Research Article

Subliminal Speech Priming

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ABSTRACT—***We present a novel subliminal priming technique that operates in the auditory modality. Masking is achieved by hiding a spoken word within a stream of time-compressed speechlike sounds with similar spectral characteristics. Participants were unable to consciously identify the hidden words, yet reliable repetition priming was found. This effect was unaffected by a change in the speaker's voice and remained restricted to lexical processing. The results show that the speech modality, like the written modality, involves the automatic extraction of abstract word-form representations that do not include nonlinguistic details. In both cases, priming operates at the level of discrete and abstract lexical entries and is little influenced by overlap in form or semantics.***

Over the past two decades, subliminal priming has become an important tool for studying the automatic stages of language processing while minimizing the involvement of conscious response strategies (Forster, 1998; Henson, 2003; Naccache & Dehaene, 2001). Subliminal priming has been developed in the domain of visual word recognition: Typically, a prime stimulus is presented for a very brief duration and is pattern masked so that participants are unaware of its presence; still, such a prime facilitates the processing of a subsequently presented conscious target stimulus (Evett & Humphreys, 1981; Forster & Davis, 1984). Unfortunately, no equivalent methodology exists in the auditory modality, and experimental studies in this area have relied on conscious presentation of stimuli (Grosjean & Frauenfelder, 1997). It is quite plausible that the processing and neural architectures underlying speech and writing differ in several significant ways (Kouider & Dupoux, 2001; Lenneberg, 1967). Without a reliable subliminal priming methodology for speech, which is the only modality for language in populations without writing (preliterate children or illiterate adults), its functional architecture remains challenging to study.

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Audition has a much better temporal resolution than vision, and it is not obvious what the analogue to visual masking could be for a speech signal (Moore, 1992). Previous attempts to develop auditory masking techniques have used attenuated word stimuli embedded in white noise or concurrent messages. These techniques are also used in so-called subliminal audiotapes, which supposedly convey relaxing subliminal audio messages. All of these procedures have failed to produce a satisfactory masking situation, mainly because they degrade stimuli up to the point where elimination of listeners' awareness of them is accompanied by elimination of any behavioral influences they might have (Greenwald, Spangenberg, Pratkanis, & Eskenazi, 1991; Moore, 1995). Other studies have attempted to present speech stimuli in parallel using dichotic-listening procedures and have manipulated attention in order to prevent awareness. This approach has also been unfruitful, as the results obtained so far suggest that elimination of attention is accompanied by elimination of any lexical processing (Dupoux, Kouider, & Mehler, 2002; Holender, 1986).

THE PRESENT STUDY

The first goal of this study was to demonstrate the feasibility of subliminal speech priming. We present a novel method in which auditory prime stimuli are not perceptually degraded, but rather are time compressed and "hidden" within a stream of spectrally similar unintelligible speechlike noise (Dupoux et al., 2002). This procedure (illustrated in Fig. 1) is similar though not identical to the procedure developed by Forster and Davis (1984). The subjective impression reported by participants is that of a clear target surrounded by unintelligible babble (the same type of noise that arises from background conversation). Crucially, because the prime is surrounded by spectrally similar nonspeech sounds in a continuous stream, it does not stand out as a discrete acoustic event, and hence is not spontaneously noticed by participants (Dupoux et al., 2002). Past research has shown that even with high compression rates, words remain quite intelligible and elicit the same kind of lexical access procedures as uncompressed words (Dupoux & Mehler, 1990).

A second objective of this study was to investigate the processing levels at which subliminal speech priming takes

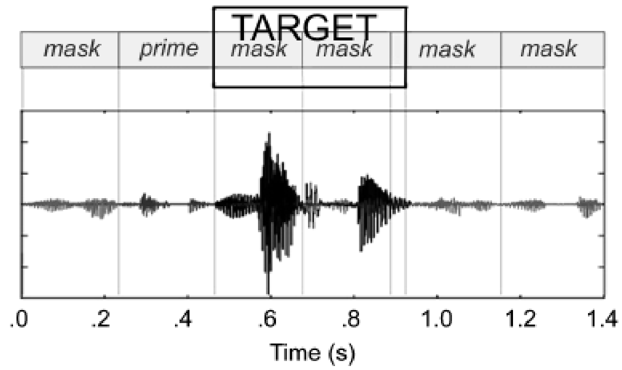

Fig. 1. Schematic description of the stimuli used in Experiments 1 and 2. Each prime was preceded by one forward mask and followed by four different backward masks. Prime and masks were attenuated (−15 dB) and time compressed to the same degree (35%, 40%, 50%, or 70% of the original duration). A target (played at a normal speech rate and unattenuated) was superimposed on this stream, with its onset coinciding with the offset of the prime. In the example stimulus sequence, the prime was the same as the target, but produced with a different voice and presented at a compression rate of 35% (recorded from Experiment 2).

place. Current models of spoken word recognition distinguish at least five hierarchical levels: sensory analysis (acoustic level), activation of phonemes (phonological level), recognition of word forms (lexical level), recovery of morphological structure (morphological level), and, finally, meaning retrieval (semantic level). We used a primed lexical decision task in French and varied the prime-target relation in order to examine the word recognition system and find out which level (or levels) of processing are affected by subliminal speech perception.

In Experiment 1, the prime and target in each pair were related morphologically, phonologically, or semantically, or the target was a repetition of the prime. To check whether we were tapping the lexical system, we contrasted repetition and phonological priming for words and nonwords. To manipulate the conscious accessibility of the primes, we time-compressed primes and masks at different compression rates: 35%, 40%, 50%, and 70% of their original duration. We were both able to identify the primes embedded in the babble stream when the compression rate was 50% or 70%, but not when the rate was 35% or 40%. Thus, using these four rates allowed us to compare priming under subliminal and supraliminal conditions. We indexed subjects' prime awareness using two tests of prime audibility (lexical decision and speech decision) at all compression rates.

By analogy to studies in the visual domain, we expected repetition priming without awareness for words, but not for nonwords (Forster & Davis, 1984). We also expected morphological priming without awareness (Frost, Forster, & Deutsch, 1997). Visual masked-priming studies have shown that the magnitude of morphological priming equals that of repetition priming under subliminal conditions (prime duration below 50 ms; see Kouider & Dupoux, 2001) in which semantically related associates do not show priming and orthographically related words show little or no priming (Rastle, Davis, Marslen-Wilson, & Tyler, 2000). Because orthographic priming tends to be weak in the lexical decision task (Forster, Davis, Schoknecht, & Carter, 1987), and semantic priming occurs only with prime durations that do not prevent prime awareness (Perea & Gotor, 1997; Rastle et al., 2000), we expected small or no phonological and semantic effects from subliminal spoken primes. Nevertheless, this analogy may not hold for semantic priming in the auditory modality. Indeed, the general failure to find clear and unchallenged evidence of subliminal semantic priming (Holender, 1986; Kouider & Dupoux, 2004) might be restricted to visual words, as the phonology-semantic link might be stronger than the orthographic-semantic link (Van Orden, 1987).

Experiment 2 investigated the acoustic and linguistic contributions to priming by comparing, at a 35% compression rate, repetition priming within and across speakers. We expected subliminal word repetition priming to tap abstract lexical representations and not to simply reflect low-level acoustical similarity. Indeed, subliminal repetition priming in the visual modality has been shown to convey abstract (shape-independent) representations of letter strings, as it occurs irrespective of the prime-target visual similarity (e.g., *radio-radio* vs. *radio-RADIO*; Bowers, Vigliocco, & Haan, 1998; Dehaene et al., 2001, 2004). Thus, we expected that if subliminal spoken primes activate linguistic representations, we would find repetition priming regardless of the acoustic similarity of prime and target. Experiment 2 was aimed at clarifying this issue by contrasting prime-target pairs spoken by the same voice or by different voices (male vs. female).

METHOD

Subjects

The participants were 104 students recruited from Paris universities. They reported no hearing impairment, were native French speakers, and were paid for their participation. Eighty-eight subjects participated in Experiment 1 (mean age = 23) and were randomly assigned to the four compression rates: 24 subjects each at the 35%, 40%, and 50% compression rates and 16 subjects at the 70% compression rate. Sixteen other students participated in Experiment 2 (mean age = 21).

Stimuli

In Experiment 1, 96 related prime-target pairs of words and 96 related prime-target pairs of nonwords were selected. For words, there were 24 pairs in each of four priming conditions: repetition, morphological, phonological, and semantic. In the repetition condition, the prime and target in each pair were the same word. In the morphological condition, feminine target words (e.g., *cousine*) were preceded by their masculine equivalent as a prime (*cousin*); half the stimuli differed by a single phonological change (target words had an additional consonant pronounced in the final position; e.g., *marquis-marquise*), whereas the other half differed in the final vowel and final consonant (target words had an additional consonant but also differed in the preceding vowel; e.g., *cousin-cousine*). In the phonological condition, word pairs were similar in form to the pairs used in the morphological condition, but did not share any morphological or semantic relation (*devis-devise*, *mandarin-mandarine*). The semantic condition included associatively and conceptually related words: 12 word pairs with symmetrical prime-target associations (e.g., *lapin-carotte*; mean associative rate = 30.9%) from the database of Ferrand and Alario (1998) and 12 conceptually related pairs sharing a large number of conceptual attributes but differing in gender-sex (e.g., *teaurau-vache*). The four conditions were matched in mean frequency of the target (3.3, 3.3, 3.2, and 3.3 per million, respectively, according to the Brulex database; Content, Mousty, & Radeau, 1990) and in the total number of target syllables (39, 39, 38, and 39, respectively).

For nonwords in Experiment 1, there were 32 prime-target pairs in each of three priming conditions: repetition, phonological, and different onset. In the repetition condition, the prime and target in each pair were the same nonword. In the phonological condition, the prime and target in each pair were similar in form, and the pairs had the same phonological variations as did the word pairs in the morphological and phonological conditions (e.g., *tarquise-tarquis*). In the different-onset condition, only the first phoneme of the prime and target in a pair differed (e.g., *zarotte-farotte*). This condition was used as a control in case priming would be absent in the phonological condition because of the combination of facilitatory priming plus shared-onset inhibition (as found in certain auditory priming studies; e.g., Slowiaczek, McQueen, Soltano, & Lynch, 2000).

Additionally, 96 words and 96 nonwords were selected to serve as unrelated primes in Experiment 1. Each was associated with one of the prime-target pairs and was matched to its associated related prime in number of phonemes, phonological (consonant-vowel) structure, and frequency (for words), but did not share any obvious formal or semantic relation either with the related prime or with the target. All stimuli were presented in a male voice. In the word and nonword repetition conditions, the same token was used for the prime and target in a pair.

In Experiment 2, 124 pairs of items (half words and half nonwords; half monosyllabic and half disyllabic) were selected. Within each pair, one item served as a target and related prime, and the other as an unrelated prime. Stimuli were recorded by both a male speaker and a female speaker.

Thirty additional items were used for training purposes in both experiments.

Procedure and Design

Figure 1 illustrates the presentation procedure used in this study. In Experiment 1, primes were time compressed to 35%, 40%, 50%, or 70% of their original duration (PSOLA algorithm; Charpentier & Stella, 1986), and masks were created by randomly selecting time-reversed compressed primes (at the same compression rate). Prime and masks were attenuated (−15 dB). Relation (related vs. unrelated) was manipulated as a within-items factor, condition was manipulated between items, and compression rate was manipulated between subjects. All subjects received the same entire set of 192 targets, which were divided into two subsets (A and B). For half the subjects, targets from subset A were preceded by a related prime, whereas targets from subset B were preceded by an unrelated prime; for the remaining subjects, it was subset B that was related to the primes and subset A that was unrelated. Participants were randomly assigned to one of the four compression rates used in this study. They were asked to decide as quickly and as accurately as possible whether the phoneme string in each trial constituted a word or not, indicating their response with their right or left hand, respectively, using a two-button response box. They were not informed about the presence of a prime.

In Experiment 2, the general procedure was the same as in Experiment 1, except that only the 35% compression rate was used, and that masks were created by digitally superimposing a female and a male time-reversed compressed prime. Relation (related vs. unrelated) and voice change (same vs. different voice) were manipulated as within-items factors. Participants received two blocks in which target voice (male or female) was held constant, but prime voice and prime-target relation were varied randomly. The order of the two blocks was counterbalanced across subjects.

The entire protocols for both experiments were programmed using the audio mixing functions of the Expe software package (Pallier, Dupoux, & Jeannin, 1997).

Measures of Awareness

Following the priming experiment, participants were asked to perform lexical decisions and speech decisions on primes. They had to concentrate on the prime, ignoring the target, and were told to take as long as they wished to respond. In the lexical decision task, participants were presented with the same (related and unrelated) prime-target pairs as in the priming experiment and with prime-target pairs differing in lexicality (word prime-nonword target, nonword prime-word target). The latter trials were used because otherwise participants would perform better than chance just by responding to the target rather than the prime. The speech decision task used prime-target pairs from the priming experiment in addition to prime-target pairs in which the prime was replaced by a time-reversed speech item (a mask). Thus, on each trial for this task, participants received either a forward mask, the prime, and then the target along with four backward masks, as in the priming experiment (see Fig. 1), or two forward masks and then the target along with four backward masks. Half the participants received a speech decision block first and a lexical decision block second. This order was reversed for the other participants. Furthermore, each experimental block was preceded by 20 training trials in which the prime was amplified to the level of the target, 100 ms of silence were introduced before and after the prime, the masks were attenuated by an additional −5 dB, and visual feedback was provided. Participants received 96 experimental trials in Experiment 1 and 112 experimental trials in Experiment 2.

RESULTS

Prime Audibility

Prime awareness was computed in the form of a d' value for each subject by treating speech as signal and nonspeech as noise (speech decision task) and words as signal and nonwords as noise (lexical decision task). We ran an analysis of variance (ANOVA) to check whether the mean d' values were significantly different from zero. In Experiment 1 (see Fig. 2), the d' values for the 50% and 70% compression rates were high in magnitude and significance, $d' = 1.00$, $F(1, 23) = 99.52$, $p < .001$, and $d' = 1.61$, $F(1, 15) = 60.70$, $p < .001$, respectively. These two compression rates showed a task effect, with lexical decision being easier to perform than speech decision—50% rate: $F(1, 23) = 6.77$, $p < .05$; 70% rate: $F(1, 15) = 5.17$, $p < .05$. By contrast, d' values for the 35% and 40% compression rates were very low, 0.21 and 0.24, respectively. Although d' was statistically significantly greater than zero for the 35% compression rate, $F(1, 23) = 14.48$, $p < .005$ (but not for the 40% compression rate), these values still indicate that the prime stimuli were quite effectively masked under these conditions (Greenwald, Abrams, Naccache, & Dehaene, 2003).

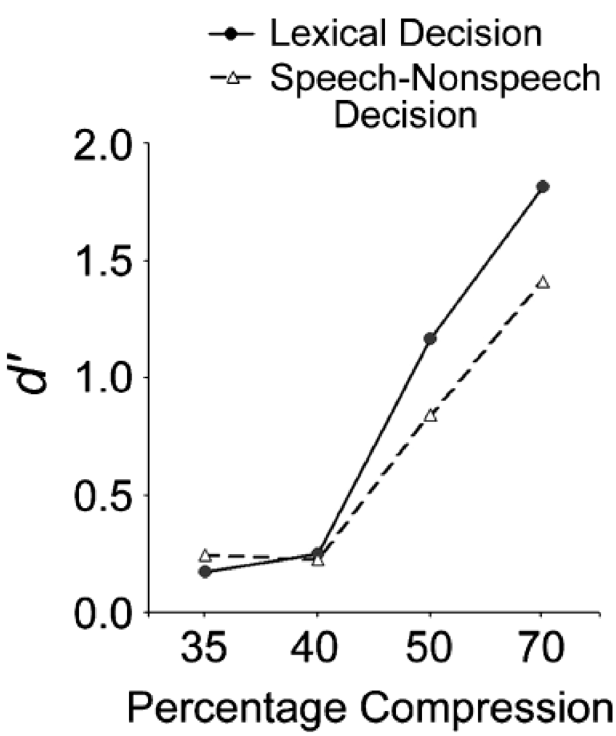

Fig. 2. Results from the prime-awareness tests: prime audibility (d') as a function of task and compression rate in Experiment 1.

In Experiment 2, which used only the 35% compression rate, the d' value was low (0.41); there was no task effect, but d' was significantly above chance, $F(1, 15) = 16.26$, $p < .005$.

A priori, these results suggest that participants were largely unaware of the primes at the 35% and 40% rates, whereas they were aware of the primes at the 50% and 70% rates. However, in order to avoid any ambiguity due to this small amount of prime audibility at the lowest compression rates, we analyzed priming effects using the Greenwald regression method (Greenwald, Klinger, & Schuh, 1995), which allowed us to evaluate whether any observed priming effect was associated with a lack of prime awareness. Moreover, we also analyzed priming while excluding participants with above-chance performance on prime-audibility measures.

Priming

The mean reaction times for correct responses were analyzed in ANOVAs with participants (F_1) and with items (F_2) as random factors. In Experiment 1, relation, condition, and the linear component of compression rate were the experimental factors, whereas in Experiment 2, the factors were relation, voice change, and lexicality. Additionally, a counterbalancing group factor corresponded to the list the participant was assigned to (participants analysis) and to which of the two subsets the item belonged to (items analysis). Reaction times more than 2 standard deviations from the mean for a particular participant and condition were replaced by the relevant cutoff. In Experiment 1, two items were omitted because of error rates greater than 30%. F values are reported only for significant effects (both $ps < .05$), along with partial eta-squared indexes (η_p^2). Because relation had no main effect and did not interact with any other factor in the errors analysis of both experiments, we restrict our discussion to reaction times.

Experiment 1

In Experiment 1, there was a main relation effect of 21 ms, $F_1(1, 80) = 80.70$, $F_2(1, 176) = 67.32$, $ps < .0001$, $\eta_p^2\text{s} > .277$. Relation interacted with condition, $F_1(6, 480) = 14.80$, $F_2(6, 176) = 11.27$, $ps < .0001$, $\eta_p^2\text{s} > .156$, and compression rate, $F_1(1, 80) = 65.73$, $F_2(1, 176) = 52.62$, $ps < .0001$, $\eta_p^2\text{s} > .230$. There was also a three-way interaction, $F_1(6, 480) = 4.36$, $F_2(6, 176) = 4.28$, $ps < .0005$, $\eta_p^2\text{s} > .022$. Further analyses considered words and nonwords separately.

Words. As depicted in Table 1, repetition priming was significant at all compression rates—35% (31 ms): $F_1(1, 22) = 8.24$, $F_2(1, 22) = 14.62$, $ps < .01$, $\eta_p^2\text{s} > .273$; 40% (47 ms): $F_1(1, 22) = 14.45$, $F_2(1, 22) = 20.41$, $ps < .005$, $\eta_p^2\text{s} > .396$; 50% (99 ms): $F_1(1, 22) = 45.99$, $F_2(1, 22) = 51.66$, $ps < .0001$, $\eta_p^2\text{s} > .676$; and 70% (112 ms): $F_1(1, 14) = 107.97$, $F_2(1, 22) = 128.61$, $ps < .0001$, $\eta_p^2\text{s} > .854$. Repetition priming increased as compression rate increased, as confirmed by a significant interaction between compression rate and relation in the repetition condi-

TABLE 1
Lexical Decision Latencies (in Milliseconds) and Error Rates in Experiment 1

	Related prime			Unrelated prime			Priming effect	
Condition and compression rate	RT (ms)	*SE*	Errors (%)	RT (ms)	*SE*	Errors (%)	RT (ms)	*SE*
Word repetition								
35%	751	22	5.2	782	23	4.9	31*	14
40%	763	25	4.9	809	22	2.8	47**	15
50%	667	21	5.9	765	16	5.2	99***	15
70%	616	22	5.7	727	26	2.6	112***	10
Nonword repetition								
35%	885	30	3.1	879	27	3.4	−5	14
40%	892	29	3.1	890	29	4.7	−3	9
50%	772	12	2.1	817	20	3.1	45***	11
70%	759	35	3.5	836	32	4.7	78***	16
Morphological (words only)								
35%	765	25	4.9	769	22	3.5	5	11
40%	818	33	3.5	800	23	3.1	−18	14
50%	720	20	1.7	753	19	2.1	34*	10
70%	673	26	3.6	750	22	4.2	76***	11
Phonological (words only)								
35%	772	23	5.6	796	26	9.7	24	14
40%	845	30	8.3	838	30	5.2	−7	11
50%	758	19	9.0	789	18	8.0	32	11
70%	771	34	5.7	792	27	6.2	21	17
Semantic (words only)								
35%	760	27	3.6	741	23	2.9	−20	10
40%	764	28	4.0	784	26	4.7	20	16
50%	696	16	3.5	716	18	2.5	20	13
70%	671	21	6.4	704	24	2.1	32*	14

Note. RT = reaction time. Significance levels are from analyses by both items and participants.
$^*p < .05$. $^{**}p < .005$. $^{***}p < .0005$.

tion, $F_1(1, 80) = 24.39$, $F_2(1, 22) = 56.01$, $ps < .0001$, $\eta_p^2\text{s} > .235$. Crucially, the regression analysis showed that the priming index at the $d' = 0$ intercept was significantly positive (intercept = 46 ms; see Fig. 3), $t(84) = 4.54$, $p < .0001$, demonstrating significant priming in the absence of prime perceptibility.

There was an overall semantic effect of 12 ms, $F_1(1, 80) = 4.20$, $F_2(1, 21) = 6.31$, $ps < .05$, $\eta_p^2\text{s} > .049$, and an overall morphological effect of 19 ms, $F_1(1, 80) = 11.01$, $F_2(1, 22) = 13.32$, $ps < .005$, $\eta_p^2\text{s} > .121$. However, in contrast to the results for the repetition condition, analyses showed that semantic priming reached significance only for the highest compression rate of 70% (32 ms), $F_1(1, 14) = 15.01$, $F_2(1, 21) = 5.63$, $ps < .05$, $\eta_p^2\text{s} > .211$, and morphological priming reached significance only for the two highest compression rates—50% (34 ms): $F_1(1, 22) = 12.01$, $F_2(1, 22) = 6.07$, $ps < .05$, $\eta_p^2\text{s} > .216$, and 70% (76 ms): $F_1(1, 14) = 44.15$, $F_2(1, 22) = 22.16$, $ps < .0005$, $\eta_p^2\text{s} > .502$. Further analyses revealed that these effects did not produce a significant regression intercept, meaning that semantic and morphological priming were not independent from prime audibility (see Fig. 3). In the phonological condition, priming did not reach significance either as a global effect or at any specific compression rate, nor was the regression intercept significant (see Fig. 3).

Nonwords. An overall repetition priming effect was observed for nonwords (24 ms), $F_1(1, 80) = 16.25$, $F_2(1, 30) = 15.51$, $ps < .001$, $\eta_p^2\text{s} > .169$. Contrary to word repetition priming, nonword repetition priming was significant only for the two highest compression rates—50% (45 ms): $F_1(1, 22) = 16.46$, $F_2(1, 30) = 15.83$, $ps < .001$, $\eta_p^2\text{s} > .345$, and 70% (78 ms): $F_1(1, 14) = 27.65$, $F_2(1, 30) = 22.41$, $ps < .0005$, $\eta_p^2\text{s} > .428$; the regression intercept was not significant (see Fig. 3). Priming for the two other nonword conditions (phonological and different-onset) did not reach significance in either global or restricted analyses.

Experiment 2

In Experiment 2, relation and lexicality interacted, $F_1(1, 27) = 27.27$, $F_2(1, 122) = 11.85$, $ps < .0001$, $\eta_p^2\text{s} > .051$. Restricted analyses revealed repetition priming for words (38 ms), $F_1(1, 14) = 36.17$, $F_2(1, 110) = 30.28$, $ps < .0001$, $\eta_p^2\text{s} > .219$, but not for nonwords (−6 ms; both $F\text{s} < 1$). Crucially, further analysis restricted to words showed no interaction between relation and voice change (both $F\text{s} < 1$). Word repetition priming

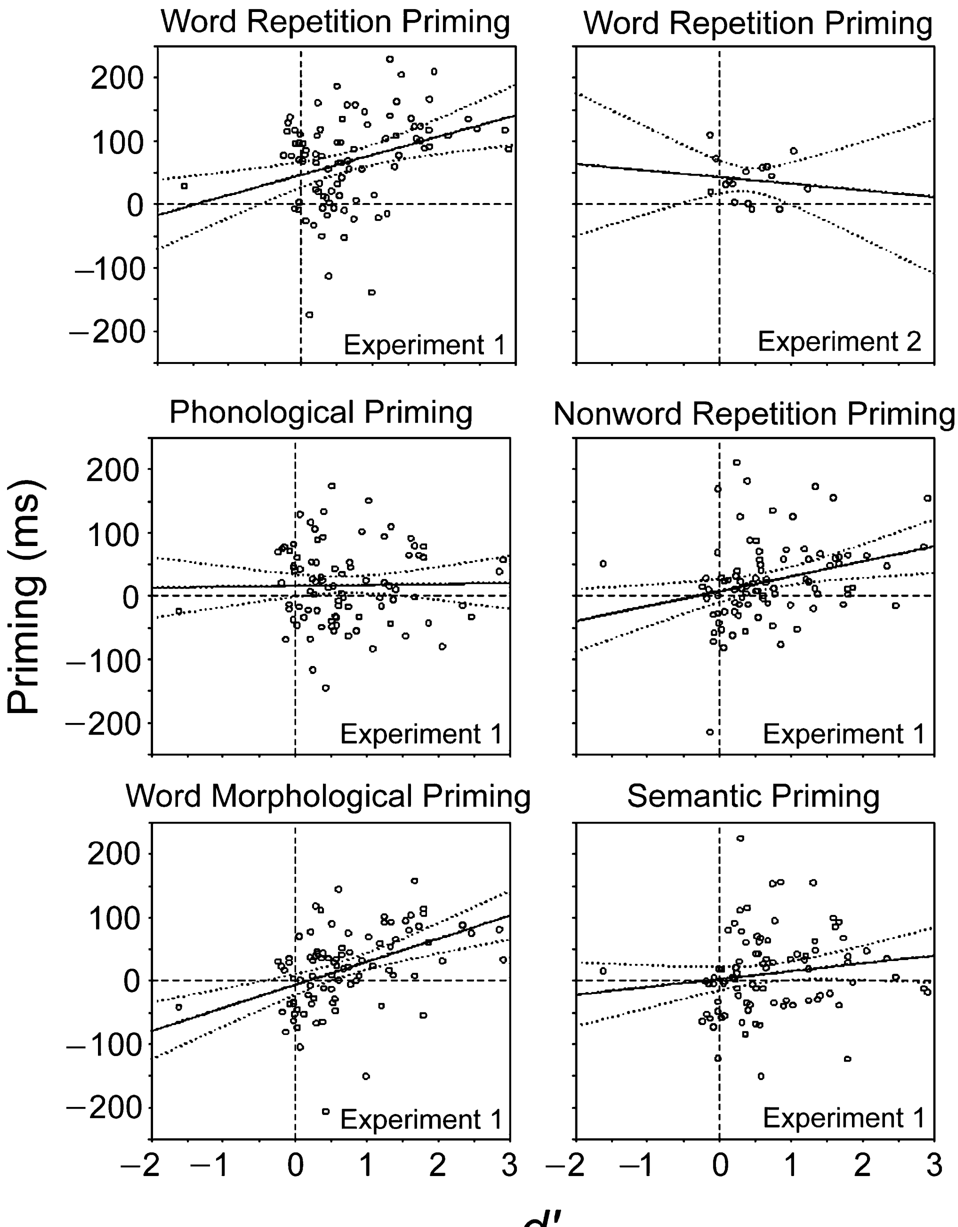

Fig. 3. Regression of priming effects (in milliseconds) on audibility (d'). Data points represent individual subjects. The regression functions (dotted lines indicate 95% confidence intervals) show the association between priming and prime audibility. Priming is interpreted as subliminal when the curve representing the lowest value in the confidence interval passes above the origin. Results are shown for word repetition priming in both experiments and for phonological, morphological, and semantic priming and nonword repetition priming in Experiment 1.

did not differ whether the prime and target were spoken in the same voice (36 ms), $F_1(1, 14) = 9.79$, $F_2(1, 110) = 7.88$, $ps < .01$, $\eta_p{}^2\text{s} > .067$, or with different voices (41 ms), $F_1(1, 14) = 14.70$, $F_2(1, 110) = 13.72$, $ps < .005$, $\eta_p{}^2\text{s} > .111$ (see Fig. 4). The regression analysis (see Fig. 3) revealed a significantly positive intercept of 43 ms, $t(14) = 3.44$, $p < .005$, suggesting that even if some participants were able to detect the primes, word repetition priming was independent of prime awareness.

Speech Priming Without Prime Audibility

In order to confirm the genuinely subliminal nature of the lexical repetition priming observed in the experiments, we performed further ANOVAs in which we excluded participants who were above chance in the prime-awareness tests. Only participants with at least 44% errors on the prime-awareness tests were included in these analyses ($n = 36$ in Experiment 1 and $n = 9$ in Experiment 2). In this subsample, d' values were not significantly above zero for either experiment (0.04 and 0.27,

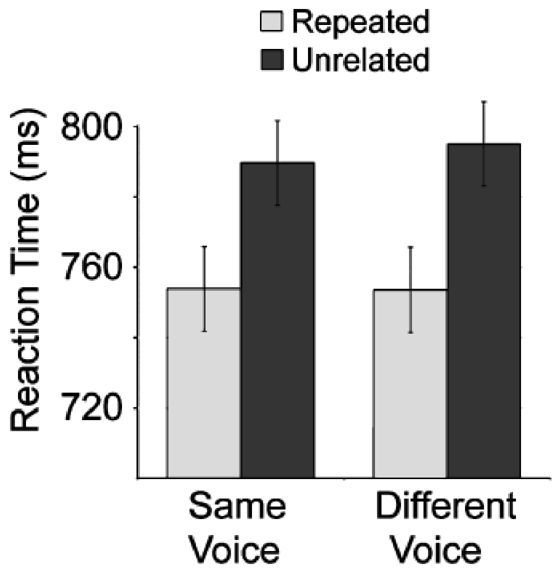

Fig. 4. Results from Experiment 2: reaction time as a function of the prime-target relation (repeated vs. unrelated) and voice change (prime and target spoken by same vs. different voice). Error bars correspond to 2 standard errors.

respectively). However, excluding these participants revealed the same pattern of results for word repetition priming: It remained high in magnitude and significance in Experiment 1 (51 ms), $F_1(1, 7) = 14.75$, $F_2(1, 22) = 40.19$, $ps < .01$, and in Experiment 2 (40 ms), $F_1(1, 34) = 26.36$, $F_2(1, 110) = 30.28$, $ps < .0001$, and did not differ as a function of voice change (39 ms for same voice, 41 ms for different voice).

DISCUSSION

By means of a priming method using babble noise masking and speech compression, we found auditory repetition priming without awareness. This effect involved lexical activation of abstract word forms, because it occurred for words, but not for nonwords (Experiments 1 and 2), and regardless of the prime-target acoustic similarity (Experiment 2). Lexical repetition priming was found under both conscious and unconscious perceptual processing conditions, whereas semantic, morphological, and nonlexical repetition priming occurred only when prime stimuli became available to awareness. Overall, priming for phonologically related stimuli did not show up at any compression rate. Thus, subliminal priming in lexical decision was restricted to abstract word forms.

From this result, we infer that the particular properties of the auditory modality do not impede the possibility of studying unconscious perception. The critical feature in our experiment was not to degrade the physical properties of the stimuli, but rather to "hide" them within a stream of apparently unintelligible nonspeech sounds with similar spectral characteristics. With this technique, we obtained statistically robust and numerically large facilitation effects for repetitions (40–50 ms), even in participants who were totally unable to identify the prime. This method is therefore a useful addition to the visual subliminal priming technique and will allow researchers to explore in detail the functional architecture involved during the basic stages of speech perception.

The pattern of facilitation demonstrated in these experiments has, by and large, the same signature that has been found in the visual modality with the same paradigm: subliminal identity priming in lexical decision for words but not for nonwords, small or no priming from form-related primes (Forster et al., 1987), no (or extremely limited) semantic priming (Abrams & Greenwald, 2000; Rastle et al., 2000), and, finally, independence from physical variations (Bowers et al., 1998; Dehaene et al., 2004).[1] We found, however, an important and prima facie surprising difference: a lack of subliminal morphological priming. Visual masked morphological priming has been found in several studies and languages, including French (Grainger, Colé, & Segui, 1991). This discrepancy might reflect a difference in morphological processes between modalities. Of course, before a conclusion regarding this issue is warranted, additional parametric manipulations will be needed; for example, it will be important to investigate other categories that are more productive than French gender (e.g., plural morphology in English).

The finding that subliminal repetition priming is speaker invariant bears implications for models of spoken word recognition. Linguists and psycholinguists initially proposed that speech sounds are processed though a dedicated system yielding the activation of an abstract, speaker-invariant code (Jakobson, Fant, & Halle, 1952; Liberman & Mattingly, 1985). In contrast, several researchers have recently claimed that word instances are stored individually as separate exemplars (Pisoni, 1996). Support for this position is based on the observation that changes in speaker voice impair the recognition of words in several memory tasks (Goldinger, 1998). However, the detrimental effect of voice change in these studies could rest on explicit recall strategies. As we have shown here, when participants have no explicit knowledge that the word has been presented twice, priming occurs regardless of voice change. This finding gives support to theories of speech processing that rely on an abstract code, rather than acoustic exemplars (Luce & Lyons, 1998; Pallier, Colomé, & Sebastián-Gallés, 2001).

Before drawing strong theoretical conclusions about the architecture of the speech recognition system, it is important to acknowledge that our results could be dependent on several

[1]Previous lexical decision studies with written words have shown that subliminal orthographic priming is restricted to low-density words (words with a small number of formally similar words; Forster et al., 1987), under masked as well as unmasked conditions (Perea & Rosa, 2000). If the same density constraint applies to spoken words, it explains why phonological priming was absent in this study. High-density words were used in the phonological priming condition (mean number of neighbors = 9.6). Thus, the absence of phonological priming at all compression rates in our study is perhaps not surprising. The absence of semantic priming without awareness is congruent with previous claims that unconscious perception is restricted to modality-specific and formal analyses of words (Abrams & Greenwald, 2000; Kouider & Dupoux, 2001, 2004).

parameters that remain to be explored. It could be, for instance, that semantic priming emerges with tasks, such as semantic categorization, that are at a higher level than lexical decision. Also, effects of acoustic similarity could emerge with lower-level tasks, such as same-different matching. Furthermore, the present masking paradigm combines three characteristics: The prime stimuli are heavily time compressed, they are surrounded by babble noise, and they immediately precede the onset of the target word (short stimulus-onset asynchrony). The specific effects of these three characteristics need to be studied parametrically. What this study demonstrates, though, is the feasibility of subliminal priming for spoken word processing. For now, our results show that lexical processing takes place at an early and unconscious stage of speech perception.

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