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Acquiring novel words and their past tenses: Evidence from lexical effects on phonetic categorisation

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ABSTRACT

Two experiments addressed how novel verbs come to be represented in the auditory input lexicon, and how the inflected forms of such novel words are acquired and recognised. Participants were introduced to new spoken forms as uninflected verbs. These varied in whether they contained a final /d/ (e.g., *confald* or *confal*). Either immediately after training or a week later they performed phonetic categorisation on variants of these forms that ended with an ambiguous phoneme on a /d/-/t/ continuum. Lexical influences in categorisation would be demonstrated by a /d/ response bias, consistent with either the learnt uninflected form (e.g., *confald*) or a regular past tense inflection of the learnt form (e.g., *confalled*). In Experiment 1, lexical effects on categorisation were present for both word types, immediately and a week after exposure. Experiment 2 replicated and extended these findings using degraded stimuli. While lexical effects on response choice were present straight away, lexical facilitation of response speed was stronger after a week. These findings provide evidence for an account of verb learning in which rapidly stored word form information can have immediate lexical properties in some respects, such as allowing generalisation of existing knowledge of verb morphology to new words. However, consolidation over time enhances these representations, enabling swift lexical influences on phoneme perception. Implications for theories of the representation of inflectional forms and the time course of lexical processing of novel words are discussed.

Introduction

It has been estimated that people acquire as many as 60,000 words by the age of 18 (Pinker, 1994). While this prodigious rate of learning will have necessarily slowed by adulthood, we continue to encounter new words as long as we are exposed to spoken or written language. But how do we learn new words? Much of the research on vocabulary acquisition has focused on explicit measures such as the recognition and recall of nonwords in paired associate learning and nonword repetition tasks (see Baddeley, Gathercole, and Papagno (1998), for a review). Performance in these tasks, however, reflects the extent to which a sufficiently strong memory trace has been left by exposure to the items; such direct measures do not necessarily indicate whether or not the item has come to be represented in the mental lexicon. In order to test whether a novel word is able to exhibit behaviour like that of existing members of the lexicon, we must turn our attention to characteristic traits of lexical entries.

This approach underlies the work of Gaskell and Dumay (2003). They noted that since competition between lexical representations is ubiquitous in models of spoken word recognition (e.g., Luce & Pisoni, 1998; Marslen-Wilson, 1987; McClelland & Elman, 1986; Norris, 1994), then the engagement of a novel word in this process is a clear indicator of its representation in the input lexicon. In their experiments, participants were exposed repeatedly to fictitious novel phonological forms such as *cathedruke* (designed to overlap strongly with existing words) in a

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phoneme monitoring task. Learning was tested directly in a forced-choice recognition test, and indirectly, by looking at the effect of the novel word on the processing of existing neighbours (e.g., *cathedral*). An increase in response time in tasks thought to index lexical competition (auditory lexical decision and pause detection) was taken to reflect the engagement of the learnt word in lexical competition with existing neighbours. Their results pointed to a dissociation between these tasks in terms of the immediacy of novel word lexical effects. Directly following exposure, novel items were recognised from a minimal pair (e.g., *cathedruke-cathedruce*) with an error rate of less than 10%. This level of performance was sustained 24 h, several days, and 1 week later. In contrast, there was no evidence of the immediate engagement of novel items in lexical competition. Longer lexical decision and pause detection responses emerged only after a delay period spanning at least 24 h (cf. Davis, Di Betta, Macdonald, & Gaskell, 2009; Dumay, Gaskell, & Feng, 2004; see also Bowers, Davis, and Hanley (2005), for similar results with visual lexical decision). Dumay and Gaskell (2007) argued that the integration into the lexicon necessary for lexical competition requires a period of consolidation, associated with sleep. They found that a 12 h period that included nocturnal sleep was sufficient for the emergence of lexical competition, while lexical competition was not evident following a 12 h period of wakefulness. This association of lexical integration with sleep has been further supported by the finding that certain aspects of sleep architecture (spindles) are correlated with the emergence of lexical competition (Tamminen, Payne, Stickgold, Wamsley, & Gaskell, 2010).

These findings point to a process of word learning with at least two stages: (1) fast acquisition of form (supporting, for example, recognition of a familiarised nonword from a minimal pair) and (2) slower integration of this form with existing information, presumably as a safeguard against catastrophic interference (French, 1999), which could lead to the overwriting of extant lexical representations. As discussed by Davis and Gaskell (2009), these two learning rates are consistent with complementary systems models of memory (McClelland, McNaughton, & O'Reilly, 1995), which argue for a division of labour between gradually acquired, long lasting memory in the neocortex and a rapidly acquired, more temporary store, in the medial temporal lobes. The finding that novel word form information is stored quickly and efficiently is not new. The literature on implicit priming indicates that even a single exposure to a nonword leads to facilitated processing of that form on subsequent presentations (e.g., Church & Schacter, 1994; Schacter & Church, 1992; Tenpenny, 1995). Priming between orthographically illegal nonwords suggests that such priming may not rely on the partial activation of pre-existing lexical representations, but on newly established perceptual representations of those forms (Keane, Wong, & Verfaellie, 2004). Explicit memory experiments show that participants are able to recall, recognise, and learn associations between nonwords with sufficient training (e.g., Baddeley et al., 1998; Gathercole, 1991), and that this learning is long lasting (Salasoo, Shiffrin, & Feustel, 1985). However, studies on the time course of lexical competition with novel words (Davis et al., 2009; Dumay et al., 2004; Gaskell & Dumay, 2003) show that such swift episodic learning of novel forms is not sufficient to support a key property of spoken word recognition. In this paper extend this approach to look at the time course for acquiring other aspects of lexical behaviour. In particular we will examine two key lexical properties: the ability to bias perception of ambiguous phonemes (as in the "Ganong effect") and the integration of novel words into an existing inflectional system (Berko, 1958).

Ganong (1980) showed for existing words that a phoneme ambiguous between /d/ and /t/ (labelled here as /?/) is judged to be more /d/-like in the context of *?ash* (where *dash* is a word and *tash* a nonword) and more /t/-like in the context of *?ask* (where *task* is a word and *dask* a nonword). He attributed this to an interaction between word and phoneme representations affecting the percept of the ambiguous phoneme. The "Ganong effect" is reliable across many experimental variations (Pitt & Samuel, 1993) having been shown to occur word-finally (McQueen, 1991; Pitt & Samuel, 1993) and word-initially (Burton, Baum, & Blumstein, 1989; Burton & Blumstein, 1995; Connine & Clifton, 1987; Fox, 1984; Pitt & Samuel, 1993, 1995). While there is some controversy as to whether the Ganong effect reflects perceptual (Magnuson, McMurray, Tanenhaus, & Aslin, 2003; Samuel, 1997, 2001; Samuel & Pitt, 2003) or post-perceptual integration of word knowledge (Norris, McQueen, & Cutler, 2000), it is agreed that existing lexical representations are at the source of this effect. If, then, a novel word gains lexical status, it ought to elicit a Ganong effect. Accordingly, just as lexical competition can be used as an index of the lexical status of novel phonological forms, the Ganong paradigm can be used to measure the magnitude of lexical activation associated with a novel word.

In a recent study, Pitt (2009) made use of the Ganong paradigm in this way to investigate the lexical strength of pronunciation variants of novel words. After learning citation forms of words (e.g. *senty*), participants were tested a week later on a /s/-/sh/ continuum (e.g. *senty-shenty*). A new word lexical bias (e.g., *senty*) was found, indicating that after a week, these novel words were able to exhibit behaviour consistent with a lexical entry. Whilst establishing that a lexical bias was possible with novel words, Pitt's main interest was in whether lexical effects would be found when a reduced variant that had undergone /t/ deletion (e.g. *seny*) was heard at test. This is a regular form of phonological variation in American English, and is common in the phonological contexts used to create the novel words. Pitt asked whether a phonological inference rule could operate on novel forms, leading to a Ganong effect for the reduced form. Pitt failed to find a lexical bias on phonetic categorisation for the reduced forms when testing a week after exposure. A Ganong effect was only found when the reduced form was presented just before testing in a context where it could be associated with its canonical form.

The Ganong effect with citation forms of novel words (Pitt, 2009) is an index of word learning in that it reflects the influence of lexical representations on the processing of sub-lexical phonetic information. This differs from lexical competition in that it is a form-based, within word effect, whereas lexical competition reflects the integration of novel items into an existing lexical neighbourhood. However, the use of the Ganong effect as a measure of the lexical status of pronunciation variants reflects the use of existing knowledge of phonological variation interacting with a novel phonological form, and as such, relies on integration of new information with existing knowledge. Another test for phonological generalisation of novel words was used by Snoeren, Gaskell, and Di Betta (2009). They examined the perception of assimilation of place of articulation (e.g., where the /n/ in *lean bacon* is articulated more like [m]) after learning novel words. Like the Ganong effect with pronunciation variants, compensation for co-articulation involves the combination of a newly learnt phonological form with existing phonological knowledge, in this case how a following phonological context licences recovery of an underlying form. Compensation for assimilation was found to occur immediately after training as well as after a day, indicating a lexical influence without the need for consolidation. While the time course of lexical behaviour found in this study differs from results on lexical competition with novel words, there was evidence for consolidation in reaction time data, as detection of assimilated consonants was quicker after a day.

In the current work we move beyond phonological generalisation to the generalisation of stored knowledge of morphology applied to novel forms. We do this by using the Ganong paradigm to assess the combination of novel forms with stored knowledge of the past tense inflection in English. The incorporation of novel verbs into an existing inflectional system is an important part of lexical acquisition. Knowledge of inflectional morphology is acquired early on in language acquisition, and can be generalised to novel words with ease by even very young children (Berko, 1958). It is still a matter of debate how this ability relates to online comprehension of novel inflected forms. The mechanism could be in the form of an actual rule (e.g., Pinker, 1994; Pinker & Ullman, 2002) or as a result of a generalisation inferred from shared form and meaning which falls out of a parallel distributed processing account (e.g., McClelland & Patterson, 2002; Rumelhart & McClelland, 1986). It is sometimes taken as given that known regular inflections are recognised via their stem forms (e.g., Marslen-Wilson, 1999), and reliable priming between inflected forms and their stems (Marslen-Wilson, Hare, & Older, 1993; Marslen-Wilson & Tyler, 1998) suggests that inflectional decomposition operates at an early stage of spoken word recognition. Such morphological processing of inflected spoken words is also reflected in the finding that the Ganong effect is influenced by inflectional status (Sedin, 2006; Sedin & Gaskell, 2004). Sedin and Gaskell found that lexical effects in inflected word–nonword continua (e.g., *agreed-agreet*) were smaller than in uninflected verb–nonword continua (e.g., *succeed-succeet*), and took these findings to support early decomposition in spoken word recognition, resulting in weaker top-down support for phonetic categorisation decisions in inflected forms. Clearly, morphological analysis of inflected forms is a pre-existing process in spoken word recognition. Accordingly, some form of generalisation would have to take place for a novel word to become involved in this process.

Experiment 1 investigated the extent to which the inflected forms of novel words elicit a Ganong effect as an index of the integration of new phonological forms and existing knowledge of regular past tense inflectional morphology. In order to compare the lexical properties of novel word representations pre-consolidation vs. after a period of consolidation, we tested participants either immediately or after a week. Our procedure involved three experimental stages. Firstly, participants were exposed to novel phonological forms via phoneme monitoring and a past tense generation task. Crucially, the tense generation task encouraged participants to treat the novel forms as English verbs. Secondly, participants' immediate familiarity with the novel forms was assessed using a two-alternative forced-choice recognition memory task. Finally, participants completed a phonetic categorisation task either immediately or a week later, to test whether the learnt forms would elicit a lexical effect on the categorisation of ambiguous phonemes at different time points. Phonemes embedded word-finally in 48 nonwords (e.g., *confal?*, where *?* represents steps along a /d/-/t/ continuum) were categorised in three conditions. In the "whole word" condition, phonetic categorisation was preceded by exposure to a corresponding /d/-final form (e.g., *confald*) in the familiarisation phase. This is akin to learning an uninflected verb that ends in /d/ (e.g., *succeed*). In the "stem" condition, participants were pre-exposed to a corresponding non-/d/-final form (e.g., *confal*), which is akin to learning a verb that can be inflected to form a /d/ ending (e.g., *agree/agreed).* The "nonword" condition was made up of those words to which there was no prior exposure, meaning that these words were completely novel when heard at test.

Given that novel phonological forms participate in lexical competition after a week delay (Gaskell & Dumay, 2003, Experiment 2a), and in line with the findings of Pitt (2009), we predicted that items in both the whole word and stem conditions would exert a lexical effect on phonetic categorisation given a sufficient delay between exposure and test. A lexical effect in the whole word condition (i.e., more /d/-responses than in the nonword condition) would reflect lexical status of the phonological form. A lexical effect in the stem condition would indicate the ability to generalise our knowledge of past tense morphology to new verbs (effectively, a lexical effect exerted by the never before heard past tense form *confalled*). We expected that these effects would be commensurate with existing findings of an increased Ganong effect for verbs that end in /d/ without inflection, compared with verbs that end in /d/ only when inflected with the past tense (Sedin, 2006; Sedin & Gaskell, 2004).

Gaskell and Dumay found "no support for the immediate generation of fully-fledged lexical representations" (2003, p. 123); mere exposure to novel phonological forms appeared not sufficient for these forms to participate in lexical competition. However, pre-consolidation effects of a novel word influencing phonological processing has been found by Leach and Samuel (2007), who demonstrated that perceptual learning of ambiguous phonemes (cf. Norris, McQueen, & Cutler, 2003) was biased by the phonological context of a novel word, immediately after familiarisation of that novel word. As described above, Snoeren et al., also found that lexical effects on phonological inference were present immediately after training. Given evidence from these studies of the presence of immediate phonological effects very soon after learning a novel word, an immediate effect for the whole word condition in our study may be expected. Though, as Snoeren et al. found in their reaction time data, benefits appear to exist for lexical processing of novel words after a period of consolidation. For the stem condition, the prediction is less clear. Like Snoeren et al., this is a case of generalisation of existing knowledge, but here at the level of morphology. Given arguments for the need for consolidation to avoid catastrophic interference when integrating novel words into the lexicon, and the generally weaker effects with inflected stems found in previous studies with existing words (Sedin, 2006; Sedin & Gaskell, 2004), a period of consolidation may be necessary before lexical biases occur from the novel inflected stems. Lexical biases shown in the stem condition (either immediately or after a delay) would imply that the stem form had a lexical status and either (a) the regular past tense inflection had lexical status also and biased categorisation as in the whole word case, despite having never been heard or (b) that some online rule governed process was in operation that facilitated /d/-responses consistent with a regular inflected form of the newly learnt representation.

Experiment 1

Method

Participants

Participants were 85 undergraduate students from the University of York, who were either paid or received course credit for their participation. Forty-four participants carried out the categorisation task immediately after training, while 41 participants did it a week later. All were native speakers of British English and had no reported hearing or learning difficulties.

Materials and stimulus construction

Materials were 48 bisyllabic nonwords, each with one /d/-final and one non-/d/-final form (e.g., *confald* and *confal*). These were designed so that the removal of the /d/ in each case resulted in a bisyllabic nonword ending in a vowel, /n/ or /l/. These phonemes were chosen to avoid consonant clusters that could potentially cue inflectionality, such as /bd/, which occurs only in past tense words such as *robbed*, and /Id/ which acts as a past tense marker following verbs ending /d/ or /t/. The 48 nonwords were divided into three lists of 16 for the purposes of counterbalancing and were matched across lists for final vowel (see Appendix A). A further 96 nonwords were derived from the original list by changing a single phoneme of each of the /d/-final and non-/d/-final forms, for use as foils in the recognition phase (e.g., *tonfald* and *tonfal*). All items had second-syllable stress, reflecting the stress pattern of the majority of present and past tense bisyllabic verbs in English.

Materials were produced by a male native British English speaker in a sound-attenuating booth, and recorded directly onto a PC using Adobe Audition. Recordings were made using a Sennheiser ME40 microphone, and digitised at a sampling rate of 44.1 kHz with a 16-bit analogue-to-digital conversion.

Stimuli for the phonetic categorisation were made from the /d/-final forms. Stimuli were matched for vowel duration because of its known influence on vowel duration (e.g., Denes, 1955; Wolf, 1978). Tokens were chosen from the available recordings that were as closely matched as possible for vowel duration in the second syllable. In cases where the penultimate phoneme was not a vowel (in *mastrind* and *confald*, for example), durations of vowel-/n/ or vowel-/l/ combinations were measured. (There were equal numbers of vowel-/d/-, /nd/- and /ld/-final items across lists.) Non-/d/-final forms, foils and /t/-final forms corresponding to the chosen /d/-final forms were selected from the recordings for use in the experiment. The construction of stimuli took place as follows. In each item, the final /d/ was excised (see below), resulting in 48 ‘carrier’ waveforms. In order to neutralise the vowel duration cue to postvocalic voicing (as judged by the experimenter) in the carriers, pitch periods corresponding to half the difference between the carrier vowel duration and the corresponding duration in the /t/-final form (e.g., the /i/ in *monyeet*) were removed. Further pitch periods were excised from the termination of the vowel in carrier waveforms where this information was a strong cue to postvocalic voicing. In any such cases, corresponding carriers across lists underwent the same modification (i.e., the equivalent number of pitch periods were removed).

To create burst continua, five clear pairs of /d/ and /t/ were excised from the word-final position of recorded whole word items. The /d/ in each case was excised beginning at the onset of any pre-burst voicing cues, or if these were not present at the burst itself. This was aligned at the burst with the corresponding /t/, and the /t/ excised to match the overall duration of the /d/. The pairs of phonemes were then amplitude-attenuated in 10% decrements, and mixed pairwise to sum to 100% (Repp, 1981). A phonetic categorisation pre-test with six participants was used to determine a continuum with the clearest endpoints and a relatively large, central region of ambiguity. This led to the selection of a 9-step continuum, with two unambiguous voiced tokens (the natural /d/, and step 1) and two unambiguous voiceless tokens (step 9, and the natural /t/) along with three ambiguous boundary stimuli (steps 4, 5 and 6). In order to extend this ambiguous region slightly, two further steps were created with 5% increments in the middle of this continuum (i.e., 45% and 55% amplitude attenuation mixed to make steps 4.5 and 5.5).

The construction of the phonetic categorisation stimuli involved splicing these nine continuum steps back into the word-final position in each of the 48 carrier waveforms. This resulted in nine versions of each of the 48 items, two ending in a clear /d/ (e.g., *confald*), two in a clear /t/ (*confalt*), and five ending in a phoneme ambiguous between the two (*confal?*).

Design

Participants were first familiarised with the novel words in two tasks, and familiarisation was then tested in a recognition memory test. In the familiarisation phase, participants were exposed to 32 of the 48 items: 16 whole word (/d/-final) forms, and 16 stem (non-/d/-final) forms. Familiarisation was followed by phonetic categorisation, where they categorised all nine versions of the 48 items (432 total); 16 whole words, 16 stems, and 16 items that were not previously encountered, acting as nonword controls. Items were counterbalanced across conditions with three exposure lists, so that each item appeared in all three conditions across participants but in only one condition for any given participant. The order of presentation of items in each task was randomised for each participant.

Procedure

The experiment was run on PCs using DMDX experimental software (Forster & Forster, 2003). Stimuli were presented over Sennheiser HD-265 headphones at a comfortable listening level. Participants were informed at the beginning of the familiarisation phase that the experiment was an investigation into the mechanisms underlying word learning. They were instructed to listen carefully, treating the items as if they were new words in their vocabulary, and they would be tested on their memory of them at the end of familiarisation. Participants did each of the two exposure tasks twice, alternating with each other.

Participants started with the self-paced past tense generation task, which was designed to make it clear that the novel words were verbs capable of undergoing inflection. After listening to an item, participants wrote down on a provided sheet what they considered to be its regular past tense. For example, they would write "*confalded*" after hearing *confald*, and "*confalled*" after hearing *confal*. Pilot work suggested a written form of the item was helpful to aid with the spelling, so this was presented on the screen for the duration of the spoken word. Participants were given examples and feedback in a practice session. Items were presented twice in each iteration of the task. Note that while participants wrote down the /d/-final form they would later encounter in phonetic categorisation, they never heard the /d/-final form for items in the stem condition.

Immediately after the past tense generation task, participants performed phoneme monitoring. This task was designed to make participants pay close attention to the phonological forms of the novel words. Participants made judgements using a Trust 850F game-pad on whether a target phoneme appeared in the spoken form of the word, with one button for "present" and another for "absent", and were told to respond as quickly and accurately as possible. Five target phonemes (/g/, /k/, /n/, /p/ and /s/) were chosen to cover a range of positions in the stimuli, and to ensure that each item received both "present" and "absent" responses throughout the task. The same target phoneme was presented on screen for the duration of a block, and each target appeared in two blocks, meaning each item appeared 10 times in each iteration of the task.

After completing each exposure task twice, participants performed a two-alternative forced choice (2AFC) recognition memory task. Each item was heard with a related foil (e.g., *confald-tonfald*). Target–foil pairs were presented one after the other in a random order. Participants indicated which of the paired items they recognised from the previous tasks by pressing one button on the gamepad for the first item in each pair, and another for the second.

The familiarisation session took approximately 45 min. Each item was heard 25 times in total, 24 times in the two familiarisation tasks, and an additional single exposure in the 2AFC task. This was assumed to be a sufficient level of exposure based on previous results (e.g. Dumay et al., 2004; Gaskell & Dumay, 2003).

The influence of exposure was tested immediately after training or a week later (day 8). To ensure that testing in the immediate condition did not affect performance in the later test, a between-participants manipulation of time of test was employed. For each of the 432 stimulus tokens participants had to decide whether the final sound in each item was a /d/ or a /t/, using the gamepad. They were told some of the decisions would be more difficult than others, but to respond as quickly and as accurately as possible in each case, and not before the offset of each item. The stimuli were split into four blocks, with the order of presentation within those blocks, and of the blocks themselves, fully randomised per participant. Each trial began 1 s after the participants' response on the previous trial, or after a response deadline of 4 s, whatever happened first. Reaction times were measured from the onset of the burst (i.e., the point at which the burst continuum was spliced onto the carrier waveform in each case). This task lasted for approximately half an hour.

Results

The data from 10 participants were excluded for poor discrimination (operationally defined as an error rate of more than 20% on either of the unambiguous /d/ and /t/ endpoints). Four further participants were excluded from the analysis: three due to an experimental error in data recording, and one because their performance in the 2AFC test was below chance level. This left a total of 71 participants: 34 in the immediate test group, and 37 in the delayed test group. We excluded from the phonetic categorisation data (less than 1% of the data): time-outs, pre-burst responses, and responses made less than 100 ms from the onset of the burst.

Analysis of performance in learning phase

The error rate in the phoneme monitoring task was low (8.5%), suggesting that participants were paying careful attention to the phonological forms of the novel items. Participants' written responses in the past tense generation task also reflected the phonological forms to which they were exposed, further suggesting that the participants had good knowledge of the novel words. While there was some variation in the spelling of the past tense forms across participants, the majority of responses (89%) were consistent with expectations. Most importantly, participants had a high level of performance in the recognition memory test, which was performed immediately after familiarisation in both the immediate and in the delayed groups, showing a mean correct response rate of 95.5% (immediate: 95.4%; delayed: 95.6%), clearly over the 50% level of performance expected by chance (immediate: ($t(33) = 45.2$, $p < .001$; delayed: $t(36) = 55.5$, $p < .001$), and in line with the performance previously reported for versions of this task (Dumay et al., 2004; Gaskell & Dumay, 2003).

Lexical identification shift analysis

To indicate the magnitude of lexical bias, we used a measure of lexical identification shift (LIS; Pitt & Samuel, 1993) across the five-step ambiguous range of the spectrum. This was calculated for the whole word and stem conditions by subtracting the mean percentage of /t/ responses per participant from the mean percentage of the nonword condition, with higher values indicating a greater tendency to respond /d/ compared to the unlearnt control words. The far right of Fig. 1 illustrates the size of these resulting lexical shifts for each of test time points.

Analysis of these lexical shifts for each test time point was conducted using a linear mixed-effects logistic regression (Jaeger, 2008), using the lmer program (lme4 package; Bates & Sarkar, 2007), in the R programming environment (R Development Core Team, 2008). Participants and items were included as crossed random effects, which simultaneously takes into account differences between participants and differences between items (Baayen, Davidson, & Bates, 2008). Initial model selection led to the inclusion of random slopes by participant and by item for step, which significantly improved upon models without their inclusion. We report regression coefficients (b), standard errors (SEs), z values and p values. The mixed-effects logistic regression model used predictors of condition (whole word, stem and nonword), the ambiguous regions of the step continuum (five levels; steps 4, 4.5, 5, 5.5 and 6), and reaction time range (fast, medium and slow responses).

Immediate test condition. Collapsed across reaction time ranges, a significant LIS was found for the whole words ($b = .34$; $SE = .071$; $z = 4.86$, $p < .001$), and for the stem condition ($b = .24$; $SE = .072$; $z = 3.37$, $p < .001$). While there were more /d/ responses for whole words compared to the stem condition, this difference was not significant ($b = -.10$; $SE = .071$; $z = 1.49$, $p = .14$). There was a highly significant main effect of step ($b = -.74$; $SE = .08$; $z = -8.01$, $p < .001$), with a greater likelihood of /d/-responses at the /d/-end of the continuum and a greater likelihood of /t/-responses at the /t/-end, as expected based on the construction of the stimuli. There was also a highly significant effect of RT range (discussed below).

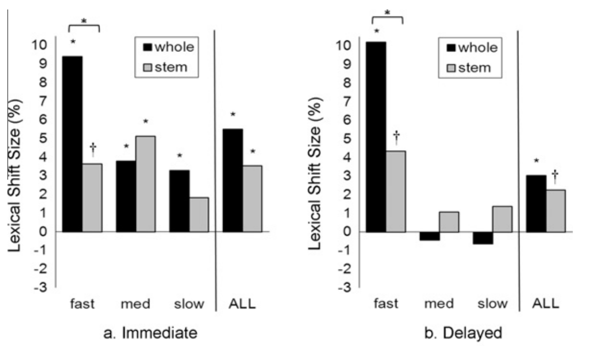

Fig. 1. Lexical identification shifts for whole words and stem conditions, compared with the nonword condition (i.e. no exposure prior to categorisation phase) for (a) immediate and (b) delayed test conditions in Experiment 1, across RT ranges and overall (far right). Asterisks indicate significance at the $p < .05$ level; crosses indicate significance at the $p < .10$ level.

Delayed test condition. There was a significant LIS for the whole word condition ($b = .17$; $SE = .071$; $z = 2.45$, $p = .014$). There was only a marginally significant LIS for the stem condition ($b = .13$; $SE = .07$; $z = 1.91$, $p = .05$), although there was also no significant difference between the stem condition and whole words ($z < 1$). There were also significant effects of step ($b = -1.04$, $SE = .10$; $z = -10.11$, $p < .001$) and RT range.

These results from both immediate and delayed test conditions indicate that participants categorised the ambiguous final phoneme in a stimulus such as *confal?* (where the ? was ambiguous between /d/ and /t/) as /d/ more often when they had been exposed to a corresponding whole word (e.g., *confald*), compared with when no exposure to this particular form was given (nonword controls). There was a similar pattern when participants were familiarised with the shorter stem form (e.g., *confal*), though this was not as reliable when tested a week after exposure.

RT range analysis

In several studies using the Ganong paradigm, lexical shifts have been analysed as a function of reaction time (Fox, 1984; McQueen, 1991; Pitt & Samuel, 1993). Analyses of this kind have proved useful in investigating the Ganong effect in existing words (e.g., Fox, 1984; McQueen, 1991; Pitt & Samuel, 1993), providing insight into the time course of the effect. It has also been suggested that fast RTs may reflect the true influence of lexical information on phonetic categorisation rather than categorisation biases with a later onset (Sedin, 2006). LISs in the current study were therefore analysed as a function of reaction time. For each participant, categorisation responses were divided into RT ranges by ranking their responses in each condition, and splitting them into three equal portions of fast (immediate range = 108–759 ms, $M = 458$ ms; delayed range = 153–887 ms, $M = 490$ ms), medium (immediate range = 396–1070, $M = 637$ ms; delayed range = 380–1480, $M = 691$ ms) and slow reactions times (immediate range = 478–3130 ms, $M = 1030$ ms; delayed range = 471–3330 ms, $M = 1150$ ms). LIS results for each reaction time range for both time points are shown in Fig. 1.

Immediate test condition. Separate mixed-effects models were conducted for each of the reaction time ranges, with predictors of condition and step. The LIS was statistically significant for whole words in the fast RT range ($b = .66$; $SE = .16$; $z = 4.13$, $p < .001$), but only marginal for the stem condition ($b = .29$; $SE = .16$; $z = 1.87$, $p = .061$). Likelihood of /d/ responses was significantly higher with whole words compared to the stem condition ($b = -.37$; $SE = .15$; $z = -2.31$, $p = .021$). For medium reaction time range responses, there was a significant LIS for both whole words ($b = .44$; $SE = .14$; $z = 3.17$, $p < .001$) and for the stem condition ($b = .51$; $SE = .14$; $z = 3.98$, $p < .001$). In the slow reaction times, a small LIS was found only for the whole word condition ($b = .20$; $SE = .10$; $z = 2.01$, $p = .044$). In the medium and slow reaction time ranges there was no significant difference between the whole word and stem conditions (all $z < 1$).

Delayed test condition. Unlike in the immediate test condition, the only significant LIS was found in fast reaction times for the whole word condition ($b = .86$; $SE = .22$; $z = 3.92$, $p < 001$), along with a marginally significant LIS for the stem condition ($b = .39$; $SE = .21$; $z = 1.87$, $p = .062$). In addition, /d/ responses were significantly higher for the whole word condition compared with the stem condition ($b = -.47$; $SE = .22$; $z = 2.12$, $p = .034$) in the fast RT range.

In summary of the RT range results across test times, the overall lexical shifts observed in the whole word conditions appear largely attributable to fast RT responses. In the case of the stem condition, fast responses also produced a LIS compared with slow responses at both time points, though the LIS was only statistically significant in the medium RT range of the immediate test group. Evidence for increased magnitude of lexical biases in the fast reaction times is consistent with other findings on known words tested with word final ambiguous phonemes (e.g., McQueen, 1991; Pitt & Samuel, 1993).

Lexical reaction time effect (LRTE) analysis

LRTE analyses are motivated by the idea that word-consistent responses ought to be faster than nonword-consistent responses because of the influence of the lexical representation (Connine et al., 1987; Pitt & Samuel, 1993). With existing words these analyses have been used to try to discriminate between different theories, by contrasting responses at the ambiguous boundary region with responses at the endpoints of a continuum. Here with novel words the equivalent analysis acts as another measure of the lexical status, with faster /d/ than /t/ responses implying that the items (or their inflected forms) had achieved a lexical status sufficient for facilitating word-consistent responding in categorisation. We restrict our analyses to the endpoints where there is clear phonetic information, which in our case includes 2 steps at each end (steps 1 and 2, and steps 8 and 9), in contrast to our 5 step ambiguous range (steps 4, 4.5, 5, 5.5 and 6). Analyses at the endpoints typically show the clearest cases of lexical bias, as in one case phonetic categorisation is lexically consistent (/d/), whereas at the other end it conflicts with a lexical representation (/t/) (Connine et al., 1987; Pitt, 2009). In addition, lexical biases are typically found to be stronger at the end points with word-final ambiguous phonemes (McQueen, 1991; Pitt & Samuel, 1993). Our main LRTE analysis compared mean /d/ and /t/ response RTs in each of the word conditions at each test time using paired *t*-tests, and these means along with standard deviations are shown in Table 1.

Table 1
Lexical reaction time effects in milliseconds at endpoints for immediate and delayed test points in Experiment 1. Brackets indicate standard deviations.

	Immediate		Delayed	
	/d/	/t/	/d/	/t/
Whole word	631 (124)	625 (124)	623 (112)	692 (154)
Stem	649 (129)	632 (132)	657 (115)	702 (169)
Nonword	691 (150)	655 (140)	696 (146)	722 (169)

In the immediate condition, an ANOVA showed there was no significant interaction between response and word condition (p's > .24), and *t*-tests revealed no significant RT difference between /d/ and /t/ responses was found in any of the conditions, except for a reverse effect in the nonword condition that was only significant by-items (−41 ms, $t(15) = 2.66$, $p = .017$). However, a week later, there was a significant interaction between word type and response, $F1(2, 72) = 3.68$, $p < .001$, $F2(2, 30) = 4.61$, $p = .017$. A significant LRTE was found in the whole word condition (69 ms, by-participants $t(36) = 3.44$, $p < .01$; by-items $t(15) = 6.44$, $p < .001$), and in the stem condition, (45 ms, $t(36) = 2.27$, $p = .029$; $t(15) = 2.42$, $p < .028$). As expected, there was no LRTE in the control nonword condition (26 ms; p's > .2).

These LRTEs suggest that only after a week were lexical representations available to facilitate responding consistent with either the learnt full form, or a regular inflection of the learnt stem form. It seems that while lexical effects on phonetic categorisation can be elicited in novel forms by their repeated presentation immediately prior to the categorisation task, such recent exposure was not sufficient to elicit the facilitation of responses consistent with that new word.

Discussion

In Experiment 1, 24 presentations of novel phonological forms in phoneme monitoring and past tense generation tasks led to good recognition of those forms immediately following exposure. More importantly, exposure to the novel items led to a lexical influence on phonetic categorisation both immediately and a week later: ambiguous phonemes were categorised as /d/ more often in the context of newly learned /d/-final words than the same ambiguous phonemes in completely novel forms. Like Pitt, we found the presence of lexical effects for novel words after a week, but in that study, lexical effects were not measured immediately. Our demonstration of an immediate lexical influence on phonetic categorisation in newly acquired words supports the case that some aspects of lexical processing are available immediately after a novel word is learned (Borovsky, Kutas, & Elman, 2010; Leach & Samuel, 2007; Snoeren et al., 2009).

Previous research on word learning using lexical competition as a measure of lexical status (Davis et al., 2009; Dumay & Gaskell, 2007; Gaskell & Dumay, 2003) has shown a qualitative shift in lexical properties following a period of consolidation, which includes at least a period of sleep (Dumay & Gaskell, 2007). With a different measure of lexical status we find no evidence for a shift in categorisation over time in Experiment 1, but our results are still compatible with an influence on consolidation on lexical representation. The LRTE results indicate that after a week, consolidated lexical representations produced faster reaction times for word-consistent responses. This matches a number of other findings. Snoeren et al. showed immediate word-like properties in the perception of assimilated forms of newly learned words but found that speed of compensation for assimilation was quicker after a day. In Davis et al. (2009), participants showed speeded responses in a naming task on words learnt a day previously compared with words learnt that day, and in Tamminen (2010), masked visual semantic priming with novel words only occurred a week after training, and not immediately or a day later.

Perhaps surprisingly, we found that the Ganong effect generalised to cases where the stimulus was a past tense form of a newly acquired stem: word-final /d/-/t/ continuum tokens were categorised to be more /d/-like in *confal?* after *confal* had been learnt. These results parallel those of Sedin (2006), who found a lexical bias in the Ganong paradigm for existing verbs such as *agree?*, and bear similarity with lexical effects found with reduced form variants of a learnt canonical form (Pitt, 2009). This indicates that treating novel words as verbs allow their fast acquired representations to interact with existing morphological mechanisms. Likewise, in Snoeren et al. (2009), immediate effects were found for the generalisation of existing knowledge of compensation for assimilation to novel words. Here, we also show immediate generalisation, but at the level of morphology rather than phonology. The effects for the past tense forms were particularly striking as participants never heard the past tense of these items before the phonetic categorisation task. However, while the inflected /d/-final forms of the novel words was never heard, there may have been some phonological activation when deciding on and writing down the past tense forms as participants were asked to generate the past tense form and write it down four times (see Frost and Ziegler (2007), for a review on the interaction between phonological and orthographic processing). It is also possible that some participants would have engaged in covert or overt production of the novel forms and their past tenses during the task. If phonological activation of the past tense form in the generation task occurred and was influential, it could weaken the argument that new lexical items can interact with pre-existing morphological processing mechanisms. Accordingly, in Experiment 2 we tested whether lexical biases with inflected stems would still be present without any exposure to the past tense in training. The past tense generation task was changed to present participle generation, which should still achieve our initial goal of encouraging participants to treat these novel forms as regular English verbs. If the results of Experiment 1 were due to the phonological activation of the past tense form in training, then the effect should no longer be found. Alternatively, if simply generating a new verb representation is crucial, then the generalisation of the Ganong effect to the past tense form should still be found.

A further change in Experiment 2 was the degrading of stimuli at test through the addition of noise. While the Ganong effect is well replicated (Burton & Blumstein, 1995; Connine et al., 1987; Fox, 1984; Ganong, 1980; Miller & Dexter, 1988; Pitt, 1995; Pitt & Samuel, 1993), it has been argued that some kind of stimulus degradation is necessary to obtain it reliably (Burton & Blumstein, 1995; Burton et al., 1989), with several studies indicating that the addition of noise to word–nonword continua typically intensifies lexical effects (Burton & Blumstein, 1995; McQueen, 1991; Pitt & Samuel, 1993). Given this fact, the effects of stimulus degradation on lexical biases for inflected and uninflected novel words was examined in Experiment 2. In particular, we considered the addition of noise might allow a greater chance to find lexical effects in the LRTE analysis immediately after familiarisation.

Experiment 2

Method

Participants

Participants were 90 undergraduate students from the University of York, who were either paid or received course credit for their participation, and had not participated in Experiment 1. Forty-four people took part in the immediate condition, and 46 in the delayed condition. All were native speakers of British English and had no reported hearing or learning difficulties.

Design and stimulus construction

The experiment was procedurally identical to Experiment 1 except for two differences. Firstly, in both blocks of the tense generation task participants had to form the present participle instead of the past tense. For example, they would need to write down "*confalling*" when exposed to *confal*, whereas in Experiment 1 they would have responded "*confalled*". The second difference was the addition of noise to the stimuli in the phonetic categorisation test phase. We adopted a degradation procedure similar to that of Burton and Blumstein (1995), who embedded their stimuli in noise of an equal duration to the word or nonword. Pink noise, also known as 1/*f* noise, with equal energy at each octave band, was chosen because spectrally it resembles natural speech and is comfortable to listen to. The noise was generated using Adobe Audition software. The SNR was defined relative to the mean RMS power of the burst continuum in each case, consequently the SNR across the rest of the stimulus varied within each token and across tokens. Based on a pilot study, a −3 dB SNR was chosen because it achieved the desired end of increasing ambiguity of the continuum steps while leaving them distinguishable from one another.

Results

For the phonetic categorisation data, the embedding of stimuli in noise meant that responding was no longer unambiguous at the endpoints, particularly at the /t/ endpoint. Consequently, the exclusion criteria used in Experiment 1 were not applicable here. Instead participants' data were removed if they were unable to identify the unambiguous /t/ tokens more than 50% of the time. This led to the removal of the data of three participants. An additional three participants' data were excluded due to data recording errors, and three participants from the delayed test group did not return a week later. This left a total of 81 participants: 42 in the immediate test group, and 39 in the delayed test group. Time-outs, pre-burst responses, and responses made faster than 100 ms from the onset of the burst were excluded (around 1% of the data).

Analysis of performance in learning phase

Participants' responses in the present participle generation test showed high accuracy and better performance than in Experiment 1, with 95% accuracy overall. In the recognition memory test, performance again was very high (immediate: 93.8%; delayed: 95%) and well above what might be expected by chance (immediate: $t(41) = 37$, $p < .001$; delayed: $t(38) = 46.2$, $p < .001$). Again, this indicates the training regime in Experiment 2 was enough to leave phonological traces sufficient for recognition of novel forms.

Lexical identification shift analysis

Lexical identification shifts (LISs) were calculated in the same way as the previous experiment. Analysis was conducted with the same mixed-effects logistic regression model as in Experiment 1, using predictors of condition (whole word, stem and nonword), the ambiguous regions of the step continuum (five levels), and reaction time range (fast, medium and slow responses). The resulting lexical shifts are shown in Fig. 2.

Immediate test condition. The mixed-effects model revealed no evidence for an overall LIS for the whole word or stem condition, or difference between them ($z < 1$). As before, there were highly significant effects of step ($b = -1.12$; $SE = .083$; $z = -13.60$, $p < .001$), and RT range.

Delayed test condition. Unlike the immediate test condition, a LIS was found for whole words ($b = .26$; $SE = .06$; $z = 3.96$, $p < .001$), and a significant difference found between whole words and the stem condition ($b = -.20$; $SE = .06$; $z = -3.19$, $p < .01$). There was no significant LIS found for the stem condition ($z < 1$). There were also highly significant effects of step ($b = -1.11$; $SE = .06$; $z = -17.45$, $p < .001$), and RT range.

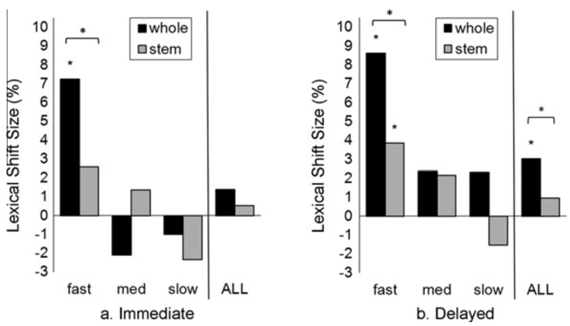

Fig. 2. Lexical identification shifts for whole words and stem conditions, compared with the nonword condition (i.e. no exposure prior to categorisation phase) for (a) immediate and (b) delayed test conditions in Experiment 2, across RT ranges and overall (far right). Asterisks indicate significance at the $p < .05$ level.

RT range analysis

Again we ranked and split each participant's RTs into three equal portions of fast (immediate range = 112–960 ms, $M = 500$ ms; delayed range = 101–937 ms, $M = 530$ ms), medium (immediate range = 418–1370 ms, $M = 703$ ms; delayed range = 325–1470 ms, $M = 741$ ms) and slow reactions times (immediate range = 586–3330 ms, $M = 1180$ ms; delayed range = 432–3450 ms, $M = 1230$ ms).

Immediate test condition. While lexical biases were not significant when aggregated across all RT ranges, like Experiment 1, responses in the fast RT range showed a highly significant LIS for whole words ($b = .46$; $SE = .13$; $z = 3.43$, $p < .001$), and a difference between whole words and stems ($b = -.35$; $SE = .13$; $z = 2.55$, $p = .01$), while there was no LIS for stems ($z < 1$). There was no significant LIS in the medium and slow RT ranges (all $z < 1$).

Delayed test condition. In the fast RT range, there was a significant LIS found for whole words ($b = .87$; $SE = .16$; $z = 6.14$, $p < .001$). There was also a significant LIS for the stem condition ($b = .40$; $SE = .14$; $z = 2.76$, $p < .01$), and significantly more /d/ responses for whole words compared with the stem condition ($b = .21$; $SE = .06$; $z = 3.13$, $p < .01$). There were no significant effects for the medium and slow reaction times (all $z < 1$).

Lexical reaction time effect (LRTE) analysis

Table 2 shows mean RTs separated by response in each of the conditions across both test time points. While the interaction across response type and all three word types was not significant ($F1 < 1.4$; $F2 < 1$), immediately after training, a paired t-test for the whole word condition comparing mean RT differences between /d/ and /t/ responses revealed a significant LRTE by-participants and marginally significant by-items (57 ms, by-participants $t(41) = 3.56$, $p < .001$; by-items $t(15) = 1.84$, $p = .084$) but no significant LRTE in the stem condition (30 ms; p's > .14), or for the nonword items (25 ms; p's > .15).

A week later, again while there was no overall significant interaction between response and word type (p's > .14), a significant LRTE was found for whole words (65 ms, by-participants $t(38) = 2.83$, $p < .01$; by-items $t(15) = 2.47$, $p = .026$), and for the stem condition (74 ms, by-participants $t(38) = 4.23$, $p < .001$; by-items $t(15) = 3.31$, $p < .001$), with no significant LRTE for the nonwords (29 ms; p's > .2). These LRTEs suggest that lexical represen-

Table 2
Lexical reaction time effects in milliseconds at endpoints for immediate and delayed test points in Experiment 2. Brackets indicate standard deviations.

	Immediate		Delayed	
	/d/	/t/	/d/	/t/
Whole word	699 (168)	756 (147)	745 (180)	810 (173)
Stem	726 (159)	756 (176)	760 (171)	833 (173)
Nonword	762 (172)	787 (185)	814 (195)	843 (158)

tations were immediately available to facilitate responding consistent with the learnt full form but not inflectional variants. A week later responses consistent with both morphologically simple and complex forms were facilitated.

Discussion

Experiment 2 again demonstrated lexical effects on the processing of ambiguous phonemes. A similar pattern to Experiment 1 was found, with a lexical bias when participants had been exposed to /d/ final novel verbs in training, and a weaker lexical bias when the test stimuli were verb stems that potentially could be inflected to become a /d/-final form. In the case of novel inflections of recently learned stems, categorisation biases only showed up in the fast reaction time range after a week. We also found a broadly similar pattern of findings in reaction time data when categorisation was made at the unambiguous ends of the continuum. A week after learning, speed of responses was influenced by whether the target phoneme was compatible with an inflected or uninflected form of a learned novel word. In contrast to Experiment 1, we also found a lexical influence on speed of word-consistent responses immediately, but only for those items where a /d/ final form was heard at training.

Experiment 2 changed the past tense generation task used in Experiment 1 to a present participle generation task. Although the lexical bias for inflected stems appeared weaker compared with Experiment 1, there was still evidence for the inflected stems showing lexical effects after a week in categorisation with responses made in the fast reaction time range, and through faster lexically consistent responses. This means we cannot attribute the effects found with inflected stems in Experiment 1 as solely due to the activation of the /d/ final past tense form in the tense generation task. Experiment 2 shows that a lexical bias consistent with a regularly inflected past tense form can be demonstrated just by explicitly asking participants to treat the novel words as verbs (without any training on their past tense forms), given enough time for consolidation. It remains a possibility that we could have found lexical effects with the past tense forms without encouraging participants to treat these words as verbs during training.

The other manipulation introduced in Experiment 2 was the use of degraded stimuli at test, with the aim of boosting lexical effects. In comparing Experiment 1 and Experiment 2, there does not appear to be stronger lexical categorisation effects with the addition of noise, despite our expectations. In actual fact, the lexical effects in the immediate test condition of Experiment 2 appeared weaker than Experiment 1, though paradoxically, we found an LRTE effect for the whole word condition immediately in Experiment 2 but not in Experiment 1. Why did the manipulation not have the intended effect on categorisation? The overall mean /d/ responses across steps in Experiment 1 was 49%, whereas it was 64% in Experiment 2. One explanation for this strong /d/ bias in Experiment 2 is that the noise could have made the burst harder to detect, which could have biased listeners to think that the closure duration was shorter, leading to the greater proportion of /d/ responses. Since we expected our lexical effects on phonetic categorisation to show up in the ambiguous region, a /d/ bias would have shifted participants' categorisation functions towards the /d/ end of the continuum, leading to less ambiguity overall, and hence less opportunity for lexical effects to exert themselves.

Comparison across experiments

The findings across all four sub-experiments displayed some common patterns. The general trend was for lexical shifts in categorisation for both the whole word and stem conditions, with larger shifts for the whole word compared with the stem condition, and for effects to be larger or only present in fast reaction times. In LRTE analyses, we found that lexicalisation tended to facilitate responses to endpoint stimuli that were consistent with the newly learned words, and these effects tended to be stronger or only present after a week. In order to help understand and qualify the general patterns across experiments, we conducted a combined analysis. We were particularly interested in three questions:

(1) Are lexical effects in the whole word and stem conditions reliable across time points?
(2) Does the strength of lexical effects change across the course of a week?
(3) Are lexical effects stronger in the whole word condition compared with the stem condition?

Lexical identification shift analysis

All data were entered into a mixed-effects logistic regression with delay of test and Experiment 1 vs. Experiment 2 as between participants factors, entered as interaction terms with the three novel word conditions (whole, stem or nonword). We again used the five mid-range of ambiguous steps as predictors. Due to our consistent findings of a Ganong effect only (or much stronger) in the fast RT range, and the increased power afforded by collapsing across experiments, we restricted our analysis to just fast reaction time responses. A significant LIS was found overall for whole words ($b = .68$, $SE = .08$, $z = 8.57$, $p < .001$) and for the stem condition ($b = .29$, $SE = .07$, $z = 3.80$, $p < .001$). There was also a significantly stronger /d/ bias for whole words compared with inflected stems ($b = .45$, $SE = .15$, $z = 3.01$, $p < .001$). There were no significant interactions with time of test and addition of noise/tense generation and experiment condition ($z < 1$), except for an interaction of the whole word condition with time of test ($b = .16$, $SE = .07$, $z = 2.03$, $p = .043$). This interaction highlights a small increase in the size of the LIS for whole words between immediate test (8.3%) and a week later (9.4%), consistent with an effect of consolidation.

These results indicate word-final ambiguous phonemes in fictitious novel sequences such as *confal?* were categorised as /d/ slightly more after a week from learning compared with straight after learning. However, time of test made no significant difference to the size of the categorisation shift following exposure to the stem form *confal*. For both whole words and inflected stems, the size of the lexical shift did not differ depending on whether participants performed past tense generation with undegraded stimuli (Experiment 1) or performed present participle generation with degraded stimuli (Experiment 2).

While not directly relevant to our research questions, it should be noted that there was a significant main effect of time of test ($b = .60$; $SE = .15$; $z = 5.91$, $p < .001$), reflecting the greater percentage of /d/-responses given after a week (65%) compared with no delay (51%). This difference is attributed to an adaptation effect following testing immediately after exposure, whereby the proximity of exposure to many /d/-final forms in familiarisation biased categorisation immediately compared with a week later, causing a voiceless shift in the perception of the /d/-/t/ continuum in phonetic categorisation (cf. Eimas & Corbit, 1973; Samuel, 2001). Given an overall lexical bias towards /d/ responses, possible adaptation was not strong enough to shift categorisation towards to more /t/ responses overall, but it would explain the reduction in /d/ responses compared with a week later. There was also a significant bias in /d/ responses comparing the two experiments ($b = 1.55$; $SE = .22$; $z = 7.11$, $p < .001$), with more /d/ responses in Experiment 2 (69%) than Experiment 1 (46%), as discussed in the last paragraph of the preceding section.

Lexical reaction time effect (LRTE) analysis

An ANOVA on RTs at the endpoints was conducted with the variables word type (whole word vs. stem vs. nonwords), response type (/d/ vs. /t/), test time, and experiment. Along with a bias for faster word-consistent responses overall, $F1(1, 148) = 16.78$, $p < .001$, $F2(1, 15) = 12.8$, $p < .01$, we found a significant interaction between time of test and response type, $F1(1, 148) = 6.92$, $p = .039$, $F2(1, 15) = 58.13$, $p < .001$. This is consistent with an effect of consolidation strengthening lexical representations over time, as across all endpoint responses we found that RTs for /d/ responses were 4 ms slower than /t/ responses immediately after exposure, but were 35 ms quicker after a week. Responses were slower overall in Experiment 2, $F1(1, 148) = 22.52$, $p < .001$, $F2(1, 15) = 296.29$, $p < .001$, as would be expected given the addition of noise making discrimination more difficult.

Separate ANOVAs for each of the word types were conducted to explore consolidation effects on RT. For whole words, there was a significant RT advantage for /d/ responses, $F1(1, 148) = 25.56$, $p < .001$, $F2(1, 15) = 19.26$, $p < .001$ and an interaction with response and time of test, $F1(1, 148) = 4.32$, $p = .041$, $F2(1, 15) = 37.41$, $p < .001$. For stems, there was again a significant RT advantage for /d/ responses, $F1(1, 148) = 14.06$, $p < .001$, $F2(1, 15) = 5.88$, $p = .028$, and an interaction with response and time of test, $F1(1, 148) = 4.26$, $p = .039$, $F2(1, 15) = 35.79$, $p < .001$. In the case of whole words, word-consistent responses were 29 ms quicker than nonword-consistent responses immediately, and 66 ms quicker a week later. In the stem condition, there was only a 9 ms difference immediately, but a 59 ms difference a week later. There was no effect of response by-participants or by-items. The test time interaction for nonwords was not significant by-participants but was by-items, $F2(1, 15) = 55.85$, $p < .001$, which we attribute to a sizable reverse LRTE effect in the immediate condition of Experiment 1. In order to assess the magnitude of any differences between whole words and stems, we conducted an ANOVA with just whole words and stems, which indicated that the size of the LRTE was larger for the whole word (28 ms overall) compared with the stem condition (18 ms overall), $F1(1, 148) = 25.77$, $p < .001$, $F2(1, 15) = 12.80$, $p < .001$.

In summary and in answer to the three questions raised above, the combined analysis found reliable evidence across experiments for a lexical bias in categorisation and RTs (1), evidence for an effect of consolidation in RTs and in categorisation biases (2), and larger effects for whole words compared with stems for categorisation and for RTs (3).

General discussion

In these experiments we found that repeated exposure to novel phonological forms influenced phonetic categorisation consistent with whole word and inflected stem forms. Lexical influences were strongest in fast reaction times, and were found in reaction times at the boundary where phonetic information was clearest. Both these patterns of data have been previously found in Ganong studies using final ambiguous phonemes of existing words (McQueen, 1991; Pitt & Samuel, 1993). Lexical effects on categorisation were observed immediately and a week after familiarisation. Across time points, the categorisation bias was larger for the whole word forms than for the inflected stem forms, consistent with the finding that past tense verbs such as *agreed* elicit a lexical effect that is smaller than uninflected verbs such as *succeed* (Sedin, 2006). While we found lexical effects on categorisation immediately, we also found evidence that consolidation over a week has the effect of strengthening lexical representations. The consolidation effect on categorisation bias was relatively minor, but in the reaction time data there was a clear effect of time of testing. Immediate lexical effects on response time were relatively small for morphologically simple verbs and absent for inflected verbs, but these effects were robust for both types after a week. Taken together, these findings suggest that certain aspects of the lexical behaviour of a novel word manifest very soon after exposure: namely, the storage of a novel form representation, its use in the disambiguation of phonemes in subsequent encounters of that form, and its engagement with inflectional morphology. On the other hand, more subtle aspects of lexical behaviour that rely on swift facilitation of processing only fully emerge after a delay.

In his study of Ganong effects for novel words, Pitt (2009) tested phonetic categorisation only after a week. Even then, a lexical bias with reduced forms was only found when those forms were explicitly associated with the citation forms before testing. This is in contrast with our finding of lexical biases for the stem condition, where participants learnt forms such as *confal* but were tested on *confald*. In Experiment 2, all that was necessary for lexical effects with these forms was treating the novel forms as a verb during familiarisation, and therefore, by implication, capable of being inflected with the regular past tense. It was not necessary for participants to hear or associate the novel form with the past tense in order to elicit the effect. The results of Snoeren et al. (2009) also differ from Pitt's, in that explicitly linking the assimilated form to the learnt canonical form was not found necessary to elicit lexically driven compensation. This may be a consequence of the strength of the various generalisations involved. The /t/ deletion phenomenon in Pitt's study is more of an optional form of variation, dependent on the speaker and speaking style, while place assimilation is more strongly conditioned by its segmental context, and correspondingly, the unassimilated and assimilated forms are more easily linked. In our case, past tense inflection is an extremely common and largely regular generalisation and is presumably an integral and obligatory part of lexical representation for regular verbs in English. As a consequence, the past tense form does not need to be explicitly linked to the stem during exposure.

Previous studies have shown that some lexical behaviours, such as participation in lexical competition (Bowers et al., 2005; Dumay & Gaskell, 2007) and semantic interference in naming (Clay, Bowers, Davis, & Hanley, 2007), occur only following a period of consolidation, which may be related to the presence of sleep (Dumay & Gaskell, 2007; Tamminen et al., 2010). The current findings show that the phonological representations behave lexically very soon after exposure, in at least some respects. The presence of immediate lexical-like behaviour is consistent with immediate influences on compensation for co-articulation (Snoeren et al.) and that novel words are able to alter the perceptual learning of phoneme boundaries immediately after learning (Leach & Samuel, 2007). Leach and Samuel described the ability of a novel word to show different patterns of behaviour at different time points by making a distinction between lexical configuration and lexical engagement. Lexical configuration refers to the process of learning about aspects of a word, such as a representation of its phonological form and its syntactic category. Lexical engagement refers to the ability of a word to interact with other lexical and sublexical representations. This distinction fits well with connectionist complementary learning systems models of memory which posit separate processes for learning encapsulated information on the one hand, and overlapping information on the other (e.g., McClelland, McNaughton, & O'Reilly, 1995; O'Reilly & Rudy, 2000). Learning novel forms for recognition is fast because it simply requires the storage of pattern separated representations (e.g., in episodic memory). However, because lexical engagement requires the interleaving of overlapping representations, the full integration of novel forms into a stable pre-existing lexicon necessitates slower learning to guard against catastrophic interference (French, 1999).

In a complementary learning systems model of word learning (Davis & Gaskell, 2009; Lindsay & Gaskell, 2010), the fast form-based acquisition of new words is thought to be reliant upon an episodic hippocampally mediated memory system, and consequently representations are accessed via this route. Representations within this system can support various aspects of lexical behaviour; in the studies reported here, we find these form-based representations are immediately available to support recognition, show a lexical bias in phonetic categorisation, and allow generalisation of existing morpho-syntactic knowledge of the past tense. Below we discuss how these "lexical configurations" could bring about a Ganong effect. However, the immediately available lexical biases shown with the stems in this study appear to be due to lexical engagement. The categorisation of the word-final phoneme in *confal?* as /d/ having only learnt *confal* requires that pre-existing processes of morphological decomposition operate on the learnt form, and as such, involves integration of new and existing information. Finding an effect of lexical engagement immediately is potentially problematic for a dual process account of word learning, as engagement should be expected to emerge only after a period of consolidation, as demonstrated by findings on lexical competition (Dumay & Gaskell, 2007). However, the morphological generalisation we find in our experiments differs from engagement in lexical competition in a number of respects. One difference is that lexical competition requires integration of representations within a single system, whereas morphological generalisation requires combining morpho-syntactic information with lexical representations. A further crucial difference is the need for fast access to lexical representations. Lexical competition in auditory word recognition requires very rapid discrimination between competing lexical candidates as the auditory signal unfolds, which is presumably aided by competing representations being available within the same neocortical system. In contrast, making categorical decisions on ambiguous phonemes may not be such a time critical process. Perhaps then, a defining feature of consolidated representations is that they allow quicker or more direct access to lexical knowledge than is possible when mediated via an episodic hippocampal system. Our pattern of results showing much stronger lexical response time effects after a week supports this line of argument.[1] This is also consistent with other kinds of lexical behaviour in the word learning literature showing delayed effects, principally results on lexical competition (Gaskell & Dumay, 2003), masked semantic priming (Tamminen, 2010), faster detection of assimilated segments (Snoeren et al., 2009), faster naming (Davis et al., 2009), and semantic interference in naming (Clay et al., 2007). In all these cases, the consolidation effect emerges when the system is stressed and required to provide access to lexical knowledge in as short a time as possible.

Turning to the implications of our research for models of morphological processing, the current data provide a new dimension to the debate over how the brain represents morphological knowledge. Whilst we acknowledge that the immediate lexical effects in the stem condition were rather weak (particularly in Experiment 2), evidence for immediate lexical effects found with the inflected stem forms in Experiment 1 and overall in the fast reaction time range are not easily explained by existing connectionist models of past tense representation (e.g.,

[1] This argument, however, is somewhat at odds with our finding of lexical effects primarily in fast reaction times.

McClelland & Patterson, 2002; McClelland & Rumelhart, 1985; Plunkett & Juola, 1999). These models are not able to acquire new mappings in a short space of time and instead require new mappings to be interleaved with existing ones over a protracted period. If novel inflectional decomposition relies on overlapping representations in a single distributed connectionist network, then these models would predict little or no ability to inflect recently learned novel stems, and thus no Ganong effect in the immediate stem condition of our experiments. Insofar as more traditional rule-based accounts (e.g., Pinker & Ullman, 2002) do not rely on shared representations, these models would seem better disposed to deal with the immediate inflectional effects that we find.

Nonetheless, Davis and Gaskell (2009) have argued on independent grounds that connectionist models of language processing need to incorporate a second mechanism that facilitates the acquisition of novel words (cf. McClelland, McNaughton, & O'Reilly, 1995). How connectionist models of morphology might operate in such a framework is hard to predict without detailed simulations, but nonetheless there is a reasonable possibility that such a system would be able to combine novel-word knowledge stored in a hippocampal system with the generalisation ability of the neocortical route in order to recognise inflected forms of novel words. Furthermore, again on independent grounds we have argued that hippocampal information should be subject to a delay compared with neocortical knowledge. This is consistent with the absence of any lexical facilitation of word-consistent response times in the immediate stem condition of our experiments, and the presence of these effects in the delayed condition (presumably after some degree of transfer between hippocampal and neocortical systems). Note though that it is not consistent with the finding that lexical biases, even in the stem condition, are strongest in the fastest responses.

With respect to the mechanism underlying the Ganong effect, the immediate lexical effect in the whole word condition in Experiments 1 and 2 requires no direct interaction with existing morphological or lexical representations and can therefore be explained by fast episodic learning in a complementary systems model. Previous studies have established that ambiguous phonemes tend to be categorised word-consistently (Burton & Blumstein, 1995; Burton et al., 1989; Connine et al., 1987; Fox, 1984; Ganong, 1980; Pitt & Samuel, 1993, 1995), but our study, along with Pitt (2009), shows a lexical effect with novel forms. It is well accepted that the Ganong effect arises through the influence of established lexical input representations on phonetic categorisation, be this via online interaction between phoneme and word representations (e.g., in the TRACE model, McClelland & Elman, 1986) or the result of a decision process biased by the influence of word representations (e.g., in the Merge model, Norris et al., 2000). Here, however, memory traces of a novel form over the space of just 1 h elicited a similar "lexical" effect.

TRACE and Merge (or by implication, the Shortlist model upon which Merge is based) posit a single locus for both lexical competition and the lexical influence on phonetic categorisation. From previous work on lexical competition (e.g., Dumay & Gaskell, 2007; Gaskell & Dumay, 2003) we know that lexical competition effects are not observable soon after learning novel words with phoneme monitoring training, as used here. Thus, as they stand, neither model is sufficient to explain the Ganong effects that we found at the immediate test point. One alternative possibility is that both lexical and fast acquired episodic representations are capable of influencing phonetic categorisation. The Merge account (Norris et al., 2000) explains the Ganong effect in terms of the combination of the contributions of lexical and phonemic activation at a decision stage of processing. An extra source of information – namely newly acquired, perhaps temporary, novel episodic information – could easily be added to these influences to explain the immediate effects found here without arguing that the underlying source of the immediate effects are lexical *per se*.

To add further complexity to the data, Gaskell, Quinlan, Tamminen and Cleland (2008) used a psychological refractory period paradigm to argue that conflicting lexical and phonemic cues to the identity of an ambiguous phoneme are not resolved at a decisional level at a relatively late stage in processing, as Merge would predict. However, this does not mean that people cannot combine separate sources of evidence when making phoneme decisions. Instead, it may be that Merge is correct in its use of a decisional level but incorrect in the application of this decisional level to the integration of lexical and phonemic sources of knowledge. Conceivably the decisional level is more relevant when combining recent episodic knowledge with more stable lexical knowledge. Of course such an account is highly speculative, but there are clear predictions that can be extracted from it. We can predict that lexical effects for newly acquired words would rely on a decisional level (e.g., when applied to the psychological refractory period paradigm) at initial test, but then as consolidation of this new knowledge proceeds the lexical bias becomes more automatic and embedded in the lexical system.

To summarise, in the current study we found that novel phonological forms elicit a lexical influence on subsequent phonetic categorisation both immediately following familiarisation, and after a week, with no further exposure. We attribute this effect to the influence of unconsolidated episodic representations influencing perceptual decisions on phonemes. Furthermore, we found that the novel past tense of learnt forms elicit a smaller but significant lexical effect on subsequent phonetic categorisation, again both immediately and after a week. While the lexical effect in the whole word case can be explained in terms of fast hippocampal learning in a dual process model of memory (McClelland, McNaughton, & O'Reilly, 1995), the stem condition effect is more problematic, and either requires the operation of a past tense rule (e.g., Pinker, 1994) on fast acquired form representations, or allowing fast learning of overlapping representations in certain circumstances. While lexical effects on categorisation were present immediately, we still found clear evidence of the consolidation of novel words over the course of a week, with a lexical bias revealed in quicker reaction times consistent with a lexical response. However the results are explained, they provide a challenge to existing models of learning and morphological representation and provide fuel for further research into the question of how proficient language users acquire novel words.

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A. Appendix

List	Item	Whole word	Foil	Stem	Foil
A	1	CONFALD	tonfald	CONFAL	tonfal
	2	BRANGELD	frangeld	BRANGLE	frangle
	3	BYSAIRD	binaird	BYSAIR	binair
	4	WECTADE	woctade	WECTAY	woctay
	5	FASTELD	nasteld	FASTEL	nastel
	6	INHEND	ikhend	INHEN	ikhen
	7	MONDUIRD	londuird	MONDUIR	londuir
	8	PULPILD	pulpeld	PULPIL	pulpel
	9	MASTRIND	bastrind	MASTRIN	bastrin
	10	NAPKIRD	shapkird	NAPKIR	shapkir
	11	DRAGUDE	drageed	DRAGOO	dragee
	12	KULLOID	kurroid	KULLOY	kurroy
	13	SCRUPERD	scruferd	SCRUPER	scrufer
	14	GOUNDRODE	toundrode	GOUNDRO	toundro
	15	TRIKUDE	trifude	TRIKOO	trifoo
	16	KORMUND	kormuld	KORMUN	kormul
B	17	RAMPALD	mampald	RAMPAL	mampal
	18	LUSTELD	fusteld	LUSTLE	fustle
	19	NARTRAIRD	narkraird	NARTRAIR	narkrair
	20	GADRADE	sadrade	GADRAY	sadray
	21	EPRELD	etreld	EPREL	etrel
	22	TEGGEND	tevend	TEGGEN	teven
	23	ENGUIRD	entuired	ENGUIR	entuir
	24	OSTRILD	osprild	OSTRIL	ospril
	25	HYBRIND	hykrind	HYBRIN	hykrin
	26	SKIRMIRD	shirmird	SKIRMIR	shirmir
	27	ECKUDE	eckoid	ECKOO	eckoy
	28	RILPOID	tilpoid	RILPOY	tilpoy
	29	SLOGERD	slozerd	SLOGER	slozer
	30	KEMBRODE	kemfrode	KEMBRO	kemfro
	31	ULSTUDE	elstood	ULSTOO	elstoo
	32	PRITTUND	primmund	PRITTUN	primmun
C	33	SHAGRALD	shaprald	SHAGRAL	shapral
	34	FACKRELD	nackreld	FACKREL	nackrel
	35	TEMGAIRD	shemgaird	TEMGAIR	shemgair
	36	MOONADE	moolade	MOONAY	moolay
	37	CLARELD	claveld	CLAREL	clavel
	38	ROSHEND	roshind	ROSHEN	roshin
	39	LOCEERD	hoceerd	LOCEER	hoceer
	40	PHONILD	phodild	PHONIL	phodil
	41	LAKRIND	yakrind	LAKRIN	yakrin
	42	CANYIRD	conyird	CANYIR	conyir
	43	PATRUDE	pakrude	PATROO	pakroo

(continued on next page)

A. Appendix (*continued*)

List	Item	Whole word	Foil	Stem	Foil
	44	NOSTROID	bostroid	NOSTROY	bostroy
	45	OPLERD	oglerd	OPLER	ogler
	46	SPECTRODE	spettrode	SPECTRO	spettro
	47	LEGUDE	degude	LEGOO	degoo
	48	CAYSUND	jaysund	CAYSUN	jaysun

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