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Short article

Lexically guided retuning of letter perception

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Participants made visual lexical decisions to upper-case words and nonwords, and then categorized an ambiguous N–H letter continuum. The lexical decision phase included different exposure conditions: Some participants saw an ambiguous letter "?", midway between N and H, in N-biased lexical contexts (e.g., REIG?), plus words with unambiguous H (e.g., WEIGH); others saw the reverse (e.g., WEIG?, REIGN). The first group categorized more of the test continuum as N than did the second group. Control groups, who saw "?" in nonword contexts (e.g., SMIG?), plus either of the unambiguous word sets (e.g., WEIGH or REIGN), showed no such subsequent effects. Perceptual learning about ambiguous letters therefore appears to be based on lexical knowledge, just as in an analogous speech experiment (Norris, McQueen, & Cutler, 2003) which showed similar lexical influence in learning about ambiguous phonemes. We argue that lexically guided learning is an efficient general strategy available for exploitation by different specific perceptual tasks.

Listeners can take advantage of lexical information to learn how to interpret perceptually ambiguous input in speech. Norris, McQueen, and Cutler (2003) demonstrated that listeners altered their category judgements for sounds from an ambiguous [f]–[s] continuum as a function of previous exposure to ambiguous phonemes in words. The listeners, who were Dutch, first took part in an auditory lexical decision experiment in which the materials included 20 Dutch words ending in each of [f] and [s]; these sounds occurred nowhere else in the experiment. For one group of listeners, the [f] sounds were replaced by an ambiguous sound [?] (midway between [f] and [s]), while the [s] sounds were natural. For another group, the [f]s were natural but the [s]s became [?]. The first group thus heard words such as *witlo?* (*witlof* means chicory; *witlos* is a nonword) and hence could use the lexicon to infer that [?] was [f]. The second group heard words such as *naaldbo?* (*naaldbos* means pine forest; *naaldbof* is a nonword) and thus could infer from lexical knowledge that [?] was [s]. In this lexical decision phase, listeners judged most [?]-final items to be words. In the [f]–[s] categorization task that followed, the first group labelled significantly more of the ambiguous fricatives as [f] than did the second group. That is, listeners had used the lexical information provided

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in the lexical decision task to adjust their phonetic categories.

Norris et al. (2003) included a number of controls in their experiment in order to check whether this learning effect was genuinely lexical. Repeatedly hearing a phoneme can produce selective adaptation (Eimas & Corbit, 1973; Samuel, 1986), and new sounds can be interpreted in terms of their contrast with known sounds (see Repp & Liberman, 1987, for a review). Either of these effects—adaptation, contrast—might produce a learning effect in the same direction as that observed by Norris et al. However, these effects would operate in the same way in all speech, irrespective of lexical content. Norris et al. therefore included conditions where the ambiguous sound always appeared in nonwords, while the unambiguous sound appeared in words. Under these conditions, no significant perceptual learning appeared. The effects observed in the experimental conditions were therefore lexical in origin. As Norris et al. argued, these lexical effects represent a beneficial effect of feedback from the lexicon, not for online lexical control of phonetic processing during speech recognition, but for longer term learning about speech sounds. Further research established that the learning is indeed usefully persistent across time (Eisner & McQueen, 2006; Kraljic & Samuel, 2005).

Lexically guided learning about speech sounds is extremely useful because of the variability that besets speech signals. Listeners are regularly presented with speech from speakers they have not previously heard, and speakers' voices differ widely. Information from the lexicon can resolve ambiguity arising from an unfamiliar pronunciation. To stay with the [s]–[f] example: If it is unclear which of these was the intended medial fricative in a bisyllable starting [træ] and ending [ɪk], the lexicon can resolve the issue on the basis that *traffic* is a word, and *trassic* is not. Learning from this experience can then help listeners to identify the correct speech sound the next time the same speaker utters a word containing [f].

This explanation makes two obvious predictions concerning the generalization of the learned knowledge about speech sounds. First, for speech sounds that are particularly dependent on speaker identity, such as fricatives, the learning should be speaker specific and should not generalize immediately to speech of other talkers, because speaker-dependent variability has no necessary implications for others' speech. Eisner and McQueen (2005) confirmed this prediction; the perceptual learning effect with fricatives does not generalize across talkers, unless there is close acoustic similarity between the two talkers' fricatives (Kraljic & Samuel, 2005). For sounds with less speaker-specific information, and thus normally greater acoustic overlap between talkers' realizations, such as stops, there is generalization across talkers (Kraljic & Samuel, in press). The second prediction is that the learning should generalize across the vocabulary to all potential productions of the speaker in question. Learning how a speaker says *traffic* should pay off in immediate implications for the same speaker's productions of *toffee*, *rough*, and *photo*. This too proved to be the case; the perceptual learning from the lexical decision task generalized such that it determined the interpretation of the ambiguous sound in minimal pairs such as *knife/nice* (McQueen, Cutler, & Norris, 2003, in press). As McQueen et al. pointed out, this generalization to words not heard in the training phase implied that the learning was affecting abstract prelexical representations—the interpretation of, for instance, [f] wherever it might appear, not the interpretation of particular words and how they may sound.

In the present study we examine whether the lexically guided learning observed by Norris et al. (2003) is speech specific and, in particular, whether it may also be observed in the processing of printed text. On the one hand, it might be predicted that the two types of processing are so different that lexically guided perceptual learning would have no role in reading comparable to its role in listening to speech. In speech, individual phonemes are smeared together as a result of the overlapping articulation of sounds during speech production. The acoustic realization of any given phoneme is also highly context dependent—a section of speech spliced out of its original context may be interpreted as a completely different phoneme (e.g., minus the /s/, the last three phonemes of *spin* sound like *bin*). Changes in pitch, loudness, or speech rate also affect the form of a phoneme, even when the context is unchanged. These intrinsic properties of natural speech make the interpretation of phonemes particularly vulnerable when unfamiliar voices are first encountered. Printed language, on the other hand, is far less variable. Tokens of a printed letter in a given font may vary in size across different texts, but are otherwise identical. Each letter is separated from every other by white space. Thus unlike phonemes, letters are discrete components of the perceptual input. Readers therefore may be able to analyse individual letters much more readily than listeners can analyse the separate sounds that make up the speech signal. The consistency and reliability of the printed form of letters mean that readers in practice rarely need assistance from lexical information to determine letter identity. If that is the case, we may observe no equivalent perceptual learning in a repetition of Norris et al.'s (2003) study with printed text.

On the other hand, a task analysis of reading text and of listening to speech suggests that these two types of processing of linguistic input are grossly parallel in structure. Models of both reading and listening distinguish a prelexical level of processing from a lexical level (compare, for example, the highly similar McClelland & Rumelhart, 1981, and McClelland & Elman, 1986, models for the recognition of written and of spoken words, respectively). The ability of the perceptual system to exploit lexical information in learning about speech sounds might be not a type of learning unique to speech perception, but rather an abstract capacity that allows knowledge represented at any higher level of processing to be exploited to tune effective processing of abstract categories at a logically earlier level of processing. Given the context dependence of phonemic realization and the speaker-dependent variability of speech signals, this type of learning may then happen to find regular application in the interpretation of ambiguous phonemes and in particular in the accommodation to new talkers. But it may equally well present itself in reading if the appropriate conditions were to be met. If that is the case, a repetition of Norris et al.'s (2003) study with printed text should be effective in inducing perceptual learning.

To assess the generality of lexically guided learning, therefore, we conducted a visual analogue of Norris et al.'s (2003) study. We presented two groups of participants with written words and nonwords, some of which contained an ambiguous letter (ambiguous between upper-case N and upper-case H). One group saw this letter in N-biased lexical contexts and also saw words with unambiguous H (e.g., REIG? and WEIGH). The other group saw the reverse (e.g., WEIG? and REIGN). Two control groups of participants saw the ambiguous letter in nonword contexts (e.g., SMIG?), plus either the words with unambiguous H or the words with unambiguous N. As Massaro (1979) has shown with lower-case ambiguous letter continua, lexical information does indeed bias the interpretation of ambiguous letters. Furthermore, Massaro concluded that the bias was attributable to the independent combination of letter and word information. That is, consistent with Norris et al.'s (2003) interpretation of their own data, processing of these ambiguous letters did not appear to involve online top-down feedback from the lexicon. The question here, therefore, was whether there would be lexically guided learning in letter perception. Participants in all groups made visual lexical decisions to the exposure items. In a second part of the experiment, they categorized an ambiguous N–H letter continuum. Lexically guided perceptual learning will entail that readers will be more likely to identify ambiguous letters as N after seeing ambiguous letters in lexical contexts where N is expected (e.g., in REIG?) than after seeing the ambiguous letters in H-biased lexical contexts (e.g., in WEIG?); exposure to the ambiguous letter in nonwords should, however, have no such effect.

Method

Participants

A total of 48 native speakers of British English with normal (or corrected-to-normal) vision took part in the main experiment. They were

Cambridge University undergraduates and members of the MRC CBU volunteer panel of similar age with some tertiary education. All participants were paid for their participation.

Letter stimuli and pretesting

The critical letters in this experiment were based on upper-case "H" and "N" in an Arial font. This enabled us to construct ambiguous letters on a continuum from N–H by rotating the diagonal line of the N. All other letters were normal unambiguous Arial characters.

To make the critical letters, we began by creating a 21-point continuum between H and N by changing the angle of the bar by a fixed angle per step. The font used was derived from an Arial font, which was manipulated using Fontographer (Version 4.1.4, Macromedia, 1996). An informal preliminary test suggested that Points 4–15 spanned most of the range from N to H. We therefore conducted a pretest using these points and the two endpoints. Participants were asked to categorize these letters as either N or H. A total of 10 native speakers of British English (MRC CBU graduate students or volunteer panel members) who did not take part in the main experiment were paid for participating.

Before the pretest participants were given written instructions, but during the pretest itself all further instructions were spoken so that instructions could not interfere with any learning of the visual stimuli. First, 10 trials consisting of 5 each of the endpoint "H" and "N" letters were presented to help participants learn the mapping to response buttons. There were then 10 blocks of the 14-point continuum. Each block of 14 items was randomized independently for each participant. There was a pause of approximately 10 seconds after every two blocks. The response buttons were labelled with lower-case "h" and "n". Assignment of response buttons was varied so that 50% of participants pressed "n" with their dominant hand, and 50% pressed "n" with their nondominant hand. Stimuli were presented on a Dell Inspiron 4000 laptop computer running DMDX (Version 2.6.04, Forster & Forster, 2003) with a video resolution of 1,400 × 1,050. The letters were approximately 7 mm high, and participants were seated approximately 50 cm from the screen. Each trial consisted of four displays, each presented for 250 ms with no delays between displays: fixation points (..); a blank screen; the letter shape; and a masking symbol (@). There was an intertrial interval of approximately 825 ms.

The results of the pretest are shown in Figure 1. Points 5, 8, 9, 11, 13 (corresponding to approximately 10%, 30%, 50%, 70%, and 90% "N" response levels) were chosen for the categorization phase of the main experiment (see Figure 2). Point 9 was used as the ambiguous letter in the lexical decision phase.

Design and procedure

There were four groups of participants, corresponding to four different lexical decision exposure phases. Two experimental groups saw 60 words containing the ambiguous letter, and two control groups saw the ambiguous letter in 60 nonwords. For one experimental group the lexical contexts of the ambiguous letter indicated that it should

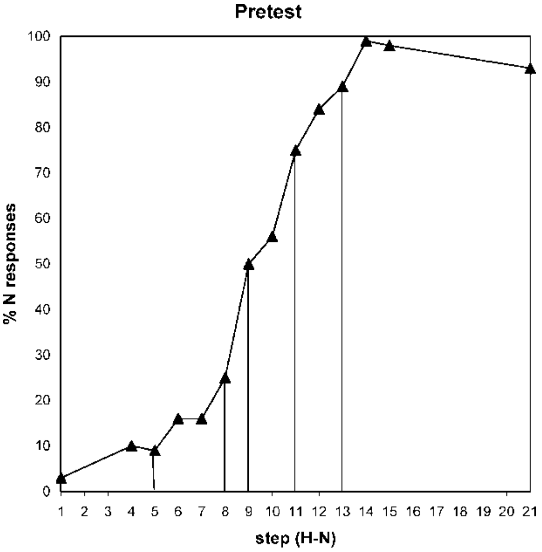

Figure 1. *Total proportion of N responses in the pretest. The five steps chosen for the main experiment are indicated with vertical lines.*

Figure 2. *The five steps of the H–N continuum used in the categorization phase. The middle letter of the continuum was the ambiguous letter used in lexical decision.*

be interpreted as an H (e.g., WEIG?). This group and one of the control groups also saw 60 words containing an unambiguous N (e.g., REIGN). For the other experimental group the word contexts for the ambiguous letter indicated that it should be interpreted as an N (e.g., REIG?). This group and the other control group saw 60 words containing an unambiguous H (e.g., WEIGH). For both control groups the ambiguous letters always appeared in nonwords (the letter string was a nonword regardless of whether the ambiguous letter was interpreted as N or H, e.g., SMIG?). Both experimental groups also saw 60 nonwords, matched to the nonwords with ambiguous letters by substitution of "?" with an unambiguous letter (e.g., SMIGS). Both control groups also saw 60 words containing neither H nor N. These were matched to the ambiguous words in the experimental groups in terms of length in letters and frequency. All four groups also saw 90 filler words and 150 filler nonwords, none of which contained either N or H. The complete design of the lexical decision phase of the experiment is shown in Table 1.

All critical experimental stimuli were between four and nine letters in length. The critical letter could appear in the first, second, or last position in the stimulus (see Appendix). Pairs of stimuli containing the critical H/N letters were matched in length, in position of the critical letter, and in terms of immediately neighbouring letters in both words (e.g., SHUT–SNUB) and nonwords (e.g., HASK–NASK). Words with a critical H had, on average, 2.1 neighbours, whereas those with a critical N had, on average, 1.38 neighbours. Control words were matched in length to individual experimental words, and, within words of the same length, the two sets were matched on word frequency.

Stimulus lists were constructed for each group and then split into three blocks. Across the four groups, matched items (e.g., REIG?–REIGN; SMIG?–SMIGS) always appeared in the same position in each block. Within any given block, items were presented in a pseudorandom order. Each of the six possible different block orders was presented to 2 of the 12 participants in each group.

Lexical decision stimuli appeared under the same presentation conditions as the pretest stimuli except that they remained on the screen

Table 1. *Lexical decision exposure phase: Design and number of stimuli per condition*

		Participant group			
		Experimental		*Control*	
Stimuli	*Example*	*?N + H words*	*?H + N words*	*? nonwords + H words*	*? nonwords + N words*
? →N words	REIG?	60	—	—	—
? →H words	WEIG?	—	60	—	—
Matched words	FEAST	—	—	60	60
N words	REIGN	—	60	—	60
H words	WEIGH	60	—	60	—
? nonwords	SMIG?	—	—	60	60
Matched nonwords	SMIGS	60	60	—	—
Filler words	RADAR	90	90	90	90
Filler nonwords	GRITE	150	150	150	150

Note: None of the matched and filler stimuli contained either N or H.

for 1,500 ms or until the participant responded, and that there was an interval of approximately 925 ms between trials. Response buttons were labelled "yes" and "no", and participants made "yes" responses with their dominant hand. They were instructed to decide as quickly and as accurately as possible whether each letter string was a real English word. Instead of a separate practice block, each block began with 12 noncritical (filler or control word) items. There was a rest break of approximately 30 seconds between each block.

Immediately following the lexical decision task, the button labels were changed to "h" and "n", and spoken instructions were given for the categorization task. A total of 12 trials displaying unambiguous lower-case "h" and "n" provided practice in mapping responses to the appropriate buttons. Norris et al. (2003) used six randomly ordered presentations of the five points on the test continuum. In order to increase experimental power, and to enable us to examine whether any shift in categorization would be maintained over a longer period, we here presented three blocks of 30 trials, separated by rest breaks of approximately 30 seconds. Stimulus presentation was the same as that in the pretest.

Results

Lexical decision

Mean lexical decision latencies and error rates are shown in Tables 2 and 3. Participants generally classified stimuli containing ambiguous letters correctly (e.g., WEIG? and REIG? as words, and SMIG? as a nonword). Analyses of variance (ANOVAs) were carried out on both the reaction time (RT) and error data for words and nonwords separately. There are four points to note about the results. First, the responses of both groups of participants in the experimental conditions tended to be faster on the unambiguous words that they saw than on the ambiguous words, $F(1, 22) = 14.66$, $p < .001$, and ambiguity had a larger effect on H words than on N words, $F_1(1, 22) = 4.53$, $p < .05$. Note that although Table 2 shows that responses to unambiguous N words were faster than responses to ambiguous N words and that the reverse was true for H words, with respect to within-subject comparisons both participant groups showed an ambiguity effect in the predicted direction: Participants who saw ambiguous N words were slower to respond to them than to unambiguous H words, and, to a lesser degree, participants who saw ambiguous H words were slower to respond to them than to unambiguous N words. This difference may reflect the fact that the H words had larger neighbourhoods than the N words. No other effects in the RT analysis of these data were statistically significant. Second, the error rates on lexical decisions to the critical word stimuli in the two experimental groups tended to decrease over the course of the experiment, $F(2, 44) = 4.02$, $p < .05$. No other effect in this error analysis was statistically significant. Third, in analyses of responses to the nonwords with ambiguous letters and the same nonwords with unambiguous letters (Table 3), there were no effects in error rates, and the only statistically significant effect in the RT analysis was of

Table 2. *Lexical decision performance for the critical words with either the ambiguous letter or unambiguous N or H*

	Ambiguous letter						*Unambiguous N or H*					
	Block 1		*Block 2*		*Block 3*		*Block 1*		*Block 2*		*Block 3*	
	RT	*%error*	*RT*	*%error*	*RT*	*%error*	*RT*	*%error*	*RT*	*%error*	*RT*	*%error*
N words	778	19	748	15	704	12	599	8	602	4	594	5
H words	623	12	623	7	621	5	672	8	657	8	649	8

Note: Mean correct reaction times, RTs, in ms measured from stimulus onset, and percentage error rates.

Table 3. *Lexical decision performance for the nonwords with the ambiguous letter and the matched nonwords*

	Block 1		*Block 2*		*Block 3*	
	RT	*% error*	*RT*	*% error*	*RT*	*% error*
Ambiguous nonwords	689	3	653	3	666	2
Matched nonwords	731	6	698	5	701	5

Note: Mean reaction times, RTs, in ms, measured from stimulus onset, and percentage error rates. Ambiguous nonwords were seen by the control groups; matched nonwords were seen by the experimental groups. The data are collapsed over whether participants saw unambiguous N words or unambiguous H words.

block: Responses became faster between Blocks 1 and 2 and then stabilized, $F(2, 88) = 5.27$, $p < .01$. Finally, responses to nonwords were not significantly influenced by whether the critical unambiguous words contained H or N: RT, $F(1, 44) = 3.74$, $p < .06$; errors, $F < 1$. None of the interactions involving this factor was significant either.

Categorization

Block 1. Total proportions of N responses in the first block are shown in Figure 3. If there was a lexically guided learning effect, this should be reflected in an interaction between training letter and experimental versus control condition. In an analysis of the data from the first block, which was most directly analogous to the analyses in Norris et al. (2003), this interaction was statistically significant, $F(1, 44) = 10.71$, $p < .005$. There was no difference between experimental and control conditions, $F(1, 44) < 1$, and no effect of training letter, $F(1, 44) = 2.75$, $p > .1$. There was also an effect of continuum step, $F(4, 176) = 78.67$, $p < .0001$, and a three-way interaction of condition, training letter, and step, $F(4, 176) = 3.25$, $p < .05$. This interaction confirms the pattern shown in Figure 3, that the lexical effect in the two experimental conditions is largest for the more ambiguous part of the H–N continuum. Further analyses examined the interaction of condition and training letter. In the experimental conditions the lexically guided learning effect (the effect of training letter) was statistically significant: $F(1, 22) = 21.26$, $p < .001$. In the control conditions there was no effect of training letter, $F(1, 22) < 1$.

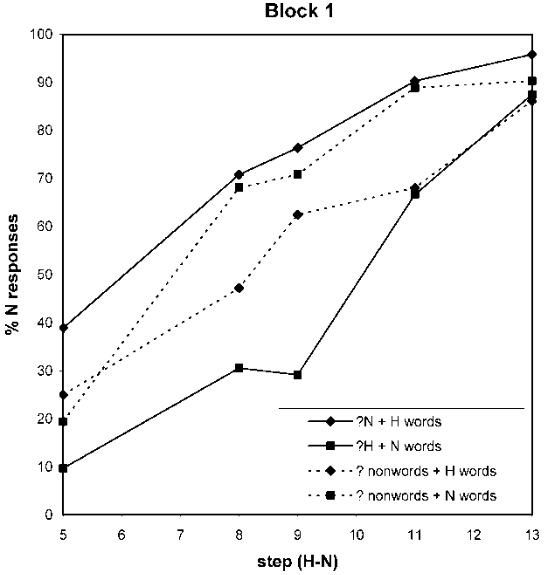

Figure 3. *Total proportion of N responses in Block 1, for each of the four exposure conditions: ambiguous N words and unambiguous H words (?N + H words); ambiguous H words and unambiguous N words (?H + N words); ambiguous nonwords plus unambiguous H words (? nonwords + H words); and ambiguous nonwords plus unambiguous N words (? nonwords + N words).*

All blocks. The same pattern was observed in the overall analysis (see Figure 4). There was no main effect of condition, $F(1, 44) < 1$, or training letter, $F(1, 44) = 2.55$, $p > .1$, but there was still an interaction of these factors, $F(1, 44) = 7.19$, $p < .05$. There was again an effect of step, $F(4, 176) = 153.66$, $p < .0001$. The only other statistically significant effects were two interactions involving the factor block: first, the effect of step changed over blocks (the categorization function became steeper with more exposure to the range of test letters), $F(8, 352) = 3.99$, $p < .001$; second, the interaction of condition and training letter changed over blocks, $F(2, 88) = 3.29$, $p < .05$. Separate analyses of the second and third blocks

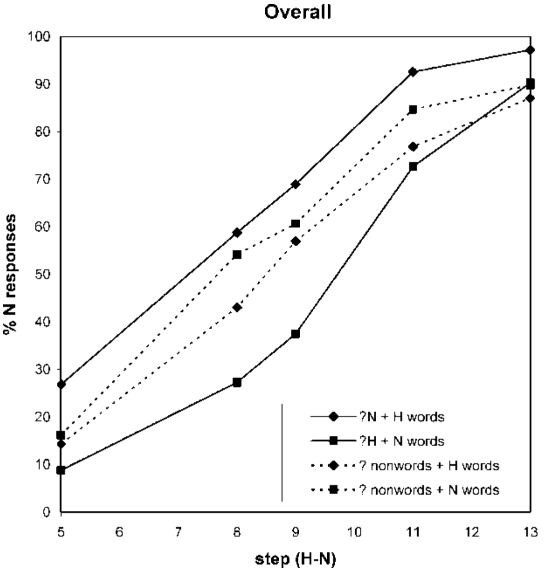

Figure 4. *Total proportion of N responses, for each of the four exposure conditions: ambiguous N words and unambiguous H words (?N + H words); ambiguous H words and unambiguous N words (?H + N words); ambiguous nonwords plus unambiguous H words (? nonwords + H words); and ambiguous nonwords plus unambiguous N words (? nonwords + N words).*

showed, however, that this was not due to a simple attenuation of the effect over time. Although the interaction between condition and letter was not significant in the second block, $F(1, 44) = 1.74$, $p < .2$, it was significant in the third block, $F(1, 44) = 6.32$, $p < .02$. This variability was almost entirely due to changes in the nonword condition. The lexically guided learning effect (i.e., the difference between the two experimental groups) became slightly smaller over time (differences between the two experimental groups in mean percentage of N responses were as follows: Block 1, 29%; Block 2, 18%; Block 3, 17%).

In an analysis of the overall data for the two experimental groups alone, the lexically guided learning effect was statistically significant: $F(1, 22) = 14.52$, $p < .005$. In a similar analysis of the two control groups alone there was no effect of training letter, $F(1, 22) < 1$. These results show that the lexically guided learning effect remains reasonably stable over the course of the test session and that there is no difference in letter identification performance between the two control groups.[1]

Discussion

Readers' judgements about the identity of ambiguous letters on an H–N continuum were affected by prior exposure to an ambiguous token in lexical contexts consistent with one or the other interpretation. Seeing the ambiguous letter "?" in WEIG? suggested that it should be seen as H, and readers with this experience later judged more of the continuum as H. Seeing "?" in REIG? suggested that "?" was N, and readers with this experience later judged more of the continuum as N. Exposure to the ambiguous letter in nonwords had no effect on the later interpretation of the continuum. Thus lexical information can be used to retune the operation of sublexical processes in reading as well as in speech perception. Despite the differences between spoken- and written-word recognition, lexically guided retuning of prelexical decision making seems to operate similarly in both domains.

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[1] Because participants were presented with lexical decision stimuli in which only one letter was unusual, this might have focused their attention on the critical letter. We therefore also conducted a version of the experiment in which we slightly varied the form of most of the letters in the lexical decision phase, so that the ambiguous N–H letter did not stand out as distinctive. None of the other letters was rendered ambiguous by this variation. The experiment was otherwise identical. The critical results were replicated. In the analyses of categorization performance in Block 1, the participants in the N-biased exposure group identified more of the test stimuli as N than did the participants in the H-biased exposure group (mean N identification proportions of 74% and 59%, respectively). There was no such difference between the two control groups (means of 60% and 58% for those who saw unambiguous H or unambiguous N, respectively). An ANOVA on these data revealed no difference between experimental and control conditions, $F(1, 92) = 3.43$, $p > .05$, and no main effect of training letter, $F(1, 92) = 3.69$, $p < .05$. There was considerable intersubject variability, such that even with twice as many participants as in the main experiment the interaction of these two factors was not statistically significant, $F(1, 92) = 2.60$, $p < .1$. One-way ANOVAs confirmed, however, that the difference between the two experimental groups was reliable, $F(1, 46) = 11.10$, $p < .005$, and that the difference between the two control groups was not, $F(1, 46) < 1$.

This finding was by no means a foregone conclusion. Listeners continually encounter new speakers who may produce speech sounds in unfamiliar ways. Lexical knowledge provides a valuable source of information that listeners can use to retune their perceptual categories and hence improve their ability to understand those new speakers. But speech perception is a highly evolved ability that may have come to depend on highly specialized processes. As we noted in the Introduction, speech differs from printed text in a number of significant ways. In contrast to the continuity and variability that characterize phonemes in speech signals, letter forms within a particular font are usually highly consistent and are helpfully separated from one another. Most readers probably rarely encounter new printed fonts with unusual or ambiguous letters. It might therefore not have been surprising had we found that the lexically guided learning that appears in speech perception did not occur with the perception of printed words.

However, rather than characterizing listening to speech as a more specialized form of perceptual processing than reading, we would argue that it is more justified to think of print as a more specialized form of perceptual input than speech. Listening to speech is something that comes naturally; reading, in contrast, must be learned. Print has been developed precisely to make the difficult task of reading easier. At the very least, print is designed to be much easier to perceive than handwritten text. Handwriting has many of the same complexities that speech presents: There are large differences among the writing styles of different individuals, the precise form of letters is contextually dependent, and the letters are not always separated by intermediate spaces.

In fact, the complexities of speech and handwriting are probably more representative of perception in general than is the perception of print. Our perceptual abilities are well adapted for functioning in a world in which complex signals arrive with rapidity, can flow into one another, and can vary as a function of the context in which they occur. The ambiguity that frequently results from these environmental effects can be resolved by recourse to learning, which uses higher level knowledge—in this case, our knowledge about the words of our language. The experience thus gained can in turn be exploited to retune the lower level decision-making processes for future encounters with ambiguity of this kind. Although we would not deny that reading involves some specialized perceptual processes, which have been developed for this particular kind of input, in this instance it seems rather that the perception of print is efficiently tuned to existing perceptual processes. It may be that, as we suggested above, lexically guided retuning is called on only infrequently when reading print; Bowers (1999) has suggested, for instance, that it may be useful in learning how to map upper- and lower-case letters onto the same underlying representation. Nevertheless, the ability to use information from one level of analysis to retune the perceptual categories used at some earlier level has such power that it certainly seems a waste to restrict it solely to the case of speech.

As we argued with respect to learning for speech perception (Norris et al., 2003), it is important to realize that this lexical guidance is not simple top-down feedback, which resolves the ambiguity of the bottom-up information stream on a case-by-case basis. The retuning is a learning effect, as is evidenced by the generalization across the continuum subsequently presented for categorization (and, in the speech case, by generalization to other words; McQueen et al., 2003, in press). Our results suggest that the ability to exploit this general learning effect characterizes the perception of print as it does the perception of speech.

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APPENDIX

Critical stimuli

H words	*N words*	*? nonwords*	*Matched nonwords*
hilt	nice	?ist	vist
harp	navy	?ask	lask
hoop	norm	?ort	dort
helm	newt	?eam	leam
shop	snob	s?of	stof
shut	snub	s?up	stup
haste	nasal	?asil	casil
hedge	nerve	?eved	leved
husky	nudge	?uved	suved
hoist	noise	?oisk	soisk
ghost	gnome	g?orp	glorp
shirt	sniff	s?ilt	smilt
khaki	knack	k?arf	klarf
shirk	snipe	s?isk	stisk
sheaf	sneak	s?eal	speal
shard	snarl	s?art	spart
shoal	snoop	s?old	stold
weigh	reign	smig?	smigs
bough	align	glig?	glige
tough	deign	grig?	grigt
cough	feign	meig?	meigt
rajah	pagan	poda?	podal
hammer	native	?aster	jaster
hockey	novice	?olfry	solfry
hectic	nectar	?ectil	bectil
humour	nutmeg	?ulder	bulder
sherry	sneeze	s?eldy	steldy
shiver	sniper	s?idis	slidis
shifty	snivel	s?ilip	spilip
shelve	sneaky	s?elky	smelky
shadow	snappy	s?abic	stabic
shovel	snooze	s?olly	spolly
plough	design	salig?	saligy
sleigh	assign	strag?	strage
trough	malign	cleag?	cleagt
purdah	turban	curpa?	curpal
holiday	nostril	?omidry	comidry
humdrum	nullify	?urdrid	curdrid
haircut	naively	?aidile	waidile
heretic	neutral	?esteem	kesteem
ghastly	gnarled	g?ofted	grofted
shuttle	snuggle	s?ullic	stullic
shopper	snooker	s?offle	sloffle
shimmer	snigger	s?ember	slember
shelter	sneaker	s?omper	slomper
borough	foreign	doraig?	doraigt
messiah	utopian	ralmia?	ralmiad
heritage	negative	?esolate	fesolate
humility	numeracy	?udilimy	dudilimy
hardback	narcotic	?aldeest	daldeest
horribly	novelist	?orepate	dorepate
shoelace	snowball	s?uskled	stuskled
shoulder	snobbery	s?esterm	slesterm
outweigh	campaign	doarbig?	doarbigt
hostility	nostalgia	?ostremit	fostremit
hamburger	narrative	?aldrimer	baldrimer
horoscope	normative	?oreagity	soreagity
harvester	narcissus	?armesote	darmesote
shoemaker	snowflake	s?olamers	spolamers
shortfall	snowdrift	s?ovatter	skovatter