers (6.4% of the data). These errors also included trials in which the participants could not stop on time the repetitive articulation (43% of errors). A summary of mean naming latencies and error rates is shown in Table 3. We conducted two analyses of variance (ANOVAs), one by participants and one by items. Syllable frequency was entered as a within-participants and a between-items factor. The presence of a distracting task was entered as a between-participants and a within-items factor. The summary of these analyses is presented in Table 4.

The ANOVAs show a main effect of syllable frequency (marginally significant by items), and an effect of the presence of the distracting task. These effects are modulated by a significant interaction between the two factors. This interaction reflects the contrastive effects of syllable frequency without and with articulatory suppression. Without articulatory suppression, the −3 ms difference was not significant with a 95% confidence interval of 8 ms; by contrast, the 20 ms effect found with articulatory suppression was significant, well outside the 95% confidence interval of 14 ms. This effect was not

Table 3
Mean naming latencies (in milliseconds), standard deviations and error rates in Experiment 2 (delayed naming with or without interfering task)

	Delayed pseudo-word naming					
	Without interfering task			*With* interfering task		
	M	St-Dev	% err	*M*	St-Dev	% err
Low frequency syllables	423	78	3.5	377	83	22.5
High frequency syllables	427	74	4.3	357	90	19.0
Effect	−4		−0.8	20		3.5
95% Confidence interval	8		3.9	14		4.8

M, mean; St-Dev, standard deviation; % err, error rate; confidence intervals calculated around the differences between condition averages using the pooled estimate of the variance for the two data sub-sets involved in the comparison; all data by participants, same significance by items.

Table 4
ANOVAs for Experiment 2 (delayed naming *with* or *without* interfering task)

	*F*1	*df*1	*p*1	*F*2	*df*2	*p*2	min *F*′	*df*′	*p*′
Latencies									
Syllable frequency	4.94	1–38	.03	2.20	1–38	.15	1.52	1–66	.22
Distracting task	5.22	1–38	.03	96.4	1–38	<.01	4.95	1–42	<.01
Interaction	9.79	1–38	<.01	5.46	1–38	.02	3.51	1–70	.07
Errors									
Syllable frequency	< 1	—	—	< 1	—	—	—	—	—
Distracting task	41.9	1–38	<.01	72.7	1–38	<.01	26.6	1–71	<.01
Interaction	2.07	1–38	.16	1.15	1–38	.29	< 1	—	—

visible in the error rates (see confidence intervals in Table 4).

The effect of the distracting task (faster naming latencies with than without articulatory suppression) might be surprising, under the assumption of an increased difficulty in the case a distracting task is performed. However, it is important to highlight that this difference cannot be readily interpreted since both experiments involved different groups of participants whose baseline performance can differ in a number of ways. Particularly, the difference does not seem to be produced by the requirement to conduct the distracting task per se since the comparison of similar conditions in Experiment 4 (to be reported below) does not show the same contrastive pattern.

Discussion

The results of this experiment are clear. When participants' responses were delayed (without articulatory suppression), the syllable frequency effect reported in immediate naming (Experiment 1) disappeared. The absence of the effect is presumably due to the fact that participants had time to encode and prepare their responses in the time between pseudo-word presentation and cue presentation. According to this view, syllable retrieval has already occurred when the cue appears on the screen; hence syllable frequency does not affect delayed naming times. The absence of an effect further indicates that the latency for triggering a previously retrieved motor program is not sensitive to its frequency of use.

The outcome of the condition with articulatory suppression was different. In this case, participants were asked to repeatedly articulate the syllable /ba/ in the time between the appearance of the pseudo-word and their response. Now a clear syllable frequency effect was observed. A simple interpretation of this finding is that the interfering task disrupted the ability of participants to prepare their responses to the point were syllables have been retrieved. Therefore, when the cue appears, the syllabic make-up of the response is not directly available to the encoding system (or is less available than if no interfering task was performed). As a consequence, this syllabic make-up has to be encoded or retrieved anew for producing the response. This retrieval is sensitive to the frequency of the syllables.

The fact that the syllable frequency effect was sensitive to presence or absence of the interfering task is important. It ties the occurrence of the effect (and hence the relevant characteristic that differentiates the two groups of pseudo-words in the immediate naming task) to the processes of word production that are disrupted by this task. As argued in Introduction, these processes are likely to be posterior to phonological encoding.

An interim conclusion from Experiments 1 and 2 is that there is a clear syllable frequency effect in French speech production, a result that is in line with that of previously reported studies. Furthermore, this effect seems to be located at the level of phonetic encoding. Before any further interpretation of these findings, we attempt to replicate this general pattern of results in a different word production situation. As noted in the Introduction, observing a similar pattern for words and pseudo-words will provide support for our interpretation of performance based on the operation of a phonological storage process rather than on long-term lexical knowledge. Furthermore, using words allows manipulating a lexical variable (namely, Age of Acquisition), the effects of which also contribute to locating syllable frequency effects (see below).

Experiment 3 was a standard immediate picture-naming task that paralleled the standard pseudo-word naming procedure used in Experiment 1. Experiment 4 was similar to Experiment 2 (also including conditions with and without articulatory suppression), only now pictures were presented instead of pseudo-words. Two characteristics of the picture names were manipulated: the frequency of their syllables, and the age at which they were acquired (i.e., their age of acquisition: "AoA"). The first factor is central to this study, and its effect is predicted to parallel the observations made in the previous experiments. The second factor, Age of Acquisition, is a lexical characteristic of the name of the picture. It is thought to affect the stage of lexeme retrieval (Barry et al., 1997; Bonin et al., in press; Ellis and Lambon Ralph, 2000; but see Belke et al., 2005, for an interpretation of the age of acquisition effect at the level of lemma selection, a distinction that holds for models that postulate two lexical levels in the production lexicon, e.g., Levelt et al., 1999).

Under this interpretation (and if we are correct in our proposal that the delayed task allows the preparation of the response up to a phonological level), we should not find effects of AoA when subjects perform the task without articulatory suppression. The predictions for the condition with articulatory suppression are more interesting. If the interfering task affects word preparation at the phonetic level, but not at an earlier stage, then the effect of AoA should disappear, even when the interfering task is used. By contrast, the effect of syllable frequency should still be observed (as it was observed in Experiment 2 when articulatory suppression was performed). In other words, testing for the effect of AoA in the delayed naming task provides an indication of the level at which the effects of the distracting task are occurring.

Experiment 3: Immediate picture naming

Method

Participants

A total of 30 psychology students at the universities of Geneva and Neuchâtel took part in this experiment. All of them were native speakers of French. Some of them (14) also participated in Experiment 1.

Materials

We selected 80 words and their corresponding black and white drawings in the Alario & Ferrand (1999) database. They were all bi-syllabic and the corresponding pictures had a name agreement above 70%. Half of the words were composed of high frequency syllables, and the other half of low frequency syllables according to the LEXIQUE database (New et al., 2001; we used this database because the mean syllable frequency was readily available for the words). Every high syllable frequency word had a mean token syllable frequency above 700 occurrences per million (mean across high frequency syllable words: 3205). Every low syllable frequency word had a mean token syllable frequency below 700 occurrences per million (mean across low frequency syllable words: 329).

Within the two syllable frequency groups, half of the words were acquired early in life and the other half were acquired late in life. Early acquired words had a rated age of acquisition inferior to 2.2 (mean = 1.8) on a 5 points rating scale (Alario & Ferrand, 1999). Late acquired words had a rated age of acquisition superior to 2.3 (mean = 2.8).

The following variables were controlled across conditions: name agreement, lexical frequency and mean phoneme frequency [all t's < 1.16]. The items could not be matched for initial phoneme, because of the limitation of material in a picture-naming task, but the sonority of the first phoneme (Goldsmith, 1990) was controlled across conditions. This was done to ensure comparable voice-key triggering sensitivity across conditions. We also included 50 mono- and tri-syllabic filler pictures from the same source. A summary of the properties of these materials is given in Table 5. A complete list can be found in Appendix B.

To assess whether the time needed to identify the pictures was comparable for the pictures in the four experimental conditions, we conducted a word-picture matching pre-test, inspired by Jescheniak & Levelt's (1994) Experiment 2. We selected 76 additional bisyllabic words and their corresponding pictures from Alario & Ferrand (1999), and from Bonin, Peerman, Malardier, M'eot, & Chalard (2003). We tested 15 participants. In each trial, they were presented with a printed word followed shortly after by a picture. They had to decide whether the picture corresponded to the word. All our

Table 5
Characteristics of words (Experimants 3 and 4)

	AoA	Syll F	Lex F	Pho F	Sonority
Early acquired					
High syll F	1.81	4177	14.1	27388	4.0
Low syll F	1.76	358	13.8	25184	4.0
Late acquired					
High syll F	2.66	2234	12.0	27496	3.9
Low syll F	2.87	325	11.6	24446	3.7

AoA, words age of acquisition; Syll F, mean syllable frequency per million; Lex F, mean lexical frequency; Pho F, mean phoneme frequency; sonority, mean sonority of the first phoneme.

experimental stimuli required "no" responses (i.e., they were preceded by a word corresponding to a different picture). There was no effect of AoA nor of syllable frequency in the picture-word verification task (early acquired words, low frequency: 525 ms, high frequency: 520 ms; late acquired words, low frequency: 523 ms, high frequency: 531 ms, all Fs < 1). This result guarantees that performance differences found between these groups of pictures in the naming task are not due to differences in their ease of recognition.

Procedure

The procedure closely matched that used for Experiment 1. Before starting the experiment itself, participants were given a booklet including all the drawings and their names. They were asked to examine the drawings and check whether the name they would use corresponded to the proposed name. Then the experiment started. The only difference with Experiment 1 is that the targets to be named were pictures rather than pseudo-words.

Results

As was done previously, incorrect responses as well as responses starting with noise or technical recording errors leading to incorrect RTs were excluded (7.1% of the data). 46% of the errors were false starts and technical recording errors while 54% of them where whole word errors (most of them were visual-semantic errors). Reaction times were considered as outliers, also excluded from further treatment, when they were below 300 milliseconds or when they were more than 3 standard deviations away from the mean of each participant (3% of the data). A summary of the results is shown in Table 6.

We conducted two ANOVAs (F_1 and F_2) with syllable frequency and AoA as, respectively, within-participant and between-item random factors (see Table 7). Naming latencies were 74 ms faster for early acquired than for late acquired words; they were 27 ms faster for words with high frequency syllables than for words with low frequency syllables. This latter effect is greater for late-acquired words than for early-acquired words, but the interaction between syllable frequency and age of acquisition was not significant. The value of the 95% confidence interval for this interaction was 32 ms around the difference means, well above the 21 ms difference of effect between late-acquired and early-acquired words.

Similar analysis conducted on the error rates showed a compatible pattern. There were more errors for late acquired words; there was a tendency for a syllable frequency effect in the analysis per participants. The interaction between syllable frequency and age of acquisition was significant: more errors were observed on late acquired words composed of low frequency syllables.

Discussion

Picture names composed of high frequency syllables were produced faster than picture names composed of low frequency syllables. This effect was clearly significant only in the analysis by participants. This result is important, as it indicates that the syllable frequency effect can be found in an experimental setting where responses are elicited naturally and where the materials are in the speaker's own mental lexicon. Besides, we observed the well-known effect of AoA on naming latencies. Syllable frequency and AoA did not interact significantly, although the effect of syllable frequency was considerably higher for late acquired words than for early-acquired words. This numerical variability in the size of the syllable frequency effect could be an explanation of the lack of statistical power of the item analysis; it may be linked to the difficulty to achieve an exhaustive match of all possible pertinent variables when picture materials are used. Most important for us is to compare these results to those of the delayed naming conditions carried out in the following experiment.

Table 6
Mean naming latencies (in milliseconds), standard deviations and error rates in Experiment 3 (immediate picture naming)

	Immediate picture naming					
	Early acquired			Late acquired		
	M	St-Dev	% err	*M*	St-Dev	% err
Low frequency syllables	731	91	3.8	817	100	12.7
High frequency syllables	712	91	5.5	776	100	6.5
Effect	19		−1.7	41		6.2
95% Confidence interval	18		2.6	22		3.6

M, mean; St-Dev, standard deviation; % err, error rate; confidence intervals calculated around the differences between condition averages using the pooled estimate of the variance for the two data sub-sets involved in the comparison; all data by participants, same significance by items.

Table 7
ANOVAs for Experiment 3 (immediate picture naming)

	*F*1	*df*1	*p*1	*F*2	*df*2	*p*2	min *F*′	*df*′	*p*′
Latencies									
Syllable frequency	29.8	1–29	<.01	2.45	1–76	.12	2.41	1–78	.12
Age of acquisition	153	1–29	<.01	15.5	1–76	<0.01	10.2	1–103	<.01
Interaction	1.99	1–29	.17	.38	1–76	.54	.32	1–98	.43
Errors									
Syllable frequency	3.99	1–29	.06	2.08	1–76	.15	1.37	1–103	.24
Age of acquisition	36.2	1–29	<.01	9.92	1–76	<.01	7.79	1–103	<.01
Interaction	13.7	1–29	<.01	6.30	1–76	.01	4.32	1–104	.04

Experiment 4: Delayed picture naming without and with articulatory suppression

As was done in Experiment 2, we assessed the origin of the syllable frequency effect (and of the age of acquisition effect) by asking participants to name the same pictures in a delayed fashion, with or without articulatory suppression.

Method

Participants

A total of 30 psychology students participated in these experiments. They were randomly assigned to one of the two conditions: 15 participants named pictures without an interfering task and the 15 others named them with an interfering task (articulatory suppression).

Materials

The pictures and targets words were those of Experiment 3.

Procedure

The procedure paralleled that of the Experiment 2. In this experiment, participants saw a fixation point and then a picture in the middle of the screen. They were asked to wait for the question mark cue to utter their response. Participants in the interfering task condition were asked to utter a syllable repetitively in the time between the picture and the response cue. The timing parameters were identical to those of Experiment 2.

Results

Errors and outliers were identified as in Experiment 2. Participants produced 170 errors (7.1% of the data) and there were 29 outliers. A summary of mean naming latencies and error rates is shown in Table 8. The data suggest that age of acquisition did not affect performance, and that syllable frequency had an effect only in the condition with interfering task. This conclusion is tentatively supported by three-way ANOVAs (by participants and items) where age of acquisition and Syllable Frequency were entered as within participants and between items factors, while Task was defined as between participants and within items.

These analysis showed an effect of task significant only in the analysis per item [$F1(1–28) < 1$, $F2(1–76) = 11.02$, $MSE = 10{,}872$, $p < .01$], a marginally significant effect of syllable frequency [$F1(1–28) = 3.79$, $MSE = 2502$, $p = .06$; $F2(1–76) = 2.62$, $MSE = 3478$, $p = .1$],

Table 8
Mean naming latencies (in milliseconds), standard deviations and error rates in Experiments 4 (delayed picture naming with or without interfering task)

	Delayed picture naming					
	Without interfering task			*With* interfering task		
	M	St-Dev	% err	*M*	St-Dev	% err
Low frequency syllables	383	99	5.0	374	68	12.4
High frequency syllables	380	102	3.7	357	55	7.4
Effect	3		1.3	17		5.0
95% Confidence interval	14		1.8	15		3.2

M, mean; St-Dev, standard deviation; % err, error rate; confidence intervals calculated around the differences between condition averages using the pooled estimate of the variance for the two data sub-sets involved in the comparison; all data by participants.

no effect of age of acquisition [$F1$ and $F2 < 1$] and no interaction of this factor with other factors [all Fs < 1].

The interaction between Syllable Frequency and Task did not reach significance [$F1(1–28) = 1.75$, $MSE = 1153$, $p = .2$; $F2(1–76) = 1.02$, $MSE = 1000$, $p = .32$]. Despite this limitation, planned comparisons on the syllable frequency effect for each Task condition were conducted. In the condition without articulatory suppression, the 3 ms difference was not significant, with a 95% confidence interval of 14 ms. By contrast, in the condition with articulatory suppression, the 17 ms difference found was significant, with a 95% confidence interval of 15 ms (see Table 8). Similar effects were found in the analysis of the error rates.

Discussion

The results of Experiment 4 can be summarized as follows. A syllable frequency effect was observed in the delayed production condition when a verbal interfering task filled the delay period. By contrast, no effect was found in the condition without interfering task. No effect of age of acquisition was found in any of the delayed naming times. These results present a pattern of syllable frequency effects that is very similar to the observations made with pseudo-words (Experiment 2). Hence the interpretation of this data can follow closely that provided for the pseudo-words.

In the delayed condition without interfering task, participants have fully encoded the syllables composing the words by the time the cue appears. Therefore, access to these representations is no longer required and syllable frequency does not affect production latencies. This result further shows that the syllable frequency effect does not originate in the peripheral triggering of a previously retrieved motor program.

In the condition with interfering task, syllables have not been activated and/or retrieved to the same extent by the time the cue appears. Therefore, syllables have to be processed before the production of the response can be triggered. This produces the syllable frequency effect in the naming latencies, an effect that is presumably tied to phonetic processing.

Observing an effect of age of acquisition in the immediate naming condition (Experiment 3) but not in the delayed naming conditions (Experiment 4) is in agreement with previous studies of this variable (Barry et al., 2001). The result in delayed naming is informative with respect to the impact of the secondary task on response preparation. If the effect of age of acquisition is interpreted as affecting lexical selection, its absence indicates that lexical selection is achieved in the time between stimulus presentation and cue presentation. Furthermore, the fact that no age of acquisition effect was observed even when an interfering task was used (i.e., in the condition where the syllable frequency effect was observed) puts an ‘‘upper limit’’ to the stage where the disruption produced by the interfering task occurs. Given the association of age of acquisition effects and lexical retrieval in various speech production models, these observations bolster the idea that the secondary task taps into relatively late stages of the process of word production while leaving lexical selection and phonological processes relatively intact.

General discussion

In recent years, models of language production have given an increasing attention to the syllable, a representational unit of potential importance for processing models. In this article, we have reported six experiments that investigate the status of syllables in the speech production lexicon. We investigated the locus of the syllable frequency effect during word and pseudo-word production. The results observed for words and pseudo-words are very similar and will be discussed together. Immediate naming latencies are sensitive to the syllable frequency of the items produced (Experiments 1 and 3). By contrast, when participants' speeded responses are given after a short delay, delayed naming latencies are no longer sensitive to this factor (Experiments 2 and 4). If, however, the delay period between response preparation and response execution is filled with an interfering articulatory task, then syllable frequency does affect delayed naming latencies (Experiments 2 and 4). The observed syllable frequency effect are summarized on Fig. 1. A secondary set of results concerns the age of acquisition of the words to be produced. Age of acquisition had an effect on immediate picture naming latencies. It had no effect on delayed naming latencies, irrespective of the presence or absence of an interfering task.

The syllable frequency effect reported here extends previous findings to a new language, French. The observation of a syllable frequency effect suggests that syllables are functional units that need to be accessed when word production is planned. As noted in Introduction, there is no *direct* empirical evidence from previous studies for locating the syllable frequency effect at phonological rather than phonetic or motor levels of processing. The conditions under which the effect is found in our investigation help to characterize its origin.

In Introduction, we argued that delayed naming should allow participants to prepare part or all of their response and that this preparation could be modulated by the requirement to perform a distracting task. In particular, various lines of evidence motivated the working hypothesis that articulatory suppression affects phonetic encoding while leaving phonological processing relatively intact. This working hypothesis was motivated by evidence from psycholinguistic and short-term memory studies indicating that phonological processes can survive articulatory suppression. This hypothesis is also motivated by the similarity of consequences that articulatory suppression and acquired apraxia of speech can have on short-term memory performance. Finally, the results of Experiment 4, particularly the fact that there is no age of acquisition effect in delayed naming, further corroborate the hypothesis that a fair amount of response preparation takes place during the delay period. If we assume that the age of acquisition effect observed in immediate picture-naming stems from the lexeme level, we can conclude that lexical access has occurred before production (during the delay period), even when articulatory suppression is performed.

As noted above, the observation of a syllable frequency effect in delayed naming latencies was tied to the distracting task. When no articulatory suppression was used, no syllable frequency effect was found. This suggests that the condition without distracting task allows the preparation of the response, including the processing level at which the syllable frequency effect occurs. Consequently, the effect of syllable frequency is not located at the level of triggering motor execution, a process that happens at the point in time where the cue appears even in the absence of a distracting task.

By contrast, the effect of syllable frequency is observed with articulatory suppression. This suggests

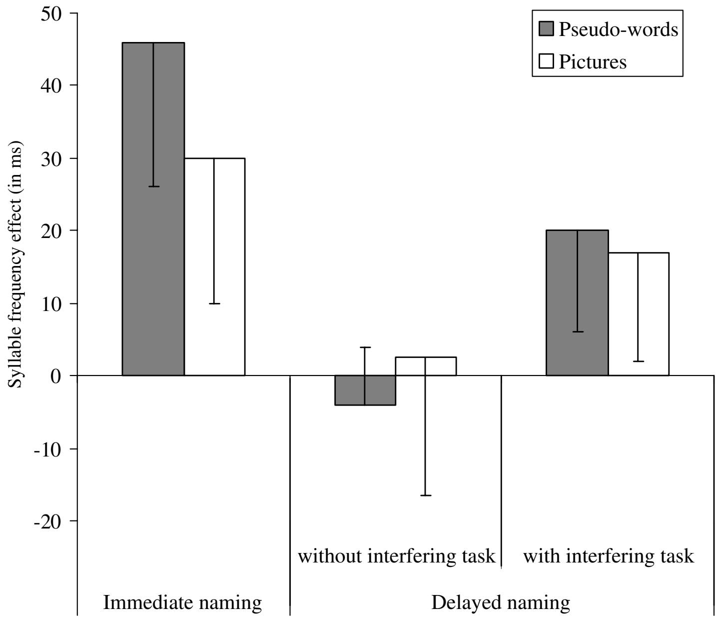

Fig. 1. A summary of the syllable frequency effect. Bars represent the difference (in milliseconds) between the high and the low syllable frequency conditions in each of the six reported experiments [whiskers are 95% confidence intervals around effect sizes, based on the pooled estimate of the variance for the two data sub-sets involved in the comparison].

that the frequency-sensitive syllable representations have to be processed at the point in time where the cue triggers the response. Since participants were given ample time to prepare their response—remember stimulus presentation lasted for 1 s before articulatory suppression—it is likely that the phonological properties of the response can be fully encoded during response preparation. Under the working hypothesis developed in Introduction, this information is maintained in a buffer while articulatory suppression occurs. By contrast, any phonetic information that may have been retrieved will not remain available. The process of retrieving that information at the phonetic level when the response cue is presented appears to be frequency sensitive. In other words, the frequency effect may be located at the phonetic level, rather than the phonological level, or the motor execution level.

A tentative specification of the mechanism involved in delayed naming with articulatory suppression can be given as follows. Speakers presumably complete the encoding of the phonological and the phonetic form during the time of stimulus presentation. The distracting task interferes with some of the buffering processes that take place during the delay period. In other words, articulatory suppression should impeach the maintenance of the buffered code, most probably clearing the phonetic buffer. Yet, the effect of repeated uttering of the syllable /ba/ might also prevent the refreshing of the phonological buffer that is usually achieved by the articulatory loop. Hence, the previously retrieved phonological representations should undergo a natural decay. Importantly, the timing parameters of our experimental procedure (1 s preparation, and a short 1 or 2 s delay) were chosen to prevent the complete decay of this activation. Consequently, although it might undergo some partial decay, phonological information should remain available. This is supported by the fact that (1) in the vast majority of pseudo-word trials participants produced the correct response, and (2) the lexical variable age of acquisition did not affect delayed picture-naming latencies, irrespective of the interfering task. In short, we interpret the syllable frequency effect in the delayed condition with articulatory suppression as a consequence of the re-encoding of syllables, which could not be maintained in a buffer during the filled delay. One possible location for storing the phonetic representation is the articulatory buffer posited by Levelt et al. (1999) model of speech production. In this buffer, syllabic gestural scores are held before articulation starts (see also Roelofs, 2002). In the experiments with the interfering task, articulatory suppression emptied this store.

Before concluding, one caveat must be made about the materials that were used in these experiments, as well as in previous investigations of the syllable frequency effect. The very nature of the question asked, which requires manipulating a variable characterizing the response items, imposes the use of a between-items design. Clearly, such design is open to the possibility of confounding factors unexpectedly contributing to the effects of theoretical interest (see, for example, the remarks about Levelt & Wheeldon's, 1994, results in Levelt et al., 1999, p. 32). In the experiments reported above, we were careful to control for many potential confounds in the materials, such as the familiarity participants have with the items in the different conditions (see the control pretests in Experiments 1 and 3), or potentially relevant phonological properties (e.g., phoneme frequency, sonority of the first phoneme, CV-structure). This does not preclude the possibility that other factors, more or less strictly correlated to syllable frequency, might play a role in the tasks we have reported. One such factor could for instance be the similarity of the materials to other real words (more specifically measured as phonological neighbourhood density; Vitevitch, 2002, 2003). The fact that in our experiments the same results were observed with pseudowords and with words is at least indicative that lexical knowledge per se is not entirely responsible for the intricate pattern we report. Further empirical investigations of the syllable frequency effect conducted in French and other languages will help to ascertain the interpretation of the findings we report.

Conclusion

We investigated the origin of the syllable frequency effect in language production. This variable was shown to affect immediate word and pseudo-word naming latencies in French. When timed responses were delayed the syllable frequency effect was observed only if participants were engaged in a distracting articulatory suppression task.

The fact that the effect is not found *without* articulatory suppression indicates that it is not due to the triggering of previously retrieved articulatory motor programs. Our interpretation of the results *with* articulatory suppression is based on the working hypothesis that this task disrupts mainly phonetic encoding while leaving major aspects of phonological encoding intact. This hypothesis is motivated by psycholinguistic and short-term memory studies. In this context, the observation of a syllable frequency effect with articulatory suppression is interpreted as evidence that the effect is located at the stage of phonetic encoding. A consequence of this conclusion is that the phonetic level involves the retrieval of syllable-sized representations, as postulated in various speech production models.

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Appendix A. Non-word stimuli (Exp 1 & 2)

[Syll-F: total syllable frequency; Pho-F: total phoneme frequency].

High syllable frequency		Syll-F (per million)	Pho-F (per million)	cv structure	Low syllable frequency		Syll-F (per million)	Pho-F (per million)	cv structure
chanzi	ʃɑ̃zi	2557	99123	cv.cv	binchai	bɛ̃ʃɛ	123	72431	cv.cv
chapé	ʃape	3751	176222	cv.cv	chongo	ʃɔ̃go	83	39762	cv.cv
chémut	ʃemy	3345	107005	cv.cv	choubai	ʃubɛ	52	82091	cv.cv
fanpeau	fɑ̃po	2584	93154	cv.cv	chunin	ʃynɛ̃	74	56006	cv.cv
féveau	fevo	1977	102467	cv.cv	gaileu	gɛlø	97	116099	cv.cv
fijat	fiʒa	3897	163018	cv.cv	meujou	møʒu	310	70366	cv.cv
mabou	mabu	4295	146532	cv.cv	ninjo	nɛ̃ʒo	53	74439	cv.cv
nirat	niʀa	4958	260236	cv.cv	quejon	køʒɔ̃	103	92102	cv.cv
panlut	pɑ̃ly	3400	140760	cv.cv	seugui	søgi	78	82325	cv.cv
vansous	vɑ̃su	4881	136939	cv.cv	teugui	tøgi	114	113808	cv.cv
cartique	kaʀtik	2038	367919	cvc.cvc	chalpic	ʃalpik	74	270709	cvc.cvc
cormal	koʀmal	2757	331827	cvc.cvc	furdar	fyʀdaʀ	62	365978	cvc.cvc
gartour	gartur	2501	364189	cvc.cvc	meltige	mɛltiʒ	118	249011	cvc.cvc
mardire	maʀdiʀ	3626	373644	cvc.cvc	tascure	taskyr	90	348447	cvc.cvc
serplé	sɛrple	2297	350291	cvc.cvc	vurbime	vyrbim	44	242477	cvc.cvc
blénire	blenir	4219	247024	ccv.cvc	flarile	flaʀil	134	358156	ccv.cvc
granquelle	gʀɑ̃kɛl	2676	281547	ccv.cvc	fropette	fʀopɛt	43	268380	ccv.cvc
pritère	pritɛr	3617	388595	ccv.cvc	glavul	glavyl	87	241625	ccv.cvc
traplie	tʀapli	2265	377782	ccv.cvc	plompousse	plɔ̃pus	81	219477	ccv.cvc
trèjour	trɛʒur	3831	334027	ccv.cvc	pralune	pralyn	123	314600	ccv.cvc

Appendix B. Words stimuli (Exp 3 & 4)

[AoA: age of acquisition; Syll-F: mean syllable frequency; Lex-F: Lexical Frequency; Pho-F: mean phoneme frequency].

High syllable frequency		AoA	Syl-F	Lex-F	Pho-F	Low syllable frequency		AoA	Syl-F	Lex-F	Pho-F
Early acquired											
avion	avjɔ̃	1.92	24626	35	19064	banane	banan	1.58	680	2	24505
balai	balɛ	1.95	1362	8	32361	bouteille	butɛj	1.92	465	38	22129
bougie	buʒi	1.96	760	11	20172	bouton	butɔ̃	1.85	643	15	21237
camion	kamjɔ̃	1.62	1619	18	32546	cerise	søʀiz	2	7	2	35096
chapeau	ʃapo	1.62	1290	42	24426	chaussette	ʃosɛt	1.58	193	2	19145
ciseaux	sizo	2.0	2444	2	32254	citron	sitʀɔ̃	1.88	220	8	34991
cochon	koʃɔ̃	1.76	2313	9	23595	crayon	kʀɛjɔ̃	1.38	147	16	27810
collier	kolje	1.86	2404	9	26954	fourchette	fuʀʃɛt	1.42	146	6	26281
couteau	kuto	1.65	2078	27	33096	giraffe	ʒiʀaf	2.12	122	1	29154
étoile	etwal	1.69	18833	32	18393	lunettes	lynɛt	2	463	37	29402
fourmi	fuʀmi	1.92	1490	3	31943	mouton	mutɔ̃	1.65	383	11	26905

gâteau	gato	1.27	1293	10	29045	nuage	nyaʒ	1.68	58	19	13531
marteau	maʀto	2.19	1549	10	41604	oiseau	wazø	1.38	324	37	22304
High syllable frequency		AoA	Syl-F	Lex-F	Pho-F	Low syllable frequency		AoA	Syl-F	Lex-F	Pho-F
orange	oʀãʒ	1.62	7647	15	15256	piano	pjano	2	423	21	21935
panier	panje	1.92	4976	16	34925	poisson	pwasõ	1.62	518	30	25096
poubelle	pubɛl	1.81	790	6	27960	raisin	ʀɛzɛ̃	2.04	479	4	18472
poupée	pupe	1.23	1471	11	32443	stylo	stilo	1.8	382	6	27277
râteau	ʀato	1.96	2055	1	33181	tomate	tomat	1.65	296	4	20970
renard	ʀønaʀ	2.15	3371	7	20832	tortue	toʀty	1.92	529	4	31025
tambour	tãbuʀ	2.15	1162	9	17715	vélo	velo	1.8	691	13	26416
Late acquired											
ampoule	ãpul	2.69	9595	7	11813	asperge	aspɛʀʒ	3.19	288	4	17966
balance	balãs	2.73	821	23	26069	bocal	bokal	2.77	564	3	16070
baleine	balɛn	2.38	704	2	27449	bureau	byʀo	2.65	667	98	30463
barrière	baʀjɛʀ	3.31	908	12	33084	cactus	kaktys	2.35	11	2	29026
canon	kanõ	3.08	1850	21	36732	cadenas	kadna	3.38	487	1	31205
ceinture	sɛ̃tyʀ	2.42	1143	21	28454	casquette	kaskɛt	2.27	128	18	31772
cerveau	sɛʀvo	3.12	1553	28	39684	gorille	gøʀij	2.5	41	2	28901
cigare	sigaʀ	2.96	2662	10	31774	guitare	gitaʀ	2.5	133	8	23610
commode	komod	2.96	2302	23	23372	hamac	amak	3.4	124	2	22327
dauphin	dofɛ̃	2.44	979	2	35068	horloge	oʀloʒ	2.69	698	12	16147
drapeau	dʀapo	2.58	912	15	35863	jumelles	ʒymɛl	2.8	257	9	17801
fusée	fyze	2.46	898	6	18510	lézard	lezaʀ	2.8	436	5	36818
moto	moto	2.23	2189	8	25488	moulin	mulɛ̃	2.31	236	15	24245
oignon	oɲõ	2.58	7601	4	7548	palmier	palmje	3.19	308	3	31562
poumons	pumõ	3.23	867	11	31111	pinceau	pɛ̃so	2.23	632	9	26391
requin	ʀøkɛ̃	2.85	3350	1	15609	poignée	pwaɲe	4.15	264	21	23157
serpent	sɛʀpã	2.23	1001	11	40242	seringue	søʀɛ̃g	3.5	3	3	30784
sifflet	siflɛ	2.38	2215	7	28122	squelette	skølɛt	3	64	9	20229
toupie	tupi	2.31	2399	2	25518	tonneau	tono	3.15	693	4	18740
valise	valiz	2.23	731	24	28418	violon	vjolõ	2.54	466	8	11701

Appendix C. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.jml.2006.05.001.

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