

## Where Is the /b/ in “absurde” [apsyrd]? It Is in French Listeners’ Minds

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In French words such as “absurde” (“bs/bt” words), the underlying linguistic code /b/ corresponds both to the spelling “b” and to the morphophonemic code {ab-} + {surd}. Yet, because of voice assimilation, the phonetic-acoustic and perceptual realization of the labial stop is [p] not [b]. In a phoneme monitoring task, listeners detected /b/ more often but more slowly than /p/ in “bs/bt” words. A phonemic gating task revealed the time course of phonetic judgments. The /b/ responses gradually increased and eventually overcame the initially dominant /p/ responses before words were identified, as a classic word-guessing gating task showed. A further phoneme monitoring task with nonwords that mimicked the “bs/bt” words confirmed that the linguistic code inducing /b/ responses built up prelexically. We propose that this code is lexically mediated by a cohort of words sharing the graphic code “b.” Alternatively, it could be conveyed by prefixes identified on-line, such as {ab-} in “absurde.” © 2000 Academic Press

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Much evidence has accumulated that people tend to hear what the structure of their language, together with the contextual situation, tells them they “should” hear rather than exactly the sounds that are physically present in the speech signal. Surface form variation is generally accommodated by listeners so that meaningful utterances are heard. For instance, as Marslen-Wilson (1999) wrote: “The sequence [hæm] in the context ‘Hand me the book’ is successfully interpreted as a token of *hand* and not *ham*, despite clear phonetic evidence to the contrary.” Phonemic restoration is another striking example of hearing what we should hear in spite of the physical evidence: Missing portions of the speech signal, roughly corresponding to pho-

nemes, are automatically “restored” in a word or a sentence context (Samuel, 1987, 1996; Warren, 1971). One remarkable aspect of this phenomenon is that listeners do not even notice that a speech segment has been removed or replaced and apparently reconstruct it on the fly. Similarly, even if cross-splicing of speech creates an impossible sequence of articulatory gestures, listeners readily interpret the cross-spliced speech sequences and appear insensitive to the manipulation (Marslen-Wilson & Warren, 1994; Streeter & Nigro, 1979; Whalen, 1984, 1991). Likewise, illegal phoneme sequences are sometimes restored or “assimilated” to legal sequences (e.g., /dla/ heard as /gla/), even in the absence of semantic or lexical information (Hallé, Segui, Frauenfelder, & Meunier, 1998). Such phenomena suggest that several sources of knowledge, superordinate to the objective stimulation, can strongly influence the interpretation of speech utterances or sound categorization and can supersede incompatible physical evidence.

Orthography is one kind of abstract knowledge that could interfere with the phonetic reality of speech sounds. Of course, this could only happen for listeners who have acquired a

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writing system in which graphic and phonological representations are related in some way. As many studies using metalinguistic tasks have shown, knowledge of sound-spelling relations in an alphabetic writing system, starting with learning the names of letters, is not independent of how speech sounds are analyzed by literate listeners (Treiman, 1985; Treiman, Tincoff, & Richmond-Welty, 1996). Rather, alphabetic knowledge seems to radically alter the way listeners analyze speech into sounds, presumably by providing them with an abstract model for analyzing speech sounds (Olson, 1996). Children who have just started learning to read and only roughly know the spoken names of letters are no longer able to separate sound and spelling (Treiman & Cassar, 1997). As children become more fluent readers/writers, the influence of orthographic knowledge on speech processing in metalinguistic tasks (such as counting sounds in words) increases (Ehri & Wilce, 1980; Landerl, Frith, & Wimmer, 1996; Treiman & Cassar, 1997; Zecker, 1991).

Only a few studies have addressed the issue of the on-line effects of orthography on speech processing. However, such effects have consistently been found. Some studies have shown that orthographic inconsistency or mismatch between orthography and phonology can hamper phonological processing. For example, listeners' performance in auditory rime monitoring or rime judgment tasks is affected by the graphic code, although these tasks require, in principle, only a phonetic judgment (Donnenwerth-Nolan, Tanenhaus, & Seidenberg, 1981; Seidenberg & Tanenhaus, 1979). It is easier and faster to decide that "pie" and "tie" rhyme than that "pie" and "rye" rhyme. [That the graphic code is activated during auditory presentation is also supported by studies using the Stroop effect paradigm with auditory primes (Tanenhaus, Flanagan, & Seidenberg, 1980).] Conflicting spelling and pronunciation have been exploited by Taft and Hambly (1985) in a different way. They used syllable monitoring in words with an unstressed first or second syllable, hence with a reduced vowel in that syllable. Target syllables with a full vowel were "incorrectly" detected in

these words provided that the full vowel in question was consistent with the spelling of the reduced vowel. For instance, /mæt/ was detected in "metallic" but /mɒt/ was not. Taft and Hambly attributed this effect to an orthographic rather than to a morphophonemic code, arguing that, for example, /læɡ/ was detected in "lagoon," which has no underlying morphophonemic code such as /læɡun/. Their conclusion, however, overlooked the well-known overgeneralization behaviors common in language learning and use, while perhaps overestimating listeners' knowledge of words' morphological composition. Orthographic mismatches between target and probe may also slow phoneme detection. The detection of phonemes that have a strongly dominant spelling in a given language can be hampered significantly when the actual spelling deviates from the dominant spelling (Dijkstra, Fieuws, & Roelofs, 1995). For example, in Dutch, /k/ is usually spelled "k," and sometimes "c." Dijkstra et al. found that the latter spelling induced a slower detection of /k/. The slower response to /k/ spelled "c" was clear only for words for which lexical access had presumably taken place because their uniqueness point preceded the /k/ (e.g., "replica" vs "paprika"), but was not clear for other cases (e.g., "cabaret" vs "kabouter"). The effect was thus considered as mediated by lexical access.

Other studies have focused on the facilitation that congruent and/or consistent orthography could induce in listening tasks. For example, auditory lexical decision is facilitated by auditory primes that share both orthography and pronunciation with the target (Jakimik, Cole, & Rudnicki, 1985): "chocolate" does not prime "chalk" (and "legislate" does not prime "leg"), but "napkin" primes "nap." When print and sound are presented in succession, the detection of, for example, /a/ is facilitated by the presentation of "A." [Symmetrically, prior presentation of audio /a/ facilitates the visual detection of "A" (Dijkstra, Frauenfelder, & Schreuder, 1993).] In line with these findings, Frost, Repp, and Katz (1988) showed that when printed words and spoken words masked by amplitude-

modulated noise are presented simultaneously, the congruence of printed and spoken words facilitates the detection of speech in the noise. Using a speech–print congruence decision task, Frost and Katz (1989) further showed that visual or auditory degradation had a less detrimental effect in Serbo-Croatian than in English. Because the interaction between orthography and phonology must be structurally more complex in the case of a deep orthography (English) than a shallow one (Serbo-Croatian), it might be more efficient for degraded stimuli to be recovered in the latter case. Thus, print may help in auditory tasks. In line with this notion, facilitatory effects of phonology-orthography consistency have been found not only in visual lexical decision (Ziegler, Montant, & Jacobs, 1997) but also in auditory lexical decision (Ziegler & Ferrand, 1998): Lexical decision is faster for words with an orthographically consistent rime.

The literature reviewed suggests that the graphic code of words may affect listeners' phonetic interpretations, even in supposedly on-line tasks such as phoneme monitoring or auditory lexical decision. However, given the paucity of the data gathered so far, certain key issues need further examination. In particular, it would be useful to know more about the locus of these interference effects in lexical access. Does the orthographic-phonetic interference emerge only after words are recognized or does it emerge before they are recognized? (For convenience, we refer to these lexical loci as post- and prelexical, respectively.) In a more detailed way, how early in the processing does the orthographic code begin to interfere with the bottom-up phonetic-acoustic information?

The present study was a first step toward answering these questions. To explore the issue, we needed a clear-cut case of conflict between the phonetic and the orthographic code. In French, voice assimilation is a ubiquitous phonological change (Carton, 1974; Grammont, 1933; Rigault, 1967). Typically, voiced stop consonants (/b/, /d/, or /g/) become devoiced (/p/, /t/, or /k/) when followed by a voiceless obstruent. For example, "médecin" (medical doctor) is pronounced /metsɛ̃/ due to a schwa

deletion and retroactive voice assimilation. Rigault (1967) demonstrated both the acoustic and perceptual reality of voice assimilation in such instances. When listeners had to transcribe /etsɛ̃/ excised from /metsɛ̃/, their judgments were based on the "sound substance" of the dental stop; that is, [t] not [d]. Rigault also showed that the "fortis" vs "lenis" distinction proposed in earlier studies was not supported by acoustic and aerodynamic measurements. No difference was found between /t/ in "médecin" and /t/ in "Hauteserve" (/otsɛrv/), contrary to the earlier description offered by Grammont (1933) of these /t/s being realized as [d̥] (voiceless "lenis") and [t] (voiceless "fortis"), respectively. In these instances of voice assimilation, then, surface phonology and orthography are incongruent, and interference between the two might be observed. Indeed, Rigault implicitly assumed that when presented with whole words or sentences, listeners would base their phonetic judgments on what he called the abstract "linguistic substance" rather than the "sound substance" of speech segments. For example, listeners would claim to hear /d/ in "médecin" because the word's orthographic code contains "d." Note that the /d/ percept in this case, and perhaps in most similar assimilation cases, could also be mediated by a morphophonemic code ("médecin" is morphologically related to "médical," "médicament," etc., in which "d" is pronounced /d/). Whatever the relevant linguistic code, is there evidence that it interferes with the phonetic code during word processing tasks? The literature we briefly reviewed suggests that it should (also see Dupoux & Mehler, 1992). To our knowledge, however, evidence of interference between the orthographic (or morphophonemic) codes and phonetic perception when subjects listen to such words as "médecin" has not yet been presented.

The current study was designed to fill that gap, using both on-line and off-line tasks to explore whether the graphic code can influence phonetic judgments and how its effect unfolds over time. We used words in which voice assimilation alters the pronunciation of a consonant letter. The conflict thus created between

the graphic and the phonetic codes could conceivably change phonetic judgments. For instance, the French word "absurde" is pronounced /apsyrd/, although the canonical pronunciation of "b" is /b/. This word also has an underlying morphophonemic code /absyrd/ because it contains the prefix {ab-}, even though many listeners may not recognize it as such. Thus, for "absurde," and for most of the stimuli used in the present study, the morphophonemic code could also interfere with the phonetic code. For the sake of simplicity, however, we consider the manipulated conflict as one between the orthographic and the phonetic codes (keeping in mind that the story may be less simple).

Although Rigault's (1967) study clearly established the acoustic and perceptual reality of voice assimilation in various contexts (within and between words), his work is not widely known. Therefore, we first attempted to replicate his findings using new spoken materials. After we confirmed that the labial stop in "absurde" is indeed [p], not [b], and is perceived as such when extracted from the carrier word, we turn to the issue of primary interest: Do listeners hear a /b/ in words such as "absurde"? Whether listeners *should* hear /p/ rather than /b/ is a different question. Trained phoneticians would probably report hearing [p], but hearing /b/ is ultimately more helpful to listeners in the normal process of word recognition because /b/ is a better match than /p/ for the linguistic code of "absurde." Thus, one cannot truly claim that hearing /p/ is "correct," whereas hearing /b/ is not. Both interpretations reflect viable analyses of the speech input that meet different needs. Hearing /p/ requires ignoring the orthographic code, whereas hearing /b/ reflects a dominant influence of the orthographic code. However, before turning to the question of what listeners hear in words such as "absurde," we must first ascertain that the labial stop in these words is [p] rather than [b].

### ACOUSTIC ANALYSES

The stimuli examined here were 16 words in which a labial stop occurred word-medially and

was spelled with "b" (e.g., "abscisse" and "obtus"). This stop was followed by either /s/ or /t/, a context which requires voice assimilation. All these words begin with "ab," "ob," or "sub." According to word etymology, these initial sequences were prefixes, with the exception of "absinthe" and "abside." Nonlinguists, however, are usually not very aware of this morphological composition.<sup>1</sup> The 16 critical test words were matched with 16 control words in which /p/ was spelled with "p" (e.g., "epsilon") and was thus unambiguously pronounced [p]. These two sets of test and control items were matched on subjective frequency, number of syllables, and phonological structure (such as syllabic position of the labial stop; see Appendix A). They were chosen from an initial set of 48 words, matched in frequency according to the "Trésor de la Langue Française" (TLF: Imbs, 1971). This initial selection was then narrowed by having 20 participants rate word frequency using a scale of 1–5. Thirty-two words were retained so that subjective frequency could be as closely equated as possible between test and control items as well as between the /s/ and /t/ contexts. The number of syllables in the test items ranged from 2 to 4 (mean = 3.1).

All of the speech materials for the acoustic analyses and Experiments 1–3 were recorded in a single session by a male native speaker of French on a Denon DTR-100P digital audio tape recorder using a Sennheiser MD 441-u

<sup>1</sup> To check this, we presented a list of words to 30 participants from the same population as those who participated in the main experiments. The list was composed of three sets of words: 12 of the 16 critical stimuli of Experiment 1; 12 words beginning with "ab," "ob," or "sub" but clearly not prefixed (e.g., "abeille," "subit," and "obélisque"); and 16 clearly prefixed words in the sense their stem was unbound and was semantically transparent (e.g., "préhistoire" and "désillusion"). Participants were asked to rate on a scale of 1–5 how confident they were that each of these words was prefixed. Words such as "abeille" received the lowest score ( $M = 1.4$ ,  $SD = 0.3$ ), whereas words such as "préhistoire" received the highest score ( $M = 4.5$ ,  $SD = 0.4$ ). Words such as "absurde" were rated in the low range of "prefixedness" ( $M = 2.2$ ,  $SD = 0.7$ ): listeners' awareness of their morphological structure was much lower than for clearly prefixed words,  $p < .0001$ , but somewhat higher than for monomorphemic words,  $p < .005$ .

microphone. The speech was digitized (16-kHz sampling rate and 16-bit resolution) and transferred to computer files.

The first evidence of the voiceless quality of the labial plosive in the “bs” and “bt” items was provided by a visual inspection of spectrograms. No trace of a voicing murmur before release burst could be seen in these items, contrary to other items with unambiguous /b/s (e.g., “abjurer” /abʒyʁe/) in which voicing was clearly marked by a voicing murmur during the closure portion of [b]. With respect to this main spectral cue for voicedness, words such as “absurde” did not differ from words such as “capsule.”

We then examined further possible cues to voicing. In English, vowels are shorter before voiceless than before voiced plosives (Peterson & Lehiste, 1960; Raphael, 1972; Umeda, 1975). Symmetrically, closure durations are longer for voiceless than for voiced plosives (Port & Rotunno, 1979; Umeda, 1977). This sort of trading relation between vowel and consonant duration also holds in French (O’Shaughnessy, 1981; Wajskop, 1979). In the materials used in this study, test and control words (e.g., “absurde” and “capsule”) did not differ with respect to either duration cue, which again points to [p] in words such as “absurde.” The mean duration of the vowel preceding the labial plosive was 76 ms ( $SD = 14.8$  ms) for test words (e.g., “absurde”) and 75 ms ( $SD = 15.1$  ms) for control words (e.g., “capsule”),  $t(28) < 1$ . The closure duration was 79 ms ( $SD = 14.5$  ms) for test words and 83 ms ( $SD = 9.5$  ms) for control words,  $t(28) < 1$ . Two control words, “somp-tuaire” /sɔ̃ptyɛʁ/ and “dompteur” /dɔ̃ptœʁ/, were not included in the measurements. The offset of the nasal vowels preceding the labial plosives in these words was difficult to determine, probably because in these cases, unlike those with non-nasal vowels, the velum remains open after closure for the first plosive is initiated. Had we taken the first clear evidence of stop closure as the acoustic offset of the vowel, the vowel duration would be as long as 150 ms and the closure duration as short as 15 ms (see O’Shaughnessy, 1981, for similar observations).

To sum up, the acoustic evidence points to

[p] rather than to [b] in words such as “absurde.” It is possible, however, that subtler cues to voicing were present in the materials and can be perceived by listeners. One way to examine this possibility is to present listeners with portions of the critical stimuli that contain the critical labial stop but provide no linguistic cues that could interfere with listeners’ phonetic judgments. This is what Rigault (1967) did to demonstrate that the phonetic realization of “d” in “médecin” /metsɛ̃/ was [t] not [d]. In the same vein, Hallé et al. (1998) used a *phonemic* gating task to show that listeners heard [t] in the shortest fragments of word-initial /tʰl/, whereas, in the following fragments, their judgments shifted toward [k] (presumably because phonotactic constraints in French allow initial /kʰl/ but not /tʰl/). We used the same gating technique in Experiment 1, using items that were excised portions of the words under scrutiny so that listeners were not influenced by lexical information (in particular, orthography) and could focus on the sound substance of the labial stops.

#### EXPERIMENT 1: PHONEMIC GATING OF EXCISED PORTIONS OF “ABSURDE” VERSUS “ABJECT”

Participants were run on a phonemic gating task in which the gated items were portions excised from entire words, comprising the labial stop and the following context (e.g., [psyr] excised from “absurde”). Items with clearly voiced [b]s, excised from words such as “ab-diquer” or “abject” were included for comparison.

##### *Method*

*Stimuli and design.* Eight test items were excised from eight words (“abscisse,” “absinthe,” “absurdité,” “subséquent,” “obtenant,” “obtusion,” “subterfuge,” “subtiliser”) that were representative of the set of 16 test words used for the acoustic analyses. (This limitation was meant to keep the experiment duration within reasonable limits.) Eight control items from eight new words with the sequence “bj” or “bd” pronounced /bʒ/ or /bd/ respectively (“abject,” “objectant,” “objurgation,” “subjugué,” “sub-



jectif," "abdiquer," "subdésertique," "subdiviser") provided a baseline for the perception of unambiguous /b/s. The test items were derived from the original words by removing the initial portion up to the middle of the closure silence. For the control items, this procedure was somewhat complicated by the presence of a voicing murmur before release burst. The initial portion of the entire word was deleted until the point of maximum spectral stability within the voicing murmur portion, roughly maintaining the second half of this portion. To avoid a discontinuity click at stimulus onset, a 20-ms amplitude ramp was applied to the initial portion of those items. For all 16 items, the first fragment, or gate, contained the initial portion of the signal up to 40 ms after the stop release burst. There were a total of eight gates, whose duration increased by 30-ms steps. The final 4 ms of each fragment was attenuated by a raised cosine function so that there were no perceivable click at gate offset. The eighth and last fragment thus included 250 ms of signal after the release burst. This fragment comprised the consonant following the labial stop (/s/, /ʒ/, /t/, or /d/), the following vowel, and part of the following consonant.

The participants received a total of 128 stimuli (16 items  $\times$  8 gates) blocked by duration (4-s ISI and 8-s IBI). This format of presentation was used rather than the more standard successive presentation format in order to avoid perseveration effects in participants' responses (see Walley, Michela, & Wood, 1995).

*Procedure.* Participants had to write down what they heard as precisely as possible and give a confidence rating for their transcription on a scale of 1–5. Importantly, in the phonemic gating task, participants are asked to avoid guessing words (Hallé et al., 1998), unlike in the usual gating task (Grosjean, 1980). The phonemic variant of the gating paradigm should tap the phonetic perception of the critical labial stops and is less likely to be biased by lexical effects. Moreover, word responses, as obtained in the classic gating paradigm, could not result in /b/ transcriptions of the initial consonant of either test or control items, since the /bs/, /bt/,

/bz/, or /bd/ clusters all are illegal word-initially. By contrast, phonemic gating for short fragments of either illegal or legal clusters can tap into a phonetic level of perception, before perception is possibly biased by phonotactic or lexical knowledge (Hallé et al., 1998). Participants were tested individually. After test completion, the experimenter checked the written responses. In cases where transcriptions were unclear as to their phonetic value, the experimenter asked the participant to clarify them.

*Participants.* Fourteen undergraduates at the Université Paris V, ages 20–25 years, participated in the experiment for course credit. None of them reported hearing or speaking problems. The data of two additional participants could not be retained: One failed to keep in time with item presentation, and the other only produced lexical responses in spite of the instruction to write transcriptions of the sounds heard rather than guessing words.

### Results and Discussion

The participants' gating responses were analyzed with respect to the consonant reported in item-initial position: /b/, /p/, or "other." Figure 1 shows the percentage of the three types of responses according to gate number for the test items (Fig. 1A) and for the control items (Fig. 1B). Consistent with the findings of Blumstein and Stevens (1980) on the perception of very short portions of plosives, place of articulation was already identified correctly at the first gate—which comprised 40 ms following release burst—about 60 to 70% of the time. For the test items, /p/ responses dominated from the first gate onward. The percentages of /p/ and /b/ responses stabilized at the third gate, with 90% or more /p/ responses. The pattern of responses for control items was roughly symmetrical, with 90% or more /b/ responses from the third gate onward. The gating data were entered in Gate (gates 1 to 8)  $\times$  Response (/b/ or /p/)  $\times$  Item-type (test or control) by-subject and by-item ANOVAs. There was a Response  $\times$  Item-type interaction,  $F(1, 11) = 775.3$ ,  $p < 0.0001$ ,  $F(2, 14) = 1139.9$ ,  $p < .0001$ , reflecting the fact that responses were mostly /p/ in the test

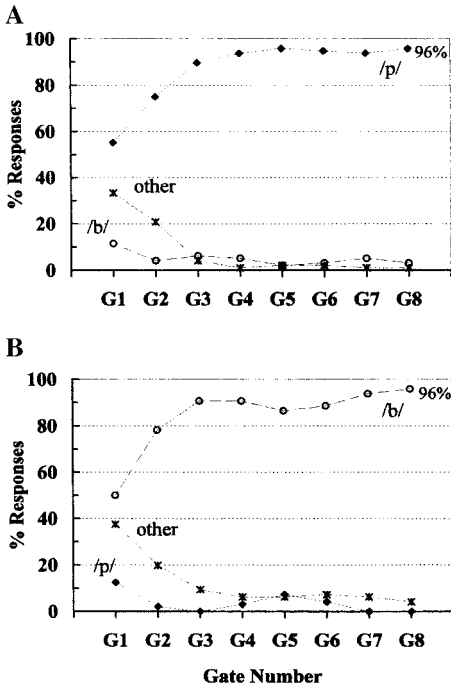


FIG. 1. Experiment 1: percentages of /b/, /p/, and "other" responses according to gate number for (A) test items ("bs" or "bt" items) and (B) control items ("bj" or "bd" items).

items and mostly /b/ in the control items. This was significant from the first gate onward. Moreover, the dominance of /p/ responses in test items did not differ from that of /b/ responses in control items,  $F_s < 1$ . Gate was highly significant, presumably because of the sharp increase of responses in the first few gates for /p/ in the test and /b/ in the control items. However, responses stabilized from Gate 3 onward and did not change after that gate, as analyses limited to Gates 3–8 showed.

The results thus showed that listeners heard /p/ rather than /b/ in "absurde," provided that the labial stop was presented without lexical context. This was consistent with the acoustic measurements, which also suggested that the sound substance of the labial stop was [p]. In words such as "absurde," however, the orthographic code for the labial stop is "b," whose canonical pronunciation is /b/. If this code interferes with phonetic perception, listeners might hear /b/ rather than /p/ in "absurde."

## EXPERIMENT 2: DETECTION OF /b/ VS /p/ IN "ABSURDE" VS "CAPSULE"

In this experiment, listeners were auditorily presented with the test and control words used in the acoustic analyses (e.g., "absurde" /apsyrd/ and "capsule" /kapsyl/). Two conditions were contrasted. In one condition (with stimuli such as "absurde"), sound and spelling were incongruent. In the other condition (with stimuli such as "capsule"), they were congruent. If listeners base their decision on the phonetic value of the labial stop contained in the stimuli, they should detect /p/ rather than /b/ in "absurde" as well as in "capsule." Conversely, if listeners are influenced by the spelling, they should detect /b/ in "absurde" but not in "capsule."

### Method

**Stimuli and design.** The 16 critical test words and the 16 control words were those used in the preceding acoustic analyses. Their mean frequency, according to the TLF, was 62. Another 64 words were included, half of which contained /b/ and the other half /p/ in word-initial or word-final position (mean TLF frequency 77). Finally, 192 filler items contained neither /b/ nor /p/ (mean TLF frequency 79). The total number of items was thus 288.

This set of 288 items was split into two test lists of 144 items, maintaining as much as possible in each list the proportions and characteristics of the various types of items. Target assignment to list (/b/ or /p/) was counterbalanced so that participants heard each item only once. Half of the participants first had to detect /b/ in one list then /p/ in the other list. The order of targets was reversed for the remaining participants.

A distractor list was constructed for the /f/ target. It contained 24 target-bearing items in initial, medial, and final position and 48 non-target-bearing fillers. This list was inserted between the two test lists. Its purpose was to make less apparent the noncanonical pronunciation of "b" in the "bs" and "bt" items of the test lists. The two test lists and the distractor list were

preceded by a practice list containing 36 items: 12 words bearing the target /t/ in initial, medial, or final position, and 24 filler words which did not bear the /t/ target.

*Participants.* Sixty participants from the same population as in Experiment 1 were tested. None of them reported a hearing difficulty or a spoken or written language problem.

*Procedure and apparatus.* Participants were tested individually in a sound-attenuated booth. They were presented with the stimuli via Sennheiser headphones at a comfortable listening level with an interstimulus interval of 1.8 s (offset to onset). They were told that they would have to make a speeded detection response to target phonemes by depressing a Morse key with their preferred hand. It was emphasized that the participants' task was to detect sounds not letters. To explain the difference between sounds and letters, examples were given that illustrated one-to-many orthography-pronunciation correspondences (e.g., "s" for either /s/ or /z/: "esprit" /ɛspri/ or "asile" /azil/) and vice versa (e.g., /z/ for either "z" or "s": "azur" /azyr/ or "asile" /azil/). Participants were warned that targets could occur anywhere in the carrier words. For each list, the target was specified auditorily with word examples in initial, medial, and final position using a standard format of specification. For example, /t/ was specified in the following way: "te" as in "tennis," "antique," or "baguette" ("te" was pronounced /tœ/, /œ/ being the French vowel closest to schwa). The presentation of stimuli and of oral instructions was controlled by a microcomputer interfaced with a digital-to-analog converter. The computer collected reaction times (RTs) measured from the release burst of the plosive targets /b/, /p/, or /t/ or from the acoustic onset of the fricative target /f/, as estimated from spectrograms.

## Results

Detection rates and RTs are summarized in Table 1. The detection rate and RT data were entered into analyses of variance. For the detection rate data, no responses were discarded. However, RTs longer than 1400 ms or shorter

TABLE 1

Detection Rate and RT in Experiment 2 as a Function of Target (/b/ or /p/) and Stimulus Type<sup>a</sup>

Target		Stimulus type	
		Test ("absurde")	Control ("capsule")
/b/	% detection	89.8% (9.4)	27.9% (18.4)
	RT	759 ms (77.4)	706 ms (234.6)
/p/	% detection	58.8% (18.7)	95.4% (5.2)
	RT	637 ms (111.2)	676 ms (82.6)

<sup>a</sup> By-item standard deviations are in parentheses.

than 100 ms were removed from the RT analysis. This criterion was based on the examination of the overall distribution of RTs: mean = 756 ms, median = 680 ms,  $SD = 346$  ms; it was set close to median +  $2 \times SD$  (1373 ms). Using this criterion, 6% of the RT data were discarded. In the participant analyses of detection rate, the full design was List-assignment (to target)  $\times$  Target-order  $\times$  Target (/b/ or /p/)  $\times$  Letter ("b" or "p")  $\times$  Context (/s/ or /t/). In the item analyses, List replaced List-assignment to target. RTs were submitted to a simplified ANOVA design (see below).

List, List-assignment to target, and Target-order had no significant effect on detection rate. Context had no significant effect. As can be seen in Table 1, the detection rate of /b/ was rather high across the board. However, it was much higher in words such as "absurde" than in words such as "capsule"; that is, when /p/ corresponded to the letter "b" rather than to the letter "p." Conversely, the detection rate of /p/ was much higher when /p/ occurred in "capsule" than in "absurde." This was supported by a significant Target  $\times$  Letter interaction,  $F(1,56) = 245.3$ ,  $p < 0.0001$ ;  $F(1,24) = 248.1$ ,  $p < .0001$ , and confirmed by planned comparisons. Moreover, /b/ was detected more often than /p/ in "absurde," whereas /p/ was detected more often than /b/ in "capsule." All these differences were highly significant, in general at the  $p < .0001$  level. To sum up, the detection rate results suggested that participants



were largely influenced by the graphic codes of the words. However, participants did not simply rely on orthography while ignoring sounds, since they were able to detect /p/ in “absurde” almost 60% of the time.

For RT analyses, three of four cases were examined: detection of /b/ and of /p/ in “absurde” and detection of /p/ in “capsule.” (The detection rate of /b/ in “capsule” was too low to undertake reliable RT analyses.) In the following, we refer to those three cases as /b/ in “b,” /p/ in “b,” and /p/ in “p.” As Table 1 shows, RTs to /b/ in “b” were about 100 ms longer than RTs to /p/ in either “b” or “p.” These differences were significant at least at the  $p < .001$  level in both participant and item analyses.<sup>2</sup> RTs to /p/ were not significantly longer in “p” than in “b” words,  $F(1,56) = 1.4$ ,  $p = .24$ ;  $F(1,28) = 1.5$ ,  $p = .22$ . In other words, RTs to /b/ were consistently longer than RTs to /p/.

The above analyses were conducted on the data pooled across all participants. As various studies have shown, however, it could be that the effects are restricted to “slow” subjects or slow responses (Dupoux, 1993; Fox, 1984). A “speed” analysis was thus run by partitioning participants according to their mean speed of performance into equal-sized subgroups of “slow,” “medium,” and “fast” participants. The main patterns observed in the pooled data held in all three subgroups: /b/ was detected more often in “b” than in “p” words and RTs were longer for /b/ than for /p/ in “b” words by about 100 ms in all three subgroups. The subgroups

did not differ in the detection rate of /b/ in “b” words. They differed, however, in the detection rate of /p/ in “b” words, which was highest for fast participants and lowest for slow participants. This was supported by analyses of the correlation between RT and detection rate. For /b/ in “b,” individual mean RTs did not correlate with detection rate,  $r(58) = -.09$ ,  $p = .56$ , but for /p/ in “b,” they correlated negatively,  $r(58) = -.26$ ,  $p < .05$ .

We also checked whether detection rates and RTs for /b/ and /p/ in “b” words correlated with subjective frequency. There was a marginally significant trend for /p/ to be detected less often in more frequent words,  $r(14) = -.48$ ,  $p = .057$ , and /b/ was detected more rapidly in more frequent words,  $r(14) = -.57$ ,  $p < .05$ . (Similar but nonsignificant trends were found for the objective frequencies from the TLF.) No other correlation approached significance. In particular, /b/ was not detected more often in more frequent words. Hence, these analyses only provided mixed support for the notion that the observed effects were modulated by lexical frequency.

### Discussion

This experiment showed that French listeners exhibit a strong tendency to detect /b/ rather than /p/ in “b” words such as “absurde” although these words are pronounced with a [p]. This finding establishes the basic framework of the present study: a robust case of orthographic influence on phonetic perception.

The rate of false positive responses for /b/ in the control words (e.g., “capsule”) was rather high. This could be due to the dominance of [p] carrier words (counting “absurde” as such) in the materials. Enhanced expectation of /b/ would increase the false positive rate for /b/. The high rate of /b/ detection in “capsule” could also indicate that the /b-/p/ contrast is intrinsically difficult, especially perhaps in word-medial position. At any rate, the important outcome of Experiment 2 is that /b/ was detected much more often in “absurde” than in “capsule” (90% vs 28%).

For “absurde,” the /b/ responses, which were

<sup>2</sup> Because miss rate was relatively high—especially in the /p/ in “b” case—and the number of items involved in each cell was small, there were many missing values in the full design of the participant data [List-assignment  $\times$  Target-order  $\times$  Case (/b/ in “b,” /p/ in “b,” or /p/ in “p”)  $\times$  Context (/s/ or /t/)]. However, pooling the data across the Context variable (/s/ or /t/ right context) made the number of missing values reasonably low: Four participants missed the /p/ in “b” value, and another one missed the /b/ in “b” value; thus, only five values were missing out of 180 (2.8%). We took the conservative option of replacing each missing value in a participant’s data by the average of this participant’s other data. (This option can only weaken the differences between the three detection cases.) There were no missing values in the full design item analysis.

presumably induced by the orthographic code, were significantly slower than the /p/ responses. Moreover, /p/ detection was distributed in the faster range of responses, suggesting it was based on a more immediately available phonetic code. It is possible that detection of /b/ in "absurde" engaged a linguistic level of representation that became available after or at lexical access, whereas detection of /p/ reflected a phonetic level of processing that occurs before lexically driven representations, including the graphic code, could exert an influence. This account is in line with the data of Dijkstra et al. (1995), which suggest that phoneme detection is biased by a word's orthographic code only when the phoneme occurs after the uniqueness point.

However, there was little converging evidence that the detection of /b/ in "absurde" engaged complete lexical access, from which the orthographic code was retrieved. First, the influence of lexical (subjective or objective) frequency was not clear-cut. Indeed, whereas /p/ tended to be detected more often in less frequent "b" words, /b/ was not detected more often in more frequent "b" words. This is only partly in line with the notion that the influence of the graphic code available from the lexicon increases with lexical frequency. Second, on a strictly postlexical account, the representations activated after lexical access, such as the graphic code, should emerge rather late relative to the auditory words. Consequently, the detection rate of /b/ in "absurde" should be highest in the slow range of response times. But such was not the case. To sum up, the postlexical nature of the orthographic effect we found is more clearly suggested by the fact that the responses reflecting a linguistic level of processing (the /b/ responses) were consistently slower than those reflecting a phonetic level of processing (the /p/ responses).

Rather than resulting from the access to a single word or, perhaps, a single morphological family, the high detection rate of /b/ in "b" words could reflect general aspects of phonemic composition in the French lexicon. That is, /b/ might occur more frequently or in more words

than /p/ after the initial sequences /a/, /ɔ/, and /sy/ that appeared at the onset of the test words. Counts using the BRULEX database (drawn from the TLF) do not support that hypothesis, however. There are about the same number of words beginning with "ab," "ob," and "sub" (341) as words beginning with "ap," "op," and "sup" (329). The cumulative frequency of the latter, where "p" is always pronounced /p/, is 365,679, whereas that of the former is 290,926, of which only 176,553 have "b" pronounced /b/. Hence, there is no general advantage for /b/ over /p/ based on lexical statistics after the initial sequences /a/, /ɔ/, and /sy/. The findings of Experiment 2 must thus reflect the influence of deeper sources of knowledge, such as the orthographic representation of specific words. Still, when in the process of lexical access do such influences emerge?

In the next experiment, we used the phonemic gating task to address this question. As Hallé et al. (1998) have shown, this variant of the gating paradigm provides information about the time course of phonetic perception for non-words. The data at each gate give a snapshot of the relative perceptual salience (or, perhaps, activation level) of the various phones that listeners hear. The novelty, here, is to use that paradigm to trace the possible influence of higher level information on phonetic processing. Contrary to Experiment 1, where excised portions of words were used (e.g., /psyrð/), the gating must now involve the entire words (e.g., "absurde") in order to let lexical information (in particular, the graphic code) exert an influence. Where in the "b" words would listeners begin reporting that they hear /b/ rather than /p/? Or, however unlikely, would they fail to report /b/s at all, even when presented with a sufficiently long fragment for a "b" word to be recognized? Experiment 3 was designed to shed light on this issue.

### EXPERIMENT 3: PHONEMIC GATING OF THE ENTIRE STIMULI

When listeners detect /b/ in "absurde," they must base their detection on a linguistic level of representation, presumably an orthographic

code. How does the interference of the graphic code with the bottom-up phonetic-acoustic information unfold over time? Does the graphic code build up and influence phonetic perception only after words are recognized? To address this issue, a phonemic gating test was conducted on the “bs” and “bt” words used in Experiment 1. This variant of the gating paradigm was chosen to avoid overestimating lexical influences on phonetic judgments. As in Experiment 1, “bj” and “bd” control items were included to provide a baseline for how consistent /b/s (i.e., /b/s in agreement with the spelling “b”) are perceived. In addition, “ps” and “pt” control items such as “rhapsodie” were also included, providing another baseline for consistent /p/s.

### Method

*Stimuli and design.* The 16 words from which the test and control items of Experiment 1 had been excised were used in their entirety. Four control words with the “ps” or “pt” sequence in which “p” was pronounced [p] were added as control items for the perception of consistent /p/s: “rhapsodie,” “autopsie,” “cleptomane,” and “Neptune.” (These words were also used in Experiment 2.) For all 20 words, the first gate contained the initial portion of the word until the point of maximum spectral stability in the vowel preceding the labial stop under scrutiny. For example, the first gate for “subterfuge” /sypterfyz/ was /sy/, with roughly the first half of the /y/ vowel. There were a total of eight gates, whose duration increased by 40-ms steps. The last gate thus included 280 ms more than the first gate. The final 4 ms of each fragment was attenuated as in Experiment 1 to avoid clicks at gate offset.

Importantly, the synchronization between the main phonetic events in the stimuli and the gates was relatively homogeneous across stimuli. The release burst of the critical labial stop occurred at the end of Gate 4. It was immediately followed by the fricative /s/ or /ʒ/ in “bs” or “bj” items. In “bt” or “bd” items, the release burst of /t/ or /d/ occurred at the end of Gate 6. The eighth (last) gate contained a substantial part of the following vowel (100 ms on aver-

age). This vowel (e.g., /y/ in “absurdité”) was the morphological family uniqueness point (UP) for six test words and for the eight “bj” or “bd” control words. For the two remaining test words, “abscisse” and “obtusion,” the UP was the consonant following /i/ and /y/, respectively. For the “ps” or “pt” control words, the UP was the next consonant after /p/. Therefore, the longest fragments listeners heard were portions of words from word onset and in general up to UP (slightly beyond for the “ps” or “pt” controls, slightly before for “abscisse” and “obtusion”).

Participants received a total of 160 stimuli (20 items  $\times$  8 gates) blocked by duration (4-s ISI and 8-s IBI). Each block contained 20 items in a random order differing from block to block.

*Participants.* Fifteen participants from the same population as in Experiments 1 and 2 were run.

*Procedure.* The procedure was the same as in Experiment 1. The instruction to avoid guessing at words was stressed so that the task itself would not elicit a lexical strategy. Lexical influence on phonetic judgments was nonetheless expected to emerge as soon as sufficient information had been presented for words to be recognized.

### Results and Discussion

The gating responses were analyzed as in Experiment 1 with respect to the consonant reported for the critical labial stop: /b/, /p/, or “other.” Figure 2 shows how the percentages of these three possible responses changed over time for the test (Fig. 2A) and control items (Figs. 2B and 2C). The pattern of responses for the “bj” and “bd” control items was similar to that obtained in Experiment 1, but the correct identification of place emerged only at Gate 3. Indeed, the release burst appeared only at Gate 4 in the present experiment, whereas it was present at Gate 1 in Experiment 1. Nevertheless, there was sufficient coarticulatory information in the vowel preceding the labial stop for place to be identified before release burst. From the fourth gate onward, there was a large majority of /b/ responses (75% or more). For the “ps” and “pt” control items, the opposite pattern ob-

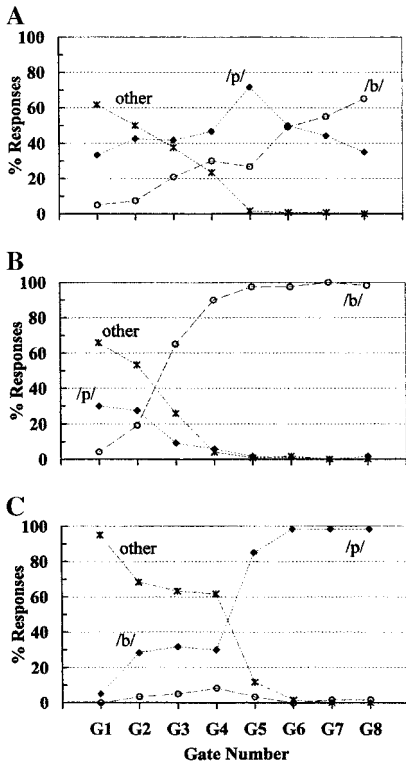


FIG. 2. Experiment 3: percentages of /b/, /p/, and "other" responses according to gate number for (A) "bs" or "bt" test items, (B) "bj" or "bd" control items, and (C) "ps" or "pt" control items.

tained: A large majority of /p/ responses appeared from the fifth gate onward, which was somewhat later than was the case for /b/ responses for the "bj" and "bd" items. Participants eventually heard /p/ in "autopsie" /otɔpsi/ and /b/ in "subjuguer" /sybʒyge/ and did not change their judgments afterward.

The pattern of responses for the test items was strikingly different, as Fig. 2A shows. Correct place of articulation emerged at Gate 3, together with phonetically correct voicing. The phonetically motivated /p/ responses reached a maximum at Gate 5 (72%) then decreased dramatically, reaching 35% at the last gate. The percentage of /b/ responses symmetrically increased from 27% at Gate 5 to 65% at Gate 8.

The gating data from Gates 5–8 (Gates 1–4 mainly showed the emergence of /b/ or /p/ against "other" responses) were entered in Gate

(Gates 5–8)  $\times$  Response (/b/ or /p/)  $\times$  Item-type (test, "b" control, or "p" control) by-subject and by-item ANOVAs. ("Other" responses were negligible in the Gates 5–8 portion.) There was a significant Gate  $\times$  Response interaction for test items,  $F(3,42) = 16.4$ ,  $p < .0001$ ;  $F(3,21) = 5.3$ ,  $p < .01$ , but not for control items. Whereas /b/ and /p/ responses approached or stayed at ceiling level for "b" and "p" control items, respectively, /p/ responses substantially decreased and /b/ responses increased for test items. To sum up, whereas /p/ responses for test items were dominant at Gate 5 (which only contained the initial portion of the labial stop release burst), they began to decrease from this gate onward to the benefit of /b/ responses, which eventually outnumbered /p/ responses at Gate 8.

Experiment 3 served to uncover the time course of the orthographic effect found in Experiment 2 for "b" words. In the early gates, listeners rarely reported a labial stop. The available acoustic information was presumably not sufficient for hearing a labial stop. From the third gate on, however, there was sufficient co-articulatory information in the speech signal for listeners to identify the upcoming stop, not only with the correct place of articulation but also with the phonetically correct voicing. This is consistent with the findings of Warren and Marslen-Wilson (1987, 1988). Coarticulation causes phonetic cues to be distributed and allows listeners to anticipate upcoming articulatory-phonetic events. Up to Gate 5, which included an average of 50 ms following the labial stop release burst, /p/ responses outnumbered /b/ responses, and the listeners' responses presumably reflected phonetic perception. From Gate 6 onward the pattern of responses gradually reversed until /b/ responses became dominant at Gate 8. This finding suggests that the responses were increasingly influenced by linguistic information as longer word fragments were presented.

These results are consistent with the detection data of Experiment 2, which showed that the graphic code strongly interfered with phonetic perception. Experiment 3 provides an in-

dication of the time course of this interference, insofar as the increasing rate of /b/ responses reflects the extent to which the graphic code was building. But do these data tell us something about the prelexical versus postlexical locus of the interference effect? Earlier studies, such as that of Dijkstra et al. (1995), have suggested that the orthographic code for auditorily presented words emerges and interferes with the phonetic code only after words are recognized. The present data suggest that the orthographic code emerged quite early (from Gates 5 and 6 onward), before the UP was reached. Indeed, in test words such as "absurde," the UP was either the vowel following /s/ or /t/ or the next consonant; that is, the UP was not reached before Gate 7. This finding could suggest that the orthographic code emerged before the words were recognized. However, there is some doubt about the relevance of theoretical UP locations (i.e., in terms of phoneme locations) in predicting word recognition. In particular, because phonetic cues are distributed and allow listeners to anticipate phonetic segments, words may be recognized before their theoretical UP.

To conclude that the orthographic code builds up prelexically, we need more concrete data indicating when the words under scrutiny are actually recognized, and thus their specific linguistic code becomes available. The classic gating paradigm (Grosjean, 1980) can be used for this purpose to determine the amount of bottom-up information that is necessary to actually recognize such words as "absurde." We thus ran 10 participants on a classic gating task using exactly the same stimuli as in Experiment 3 in order to find out whether the /b/ responses in Experiment 3 were determined postlexically or emerged prelexically. The mean word identification rate<sup>3</sup> for items such as "absurde" was

only 6% at Gate 5 then gradually increased to 49% at Gate 8. This is well below the size of the orthographic effect found in the phonemic gating task, in which /b/ responses for the "b" words increased from 27 to 65%. It is thus unlikely that the graphic code inducing /b/ responses emerges only after a word (or at least, any member of its morphological family) has been recognized. In other words, the orthographic effect found in Experiments 2 and 3 is not strictly postlexical. However, the effect could be lexical in the sense that it is induced by the word candidates conceivably engaged in the mechanism of lexical access. In the classic gating task, listeners frequently reported incorrect guesses (e.g., "abstinence" for "abscisse") which were nonetheless consistent with both the pronunciation and the spelling of the target items. The percentage of all such word candidates that were consistent with both /p/ and "b," whether correct or incorrect guesses, became sizable at Gate 5 (44%) and reached a ceiling of 85% at Gate 6. The orthographic effect found in Experiment 3 is thus more likely induced by the entire set of the words with /p/ spelled as "b" than by the subset of words considered as correct guesses. In other words, the interference effect does not *follow* word recognition, but unfolds on-line with the word recognition process.

The latter account is consistent with a cohort-like view (Marslen-Wilson & Welsh, 1978; Marslen-Wilson, 1987). On this view, each gated stimulus activates a set of phonetically compatible words. For each gate, the orthographic codes of the currently activated cohort of words are available and can influence phonetic perception. For example, before sufficient acoustic information is presented to guess "absurde" (or any word of the same morphological family) but as soon as /s/ is heard, the cohort of words reduces to words such as "abstinence" and "abscisse," which all share the "b" spelling for /p/. Even when the task is phonetic transcription rather than word-guessing, cohort activation might be irrepressible. As soon as the words in the currently activated cohort strongly

<sup>3</sup> The criterion used to accept a response as correct was quite liberal: Responses had to be words of the same morphological family as the words that had been presented. For example, words such as "absurde" and "absurdement" were accepted for "absurdité." The notion of morphological family was rather broad. For example, "subtil" and "subtiliser" were considered as belonging to the same family and likewise for "objet," "objectif," "objectant," or "objecter."



favor the "b" spelling, it could start biasing phonetic transcriptions toward [b].

So far, the arguments that the orthographic effect is not strictly postlexical (i.e., does not arise from access to specific lexical items) but rather emerges in synchrony with the lexical access mechanisms are based on gating data. In the case of nonwords with an initial illegal cluster (Hallé et al., 1998), the data obtained in the phonemic variant of the gating paradigm seem to illustrate phonetic processing as it unfolds over time. The phonemic gating data from Experiment 3, however, were obtained for legal words and could reflect postperceptual off-line judgments; that is, judgments based on conscious guesses. We thus resorted to a more on-line task to examine further the locus of the interference effect we found. In the next experiment, we used a phoneme monitoring task with a set of nonwords that mimicked the previous test and control words in that they could activate similar cohorts of "b" and "p" words, respectively.

#### EXPERIMENT 4: DETECTION OF /b/ VS /p/ IN /apsøri/ VS /rapselyg/

This experiment was designed in the same way as Experiment 2, but used nonwords instead of words. A set of nonwords beginning with the phonetic sequence [aps], [ɔps], [ɔpt], [syps], or [sypt] replaced the "b" words (test items) used in Experiment 2 (e.g., /apsøri/ paralleled "absurdité"). Likewise, a set of nonwords replaced the "p" words (control items) by maintaining the initial phonetic sequence up to /s/ or /t/ (e.g., /rapselyg/ paralleled "rhapsodie"). The nonwords were thus structurally similar to the words used in Experiment 2. If listeners are biased to detect /b/ in nonwords such as /apsøri/ but not in /rapselyg/, a prelexical account of the mechanisms at work for structurally similar words would be supported. Conversely, if listeners only detect /p/, not /b/, a postlexical account would be supported.

#### Method

*Stimuli and design.* All the stimuli were nonwords. Sixteen of them were structurally similar

to the "b" words of Experiment 2 (e.g., /apsøri/); these were the test items. Likewise, there were 16 control items similar to the "p" words of Experiment 2 (e.g., /rapselyg/). All of these test and control items were three syllables long. They were otherwise matched with respect to phonological structure (see Appendix B). The deviation point (DP) of these 32 test items (the phoneme where they departed from a possible word) was either the vowel after /ps/ or /pt/ or the consonant following that vowel. That is, the DP occurred two or three phonemes after the labial stop to be detected. Another 48 nonword items were used, half of which contained /b/ and the other half /p/ in word-initial or -final positions. Finally, 140 filler items contained neither /b/ nor /p/. The number of syllables in the nonwords other than test and control items ranged from 2 to 3 (mean = 2.7). The total number of items was 220.

This set of 220 items was split into two test lists of 110 items, maintaining as much as possible the same proportions and characteristics of the various types of items in each list. The same design as in Experiment 2 was used. Target assignment to list and target order were counterbalanced so that each participant heard each item only once for the detection of either /b/ or /p/ in either the first or the second list he or she received. The two test lists were preceded by a training list containing 27 disyllabic nonword items: 9 bore the target /k/ in initial, medial, or final position and 18 were non-target-bearing fillers.

The nonwords were recorded by a male native speaker of French, using the same apparatus as for Experiment 2. They were digitized (16-kHz sampling rate and 16-bit resolution) and transferred to computer files. The voiceless quality of the labial plosive in all the test and control items was assessed by visual inspection of spectrograms. No voicing murmur could be observed during the closure portion.

*Participants.* Forty students from the same population as in Experiments 1–3 participated in the experiment for course credit or voluntarily. None of them reported any hearing difficulty or spoken or written language problems.

TABLE 2

Detection Rate in Experiment 4 as a Function of Target (/b/ or /p/) and Stimulus Type<sup>a</sup>

		Stimulus type	
		Test (/apsøri/)	Control (/rapselyg/)
/b/	% detection	53.8% (21.1)	25.0% (14.4)
	RT	858 ms (154.3)	921 ms (202.1)
/p/	% detection	84.1% (13.4)	96.3% (5.5)
	RT	779 ms (106.4)	760 ms (89.5)

<sup>a</sup> By-item standard deviations are in parentheses.

Many of them reported that the task was quite difficult. This was perhaps due to the fact that nonwords were used. The data of eight additional participants were not retained for analysis because the detection rate in the presumably easy experimental conditions (detection of /p/ in test and control items) was below 50%, which we considered too low to provide meaningful results.

*Procedure and apparatus.* The same apparatus and procedure as in Experiment 2 were used, except that participants were told that they would hear nonwords. For each list, the target was specified auditorily with word examples in initial, medial, and final position using the same format of specification as in Experiment 2. For example, /k/ was specified in the following way: /kœ/ as in “court,” “écu,” or “antique” (/kur/, /eky/, and /ätik/, respectively). RTs were measured from the release burst of the plosive targets /b/, /p/, or /k/.

Results and Discussion

Detection rates and RTs are summarized in Table 2. Because this experiment exclusively involved nonwords, the detection of /b/ in both the test and control items could be considered a false positive and the nondetection of /p/ a miss. The detection rate and RT data were analyzed in the same way as in Experiment 2. Whereas all of the responses were included in the detection rate analysis, RT values below 100 ms or above 1400 ms were excluded from the RT analysis

based on the overall distribution of RT values (mean = 837 ms, median = 760 ms, *SD* = 324 ms; median + 2 × *SD* = 1408 ms); 6.1% of the RT data was thereby discarded.

List, List-assignment to target, and Target-order had no significant effect on detection rate. Context (/s/ vs /t/ following /p/) had no significant effect overall. False positive detection rate of /b/ was higher in test items, such as /apsøri/, than in control items, such as /rapslyg/. Conversely, correct detection rate of /p/ was lower in test than in control items. This was supported by a significant Target × Item-type (test vs control) interaction, *F*(1,36) = 69.7, *p* < .0001; *F*(1,24) = 56.0, *P* < .0001, and confirmed by planned comparisons significant at the *p* < .0001 level (54% > 25%) or at the *p* < .0005 level (84% < 96%). The pattern of results was thus similar to that obtained with words in Experiment 2: Listeners detected /b/ in nonwords such as /apsøri/, just like they detected /b/ in words such as “absurde” /apsyrd/. However, the effect was more modest in Experiment 4, as can be seen by comparing Tables 1 and 2. For instance, /p/ was detected more often than /b/ in /apsøri/, unlike in Experiment 2, where /p/ was detected less often than /b/ in “absurde.”

The data for the detection of /b/ in control items (e.g., /rapselyg/) were not used in the RT analysis because the detection rate was too low (25%) to undertake reliable analyses. As in Experiment 2, only three of four cases were thus examined: detection of /b/ in test items, of /p/ in test items, and of /p/ in control items. Target-order, List-assignment to target or List, as well as Context (/s/ vs /t/) had no significant effect. As Table 2 shows, RTs to /b/ in test items were about 80 ms longer than RTs to /p/ in either test or control items. These differences were significant in both the participants and items analyses (*p* < .01 and *p* < .05, respectively).<sup>4</sup> RTs to

<sup>4</sup> Miss rate was relatively high for the detection of /b/ in test items, and the number of items involved in each cell was small. Hence, there were many missing values in the full design of the participant data. As for the analyses in Experiment 2, the data were pooled across the Context variable. This made the number of missing values reason-

/p/ in test and control items did not significantly differ ( $ps > .1$ ). Thus, as for words in Experiment 2, RTs to /b/ were consistently longer than RTs to /p/.

Did the effects depend on the participants' speed of performance? That is, were the observed effects limited to, for example, slow responders? The answer is a clear "no," based on speed analyses similar to those conducted in Experiment 2 in which participants were partitioned into groups of 13 "fast," 14 "medium," and 13 "slow" responders. The main patterns observed in the pooled data held in all three subgroups: /b/ was detected more often in test than in control items, and RTs were longer for /b/ than for /p/ in test items (or /p/ in control items) by about 80 ms in all three subgroups. However, as a correlation analysis revealed, the detection rate for /b/ in test items was negatively correlated with the mean latency of such responses,  $r(38) = -0.375$ ,  $p < .05$ . (No other significant correlation was found.) In other words, the "bias" toward hearing /b/ in /apsøri/ was more pronounced in faster responses.

Together, the results suggest that the same kind of effect found for words in Experiment 2 also emerged for nonwords, although to a lesser extent. Moreover, the orthographic effect seems to arise on-line during processing, a possibility that the gating data of Experiments 3 had left open. Does this necessarily mean that the observed effect was not lexically motivated? The test or control nonwords used in Experiment 4 were chosen so that their beginnings were phonetically compatible with either "b" words or "p" words, respectively. Therefore, it was possible that, at some point in time, test nonwords activated a cohort of (mainly) "b" words, whereas control nonwords activated a cohort of "p" words, which would explain the higher rate

of false positive detection for /b/ in test than in control items. Indeed, for the control nonwords (e.g., /rapselyg/), the orthographic code in the cohort of "p" words was always congruent with /p/ and thus did not interfere with the phonetic evidence for /p/. By contrast, for the test nonwords (e.g., /apsøri/), the orthographic code of the "b" words in the activated cohort was congruent with the phoneme /b/ and could interfere with the phonetic evidence for /p/, inducing more /b/ responses than in the case of control nonwords. As for the time course of cohort activation, the cohort activated by the test nonwords mainly comprised "b" words when /s/ or /t/ in /ps/ or /pt/ had been identified then necessarily vanished after the DP was reached. The influence of the "b" cohort on phonetic perception should thus decline over time. Hence, the detection rate of /b/ in test nonwords should be lower for longer RTs. This expectation was supported by the negative correlation found between detection rate and response latency for /b/ in /apsøri/.

The longer RTs for the detection of /b/ than of /p/ in test items such as /apsøri/ can be explained by the interference between a phonetic and a linguistic code. On a cohort activation account, the latter code could be either graphic or morphophonemic, generated via the activation of a cohort of words compatible with the available phonetic input. An interesting alternative account is that morphological decomposition may be tentatively performed prelexically. For instance, as soon as an utterance begins with the sequence [ap] or [ab] followed by a consonant, listeners may extract the prefix {ab-}, even though the upcoming speech sequence does not easily lend itself to a transparent stem.

Whatever the correct account, the fact that the interference effect inducing /b/ responses for phonetically voiceless [p]s is still at work for nonwords indicates that a linguistic code for words is generated quite early in the processing of a speech utterance. This is in line with the view of a linguistic code that is computed prelexically rather than derived from the entries of the lexicon after words have been accessed.

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ably low: two of 120 values (1.7%) had to be replaced. As in Experiment 2, we followed the conservative option of replacing each missing value in a participant's data by the average of this participant's other data. In the full design item analysis, there was one missing value for the detection of /b/ in test items: It was replaced by the average value in that detection situation for the group of subjects involved.

## GENERAL DISCUSSION

The existing literature offers evidence for interference between orthography and surface phonology in the processing of spoken words. This study provided further evidence for such interference. We have tentatively assumed that the linguistic code that interfered with the phonetic interpretation of words as well as nonwords was the orthographic code. However, the orthographic and morphophonemic codes were almost perfectly congruent in our materials and so the question of whether the morphophonemic code played a role remains a matter of speculation. In any case, the focus of this study was the time course and origin of the observed interference, an issue that had received little attention in earlier investigations.

Experiments 1 and 2 set the stage with a clear example in which the graphic code strongly influences the phonetic perception of specific words: French listeners do hear /b/ more easily than /p/ in words such as “absurde,” although the surface form is /apsyrd/ not /absyrd/. The latter point was demonstrated both by acoustic measurements and by perceptual assessment of the critical labial stop excised from its linguistic context (Experiment 1). French listeners nonetheless were able to detect /p/ in “absurde,” though much less readily than /b/. On the other hand, the detection of /p/ was much faster than that of /b/. A tempting account of these findings was that hearing /p/ involved a prelexical “low level” of phonetic perception, whereas hearing /b/ required a postlexical reanalysis of the words heard. However, the data in Experiment 2 did not lend clear support to the postlexical account. We thus further explored the time course and origin of the orthographic–phonetic interference effect. In Experiment 3, two versions of the gating paradigm—phonetic transcription and word guessing—were used. The results suggested that the interference effect was not strictly postlexical. That is, it did not result from the recognition of a specific lexical entry and was more likely conveyed by a cohort of similarly spelled words which were compatible with the acoustic input. It might be the case, how-

ever, that cohort activation in a gating task arises postperceptually. Hence, there remained some doubt about how reliably the results reflected the on-line processes of lexical access via cohort activation. We addressed that issue in Experiment 4, resorting to a phoneme monitoring task that used nonwords mimicking the words used in Experiments 2 and 3 so that similar cohort activation could occur during the process of (tentative) lexical access. Surprisingly, the detection of /b/ induced by those nonwords mimicking “b” words still occurred at a moderately high rate. The data thus suggested that the graphic code that caused the interference effect emerged from the lexical access mechanism itself, presumably from cohort activation. At any rate, it is a real-time mechanism, which is automatically at work for both words and nonwords.

Together, the findings point to real-time mechanisms whose function is to produce words and meaning from the speech input, whatever its lexical status. On this view, access to word and meaning is a dynamic process that involves real-time computation rather than, for example, a passive pattern matching mechanism.

What is the nature of this dynamic process? In discussing Experiments 3 and 4, we have favored a cohortlike mechanism: At each point in time, the linguistic code /b/ could be conveyed by a cohort of words that are phonetically compatible with the acoustic input, yet spelled with a “b.” There might be, however, some difficulty with the cohort activation account. It happens that there are more words in French beginning with “abs” (41), “obs” (45), and “subs” (16) than with “obt” (10) or “subt” (6); there is no word beginning with “abt.” This advantage of “bs” over “bt” words also holds when considering word tokens (cumulated frequencies) instead of word types. Given that difference, one would predict that hearing /b/ should be more likely for the words with “s” than with “t.” However, in the analyses of Experiments 2 and 4, the Context factor (/s/ vs /t/) had no significant effect. We cannot, however,

dismiss the cohort account on the basis of a null effect.

On-line phone-to-grapheme conversion could also account for the prelexical nature of the interference effect we found. For example, upon hearing initial /aps/, the graphic code "abs" could be activated and could activate, in turn, the phoneme /b/. As Dijkstra et al. (1993) have shown, simple sounds may activate simple graphemes (e.g., the vowel /a/ activates the letter "A"). But the mapping between /aps/ and "abs" is not straightforward and is not motivated by a conversion rule: /aps/ *could* be spelled "aps" just like /apt/ is spelled "apt." Worse, /opt/ can be spelled either "opt" or "obt" (as in "optique" or "obtus"). The mapping is thus simply motivated by the peculiarities of the French print lexicon. In sum, if a phone-to-grapheme conversion mechanism is at work to convert [p] into "b" in the phonetic contexts of [apsyrd] or [apsøri], it depends on the contingencies of the French print lexicon, not on predictable regularities. This mechanism would not essentially differ in its workings from any mechanism engaging the whole lexicon, such as cohort activation. But it would differ from cohort activation in its usefulness. Phone-to-grapheme conversion fulfills no need specific to speech, whereas cohort activation indeed aids in word retrieval. Therefore, the phone-to-grapheme account is not considered any further.

We mentioned another alternative account to cohort activation: morphemic decomposition. This view is still a matter of heated debate for both written and spoken word recognition (Laudanna, Burani, & Cermele, 1994; Marslen-Wilson, in press; Schriefers, Zwitserlood, & Roelofs, 1991; Taft, 1981; Taft & Forster, 1975; Tyler, Marslen-Wilson, Rentoul, & Hanne, 1988; Wurm, 1997). According to most of the current research on speech perception, discontinuous access to stems and affixes is unlikely to explain how prefixed words are recognized (Greber & Frauenfelder, 1999; Schreuder & Baayen, 1994; but see Taft, 1981). Yet evidence for derivational prefix activation in spoken words has been found using cross-modal or

intramodal priming paradigms (Marslen-Wilson, Ford, Older, & Zhou, 1995, 1996; Marslen-Wilson & Zhou, 1996). However, it seems to be limited to cases of transparent morphological composition and to productive affixes. In the words used in the present study, such as "absurde," the morphological composition was opaque for most listeners (see footnote 1). The prefixes were common ones (although the {ab-} and {sub-} prefixes are notably more common than {ob-}), whereas the relationship of the stems to the entire words was far from transparent for most French speakers. Listeners, we believe, could identify at least common prefixes, however, opaque the following stem may be. We are not arguing here for an affix-stripping vs a full listing account of word recognition for prefixed words. We rather suggest that lexical access may begin with the tentative identification of common prefixes. Therefore, in certain instances, prefix activation may occur early in the processing of spoken words (as well as of nonwords, as Experiment 4 suggests) and possibly interfere with the phonetic code. According to this "prefix activation" account, common prefixes such as {ab-} or {sub-} are automatically activated in nonwords as well as words, whether they actually are prefixes, or, more exactly, independent of listeners' linguistic intuitions. If prefixes are potentially accessed prelexically, can this help language processing? If so it is probably not by speeding up the computations involved in lexical access (see Schreuder & Baayen, 1994: Prefix-stripping cannot be motivated by considerations such as computational parsimony). Prelexical access to prefixes, however, may contribute to the construction of semantic representations, which can build up on-line (see Van Petten, Coulson, Rubin, Plante, & Parks, 1999).

We are thus left with two possible accounts of the data. One explanation rests on cohort activation and is consistent with the activation of a graphic code interfering with the phonetic code. The other rests on prefix activation and is consistent with the activation of a morphopho-



nemic code. Although we favor the former interpretation, which is more in line with the findings reported in the literature, further research is needed to clarify this issue.

At any rate, both cohort activation and prefix activation entail activation of a linguistic code which may supersede incompatible phonetic evidence. The eventual dominance of the linguistic code over the phonetic code requires additional processing time. The robust effect found with RTs (longer RTs for detecting /b/ than /p/ in “absurde” as well as in /apsøri/) is most readily interpreted in the following way: /p/ responses are based directly on the bottom-up phonetic information, which is available as soon as the [p] phone occurs; /b/ responses must be based on a linguistic code (lexically mediated by a cohort of congruent words or, alternatively, by prefix identification), which cannot be available before the phonetic context following [p] occurs. These empirical findings could be accommodated by models such as Merge (Norris, McQueen, & Cutler, in press), in which phonetic decisions can be made either on the sole basis of the early available bottom-up information or after integration of the bottom-up information with the later available lexical codes. In the latter case, responses should naturally be slower. (The “tentative framework” proposed by Dupoux and Mehler, 1992 has some similarity with the Merge model in that responses can be derived from the simultaneous inspection of various activated codes.) Our RT data are also compatible with a TRACE-like account (McClelland & Elman, 1986), in which phonetic decisions are made at the phoneme node level, which receives top-down feedback from higher level nodes, possibly interfering with the bottom-up information. By this account, /b/ responses, which require the propagation of feedback activation, should be slower than /p/ responses, which reflect the initial bottom-up activation.

To summarize, this study illustrates the role of linguistic knowledge in speech sound perception. Should we consider the present effects to be a kind of perceptual illusion? We could an-

swer “yes,” given that there was a substantial discrepancy between the objective phonetic reality and the human perception of that reality. However, this kind of illusion is ultimately useful and even necessary in order to interpret the physical world in an efficient way. Therefore, it should not be considered a mere side effect of the perception of physical objects and events. Rather, we interpret the present data as showing how purposeful the on-line analysis of speech tends to be. French listeners do not hear /b/ because they identify the word “absurde” but, rather, derive /b/ on-line from /aps/ because this helps them to identify “absurde.”

APPENDIX A

Test and Control Items Used in Experiment 1 for Each of the Two Lists (See Text)<sup>a</sup>

List 1		List 2	
Item	Rating	Item	Rating
“bs” items			
abside	1.3	abscisse	4.2
absurdité	4.7	absinthe	2.2
inobservé	3.0	inobservance	1.6
subsumer	1.8	subséquent	1.9
<i>M</i>	2.7	<i>M</i>	2.5
“bt” items			
subtilement	4.1	subtilité	4.3
subterfuge	2.6	subtiliser	2.1
obtusion	1.3	obturer	2.0
obtenant	3.2	obtus	2.7
<i>M</i>	2.8	<i>M</i>	2.8
“ps” items			
asepsie	1.3	autopsie	4.1
éclipser	4.2	ellipsoïde	1.4
rhapsodie	1.9	lapsus	4.4
epsilon	2.2	ipso-facto	1.8
<i>M</i>	2.4	<i>M</i>	2.9
“pt” items			
opticien	4.3	opter	3.3
cleptomane	3.0	septicémie	2.2
cheptel	1.8	Neptune	2.8
somptuaire	1.7	dompteur	3.0
<i>M</i>	2.5	<i>M</i>	2.8

<sup>a</sup> Subjective frequency rating (on a scale of 1–5) is shown for each word and averaged by item type.

## APPENDIX B

Test and Control Items Used in Experiment 4 for Each of the Two Lists and Examples of Words with the Same Initial Phonetic Sequence

List 1	List 2	Examples of similar words
<b>Test items</b>		
/apsøri/	/apsalog/	abscisse /apsis/
/apsi f <sup>er</sup> /	/apsēkyr/	
/ɔpsādrē/	/sypsomir/	obséquieux /ɔpsəkjø/
/ɔpselɔn/	/sypsiler/	subséquent /sypsekā/
/ɔptemi/	/ɔptulād/	obturer /ɔptyre/
/ɔptymir/	/ɔptœrel/	
/syptākklø/	/syptarlē/	subterfuge /syptērɸyʒ/
/syptisēʒ/	/syptervil/	
<b>Control items</b>		
/rapselyg/	/lapsøter/	lapsus /lapsys/
/rapsoʒe/	/lapsyri/	
/ipsefiʒ/	/epsolā/	ipso-facto /ipsofakto/
/ipsokyr/	/epsoder/	epsilon /epsilɔn/
/septāgy/	/septoklē/	sceptique /septik/
/septolis/	/septiral/	
/kleptyre/	/fēptørle/	cleptomane /kleptoman/
/kleptoʒā/	/fēpterli/	cheptel /fēptel/

## REFERENCES

- Blumstein, S. E., & Stevens, K. N. (1980). Perceptual invariance and onset spectra for stop consonants in different vowel environments. *Journal of the Acoustical Society of America*, **67**, 648–662.
- Dijkstra, T., Fieuws, S., & Roelofs, A. (1995). Orthographic effects on phoneme monitoring. *Canadian Journal of Experimental Psychology*, **49**, 264–271.
- Dijkstra, T., Frauenfelder, U., & Schreuder, R. (1993). Bidirectional grapheme–phoneme activation in a bimodal detection task. *Journal of Experimental Psychology: Human Perception and Performance*, **19**, 931–950.
- Donnenwerth-Nolan, S., Tanenhaus, M. K., & Seidenberg, M. S. (1981). Multiple code activation in word recognition: Evidence from rhyme monitoring. *Journal of Experimental Psychology: Human Learning and Memory*, **7**, 170–180.
- Dupoux, E. (1993). Prelexical processing: The syllabic hypothesis revisited. In G. Altman & R. Shillcock (Eds.), *Cognitive models of speech processing* (pp. 81–114). Hillsdale, NJ: Erlbaum.
- Dupoux, E., & Mehler, J. (1992). Unifying awareness and on-line studies of speech: A tentative framework. In J. Alegria, D., Holender, J. Junça de Moraes, & M. Radeau (Eds.), *Analytic approaches to human cognition* (pp. 59–75). Amsterdam: North-Holland.
- Ehri, L., & Wilce, L. (1980). The influence of orthography on reader's conceptualization of the phonemic structure of words. *Applied Psychology*, **1**, 371–385.
- Fox, R. A. (1984). Effect of lexical status on phonetic categorization. *Journal of Experimental Psychology: Human Perception and Performance*, **10**, 526–540.
- Frost, R., Repp, B. H., & Katz, L. (1988). Can speech perception be influenced by simultaneous presentation of print? *Journal of Memory and Language*, **27**, 741–755.
- Frost, R., & Katz, L. (1989). Orthographic depth and the interaction of visual and auditory processing in word processing. *Memory & Cognition*, **17**, 302–311.
- Grammont, M. (1933). *Traité de Phonétique*. Paris: Delagrave.
- Greber, C., & Frauenfelder, U. (1999). On the locus of morphological effects in spoken-word recognition: before or after lexical identification? *Brain and Language*, **68**, 46–53.
- Grosjean, F. (1980). Spoken word recognition and the gating paradigm. *Perception & Psychophysics*, **28**, 267–283.
- Hallé, P. A., Segui, J., Frauenfelder, U., & Meunier, C. (1998). The processing of illegal consonant clusters: A case of perceptual assimilation? *Journal of Experimental Psychology: Human Perception and Performance*, **24**, 592–608.
- Imbs, P. (1971). *Études statistiques sur le vocabulaire français. Dictionnaire des fréquences. Vocabulaire littéraire des XIXe et XXe siècles* [Statistical studies on French vocabulary. Dictionary of frequencies. Literary vocabulary of the 19th and 20th centuries]. Centre de recherche pour un Trésor de la Langue Française (CNRS). Paris: Librairie Marcel Didier.
- Jakimik, J., Cole, R. A., & Rudnicky, A. I. (1985). Sound and spelling in spoken word recognition. *Journal of Memory and Language*, **24**, 165–178.
- Landerl, K., Frith, U., & Wimmer, H. (1996). Intrusion of orthographic knowledge on phoneme awareness: strong in normal readers, weak in dyslexic readers. *Applied Psychology*, **17**, 1–14.
- Laudanna, A., Burani, C., & Cermele, A. (1994). Prefixes as processing units. *Language and Cognitive Processes*, **9**, 295–316.
- Marslen-Wilson, W. D. (1987). Functional parallelism in spoken word recognition. *Cognition*, **25**, 71–102.
- Marslen-Wilson, W. D. (1999). Abstractness and combination: The morphemic lexicon. In S. Garrod & M. Pickering (Eds.), *Language processing* (pp. 101–119). Hove, UK: Psychology Press.
- Marslen-Wilson, W. D., Ford, M., Older, L., & Zhou, X-L. (1995, July). *The morphemic lexicon: Priming derivational affixes*. Paper presented to the Experimental Psychological Society, Birmingham, UK.
- Marslen-Wilson, W. D., Ford, M., Older, L., & Zhou, X-L. (1996). The combinatorial lexicon: Priming derivational affixes. In G. W. Cottrell (Ed.), *Proceedings of*

- the 18th Annual Conference of the Cognitive Science Society, (pp. 223–227). Mahwah, NJ: Erlbaum.
- Marslen-Wilson, W. D., & Warren, P. (1994). Levels of perceptual representations and process in lexical access: Words, phonemes, and features. *Psychological Review*, **101**, 653–675.
- Marslen-Wilson, W. D., & Welsh, A. (1978). Processing interactions and lexical access during word recognition in continuous speech. *Cognitive Psychology*, **10**, 29–63.
- Marslen-Wilson, W. D., & Zhou, X.-L. (1996, January). *Modality specificity in lexical access?* Paper presented to the Experimental Psychological Society. London, UK.
- McClelland, J. L., & Elman, J. L. (1986). The TRACE model of speech perception. *Cognitive Psychology*, **18**, 1–86.
- Norris, D., McQueen, J. M., & Cutler, A. (in press). Merging information in speech recognition: Feedback is never necessary. *Behavioral and Brain Sciences*, **23**.
- Olson, D. R. (1996). Towards a psychology of literacy: On the relations between speech and writing. *Cognition*, **60**, 83–104.
- O'Shaughnessy, D. (1981). A study of French vowel and consonant durations. *Journal of Phonetics*, **9**, 385–406.
- Peterson, G. I., & Lehiste, I. (1960). Duration of syllabic nuclei in English. *Journal of the Acoustical Society of America*, **32**, 693–703.
- Port, R., & Rotunno, R. (1979). Relation between voice-onset time and vowel duration. *Journal of the Acoustical Society of America*, **66**, 654–662.
- Raphael, L. J. (1972). Preceding vowel duration as a cue to voicing characteristics of word-final consonants in English. *Journal of the Acoustical Society of America*, **51**, 1296–1303.
- Rigault, A. (1967). L'assimilation consonantique de sonorité en français: Étude acoustique et perceptuelle [Voicing assimilation in French consonants: An acoustic and perceptual study]. In B. Hála, M. Romportel, & P. Janota (Eds.), *Proceedings of the 6th International Congress of Phonetic Sciences, Prague* (pp. 763–766). Prague: Academia Publishing House of the Czechoslovak Academy of Sciences.
- Samuel, A. G. (1987). The effect of lexical uniqueness in phonemic restoration. *Journal of Memory and Language*, **26**, 36–56.
- Samuel, A. G. (1996). Does lexical information influence the perceptual restoration of phonemes? *Journal of Experimental Psychology: General*, **125**, 28–51.
- Schreuder, R., & Baayen, R. H. (1994). Prefix stripping re-visited. *Journal of Memory and Language*, **33**, 357–375.
- Schriefers, H., Zwitserlood, P., & Roelofs, A. (1991). The identification of morphologically complex spoken words: Continuous processing or decomposition? *Journal of Memory and Language*, **30**, 26–47.
- Seidenberg, M. S., & Tanenhaus, M. K. (1979). Orthographic effects on rhyme monitoring. *Journal of Experimental Psychology: Human Learning and Memory*, **5**, 546–554.
- Streeter, L. A., & Nigro, G. N. (1979). The role of medial consonant transitions in word perception. *Journal of the Acoustical Society of America*, **65**, 1533–1541.
- Taft, M. (1981). Prefix stripping revisited. *Journal of Verbal Learning and Verbal Behavior*, **20**, 289–297.
- Taft, M., & Hambly, G. (1985). The influence of orthography on phonological representations in the lexicon. *Journal of Memory and Language*, **24**, 320–335.
- Taft, M., & Forster, K. I. (1975). Lexical storage and retrieval of prefixed words. *Journal of Verbal Learning and Verbal Behavior*, **14**, 638–647.
- Tanenhaus, M. K., Flanigan, H. P., & Seidenberg, M. S. (1980). Orthographic and phonological activation in auditory and visual word recognition. *Memory & Cognition*, **8**, 513–520.
- Treiman, R. (1985). Spelling of stop consonants after /s/ by children and adults. *Applied Psycholinguistics*, **6**, 261–282.
- Treiman, R., Tincoff, R., & Richmond-Welty, E. D. (1996). Letter names help children to connect print and speech. *Developmental Psychology*, **32**, 505–514.
- Treiman, R., & Cassar, M. (1997). Can children and adults focus on sounds as opposed to spelling in a phoneme counting task? *Developmental Psychology*, **33**, 771–780.
- Tyler, L. K., Marslen-Wilson, W. D., Rentoul, J., & Hanney, P. (1988). Continuous and discontinuous access in spoken word-recognition: The role of derivational prefixes. *Journal of Memory and Language*, **27**, 368–381.
- Umeda, N. (1975). Vowel duration in American English. *Journal of the Acoustical Society of America*, **58**, 434–455.
- Umeda, N. (1977). Consonant duration in American English. *Journal of the Acoustical Society of America*, **61**, 846–858.
- Van Petten, C., Coulson, S., Rubin, S., Plante, E., & Parks, M. (1999). Time course of word identification and semantic integration in spoken language. *Journal of Experimental Psychology: Human Perception and Performance*, **25**, 394–417.
- Wajskop, M. (1979). Segmental durations of French inter-vocalic polysyllables. In B. Lindblom & S. Ohman (Eds.), *Frontiers of speech communication research* (pp. 109–123). New York: Academic Press.
- Walley, A. C., Michela, V. L., & Wood, D. R. (1995). The gating paradigm: Effects of presentation format on spoken word recognition by children and adults. *Perception & Psychophysics*, **57**, 343–351.
- Warren, P., & Marslen-Wilson, W. (1987). Continuous uptake of acoustic cues in spoken word recognition. *Perception & Psychophysics*, **41**, 262–275.
- Warren, P., & Marslen-Wilson, W. (1988). Cues to lexical

- choice: Discriminating place and voice. *Perception & Psychophysics*, **43**, 21–30.
- Warren, R. M. (1971). Identification times to phonemic components of graded complexity and for spelling of speech. *Perception & Psychophysics*, **9**, 345–349.
- Whalen, D. H. (1984). Subcategorical phonetic mismatches slow phonetic judgments. *Perception & Psychophysics*, **35**, 49–64.
- Whalen, D. H. (1991). Subcategorical phonetic mismatches and lexical access. *Perception & Psychophysics*, **50**, 351–360.
- Wurm, L. H. (1997). Auditory processing of prefixed English words is both continuous and decompositional. *Journal of Memory and Language*, **37**, 438–461.
- Zecker, S. G. (1991). The orthographic code: Developmental trends in reading-disabled and normally-achieving children. *Annals of Dyslexia*, **41**, 178–192.
- Ziegler, J. C., & Ferrand, L. (1998). Orthography shapes the perception of speech: The consistency effect in auditory word recognition. *Psychonomic Bulletin & Review*, **5**, 683–689.
- Ziegler, J. C., Montant, M., & Jacobs, A. M. (1997). The feedback consistency effect in lexical decision and naming. *Journal of Memory and Language*, **37**, 533–554.

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