Activating Verb Semantics from the Regular and Irregular Past Tense.

Catherine E Longworth (cat@csl.psychol.cam.ac.uk)
Billi Randall (bjr22@cam.ac.uk)
Lorraine K Tyler (lktyler@csl.psychol.cam.ac.uk)
Centre for Speech and Language, Dept. Exp. Psychology, Downing Site, Cambridge, CB2 3EB, UK.

William D Marslen-Wilson (william.marslen-wilson@mrc-cbu.cam.ac.uk)
MRC Cognition and Brain Sciences Unit, 15 Chaucer Road, Cambridge, CB2 2EF, UK

Abstract

Theoretical accounts of the processing of inflectional morphology make implicit, untested assumptions about the activation of verb semantics from inflected verbs. This research used semantic priming to investigate the extent to which regular and irregular past tense forms activate verb semantics, in comparison to the verb stem. The results show that past tense forms activate verb semantics to the same extent as verb stems and without differences due to verb regularity. These results provide constraining data for models of inflectional morphology.

Introduction

Research on the mental representation and processing of inflected words has focused on the type of underlying processing system required to account for our ability to produce and comprehend regularly and irregularly inflected words. The English past tense in particular has formed an important test case for such research. It provides a sharp contrast between the productive regular past tense and a limited set of irregular forms. Theoretical accounts divide into those suggesting that all inflected forms, both regular and irregular, are stored using associative memory (e.g. Rumelhart and McClelland, 1986) and those proposing that the predictability of the regular past tense allows us to compute the inflected forms from their verb stems using symbolically based rules (e.g. Pinker, 1991).

Such accounts focus primarily on the processing and representation of the regular and irregular past tense as phonological forms, tending to neglect the important issue of how these forms contact their underlying semantic and syntactic content. Nonetheless, they incorporate assumptions, explicit or implicit, about how these inflected forms map on to their semantics. Pinker has suggested that the regular past tense is not stored in its own right but computed using symbolic rules, whereas the irregular past tense is stored independently of its stem (Pinker, 1991). Comprehension of the regular past tense is assumed to require rule-based decomposition into stem and inflection. This process may delay semantic activation relative to the irregular past tense, which is not assumed to require rule-based processing.

The related account proposed by Marslen-Wilson and Tyler (1998) explicitly postulates that the regular and irregular past tense activate the semantic representations of their verb stems through different routes. The morphophonologically complex regular past tense is parsed into its stem and affix in order to access stem semantics, whereas the irregular past is recognised as a full form, which must subsequently be mapped onto verb semantics assumed to be stored at the level of the lexical entry.

Strict full-listing accounts (Butterworth, 1983) suggest that all past tense forms are stored in memory, with semantic representations presumably stored independently of their verb stems. Activating such representations would not be delayed by rule-based processing, and would not be expected to differ according to morphological complexity or verb regularity.

Parallel-distributed processing models (Joanisse and Seidenberg, 1999; Plunkett and Marchman, 1993; Rumelhart and McClelland, 1986) have assumed that both the regular and irregular past tense activate semantic units associated with their verb stems. In common with strict full-listing accounts, the fact that the regular and irregular past tense have differing degrees of phonological and orthographic similarity to their stems is not assumed to entail differential processing. However, if a mapping is less consistent (as in irregular forms) this may lead to slower or less efficient activation.

It can be seen that although these accounts focus on the consequences of the variable predictability of past tense form from its associated verb stem, they inevitably make theoretical assumptions about the activation of verb semantics from inflected forms as well. Typically one would use semantic priming to test assumptions relating to the organisation of semantic representations or the time course of its activation. However, research using semantic priming has tended to use concrete nouns and/or uninflected verbs. This is because morphologically simple words are assumed to

be the paradigmatic forms associated with semantic information, and semantic priming is thought to reflect either activation spreading between their semantic representations or a reactivation of shared properties of these representations. Morphological priming, on the other hand, uses complex words as primes, targets or both, and is a form of repetition priming. It is thought to reflect the reactivation either of an underlying morpheme (Marslen-Wilson, Tyler, Waksler and Older, 1994) or of shared semantic and form units (Plaut and Gonnerman, 2000), depending on the theoretical account. As such, the task is used to explore lexical representation and access.

What would be expected if verbs in the past tense were used as semantic primes? Ultimately they must contact verb semantics since the presence of verb inflection is a normal part of language comprehension. However, all accounts, except perhaps strict full-listing theories, assume that verbs in the past tense are processed as modified forms of their stems, as inflectional morphology does not change word meaning or form class. The stem is viewed as the most basic form of a verb and assumed to be associated with its semantic representations. Inflected verbs are assumed to be phonological modifications of the verb stem.

So how do these modified forms map on to the verb semantics associated with their stems? How long does this process of mapping take? If semantic priming is the facilitation of responses due to a semantic relationship between morphologically simple words will there be any semantic priming from the past tense at all? Alternatively there might be priming when the modified form maps onto verb semantics, but the delay due to this processing might reduce the degree of facilitation in comparison to that from the verb stem. Perhaps the greater similarity of form between the regular past tense and associated verb stems will speed up mapping onto verb semantics via the stem. This could lead to more semantic priming from the regular past than the irregular.

These questions were addressed by the following experiments using verb stems and their past tense forms as semantic, rather than morphological, primes. The motivation for this research was not to adjudicate between theories postulating one or more processing routes for inflectional morphology. Rather the aim was to provide evidence about the activation of verb semantics from inflected forms, in order to constrain currently untested assumptions implicit in these theories.

Experiment 1: Intramodal auditory semantic priming.

Morphological priming with auditory presentation of both past tense primes and verb stem targets has shown facilitation of lexical decision responses to targets following regular and irregular past tense primes (Marslen-Wilson and Tyler, 1997). It seemed prudent to begin our investigation of semantic priming from the past tense with auditory presentation of both primes and targets.

Rather than simply using regular and irregular past tense forms as semantic primes, a within-item design was selected so that each verb prime would be used in both its stem and past tense form (i.e. both "blame ACCUSE" and "blamed ACCUSE"). This allows us to establish that the uninflected forms are sufficiently semantically related to their targets to cause priming. Also, if the past tense items do prime, this can be measured against the amount of priming from the associated stem, to ascertain the effects of mapping onto verb semantics from an inflected form.

52 regular and 52 irregular verb primes were paired with semantically related verb targets. Semantic relatedness was established empirically by asking participants to rate this on a nine-point scale (1 = extremely unrelated, 9 = extremely related). Separate ratings were collected for stem and past tense forms of each prime. Groups of 15 participants (native speakers of UK English, aged between 18 and 40, with no language disorders) rated the semantic relatedness of either the stem or past tense form of each verb prime paired with its target. Past tense prime-target pairs were rated slightly less related than their associated stem prime-target pairs (mean rating for stems = 7.34, sd .63, mean rating for the past tense = 7.12 sd .73, $F(1,96) = 13.54$, $p < .001$) with no effect of verb regularity.

Unrelated primes (e.g. "laugh ACCUSE" and "laughed ACCUSE") were selected by rotating test primes about their targets whilst maintaining tense and verb regularity. This ensured that there could be no systematic differences between test and control primes in each condition, other than semantic relatedness to targets. The semantic relatedness of control primes and their targets was pretested in the same way as the test primes. Past tense prime-target pairs were again rated as slightly less related than their associated stem prime-target pairs (mean rating for stem controls = 2.39, sd .84, mean rating for past tense controls = 2.07 sd .65, $F(1,96) = 13.16$, $p < .001$) with no effect of verb regularity. Related test primes had a mean rating of 7.23 (sd = .69) and unrelated controls had a mean rating of 2.2 (sd = .75). As our aim was to examine semantic rather than associative priming, all primes were selected to have a low associative strength to their targets.

To ensure that any differences in semantic priming between regular and irregular past tense primes were due to verb regularity we matched primes across verb regularity for semantic relatedness and associative strength to targets, familiarity, imageability, and surface and cumulative frequencies from the Celex Lexical

Database (Baayen, Piepenbroek and Gulikers, 1995). Number of syllables could not be matched, as the regular past tense tends to be longer than the irregular form. Targets were matched across conditions for surface and cumulative frequencies, familiarity, imageability and number of syllables. Since many English verbs can also be used as nouns, we ensured that all primes had higher surface and cumulative frequencies as verbs.

The listener's task was to make a lexical decision to each target, with instructions to respond as quickly and accurately as possible. A range of fillers was selected to ensure that semantic relationships, verbal primes or inflected verb primes could not be used to predict word targets. To this end we used 208 unrelated noun/adjective prime-target pairs, with half the nouns in the plural form and nonwords used for half the targets. We also used 104 verb-nonword pairs with the same proportions of regular and irregular, stem and past tense primes as the test items.

The materials were divided into four versions of the experiment. These were balanced so that all targets appeared once in each version. Each version had the same target preceded by either a semantically related stem or past tense or a control stem or past tense. All versions had 460 trials: 24 practice trials, 20 "warm-up" trials, 52 test trials (13 of each condition), 52 control trials (13 in each condition) and 312 filler trials. Semantically related verb pairs made up 25% of the word targets heard. These were pseudo-randomly distributed throughout the list, with the same order of test and filler items in each of the four versions. There were an equal number of word and nonword targets in each version.

All items were recorded by a female native speaker of English onto DAT tape. They were digitized at a sampling rate of 22kHz, and were played binaurally to the listeners over headphones under the control of DMDX experimental software (Forster and Forster, 1990).

There was a 200 millisecond interval between primes and targets and participants had up to 3 seconds to respond. After responding the next trial followed in 1500 milliseconds. Reaction times were measured from target onset. The experiment lasted approximately 50 minutes in total.

60 participants (native speakers of UK English, aged between 18 and 40, with no language disorders) took part in the experiment. 15 participants were randomly assigned to each version of the experiment.

Results

The data from four participants were discarded because of relatively high error rates and unusual, or variable reaction times. Six items were also removed, four because of experimenter error and two because of high error rates. This left a total of 56 participants and 98 items.

For the analysis of reaction times, all errors (2.5%) and extreme values (0.1%, defined as $\leq 500 \geq 2000$ msec) were removed from the data. Mean reaction times were then calculated over participants and items. These were entered into two analyses of variance on participant (F_1) and item (F_2) means, with the factors of prime type (test or control), verb regularity (regular or irregular), tense (stem or past tense) and version (1-4). Item means are shown in Table 1.

There was a main effect of prime type (F_1 (1,52) = 166.53, $p < .001$; F_2 (1,90) = 91.31, $p < .001$) due to faster reaction times following semantically related (mean RT = 826 msec, sd = 82 msec) compared to unrelated (mean RT = 875 msec, sd = 89 msec) primes.

There was also a main effect of tense (F_1 (1,52) = 14.37, $p < .001$; F_2 (1,90) = 15.69, $p < .001$) with reaction times following past tense items (mean RT = 857 msec, sd = 87 msec) being slower than those following verb stems (mean RT = 843 msec, sd = 90 msec). There was no main effect of verb regularity. There were no interactions between priming, tense and regularity. Planned comparisons confirmed that there was significant priming for every condition.

Discussion

This first experiment found that past tense primes significantly facilitated lexical decision responses to semantically related targets. With auditory presentation these inflected words were able to map onto their verb semantics sufficiently strongly and quickly to prime responses to related words presented 200 milliseconds later. Not only did the related past tense items facilitate responses but the main effect of priming and the absence of any interaction between priming and tense shows that they primed as much as their associated stems. This is surprising as semantic priming is

Table 1 Mean item reaction times and standard deviations for intramodal semantic priming.

	STEM PRIMES			PAST TENSE PRIMES		
	Test	Control	Diff	Test	Control	Diff
REGULAR	818 (82)	872 (85)	54 ***	840 (74)	883 (82)	43 ***
IRREGULAR	815 (86)	868 (94)	53 ***	830 (85)	876 (95)	46 ***

*** $p < .001$

generally thought to reflect semantic relationships between basic lexical forms. As the past tense is an inflected, or modified, form of its verb stem one might not have expected both to prime equally, especially as past tense prime-target pairs had been rated as being less related than their associated stem prime-target pairs in pretests.

The phonological form of the regular past tense is nearly identical to that of its stem so perhaps it is more predictable that this could map onto verb semantics as quickly as its stem. However, the phonology of words in the irregular past tense is less similar to their verb stems than the regular past tense, so we might have expected these to prime less. The lack of a significant interaction between priming, tense and regularity shows that this was not the case. Both the regular and irregular past tense primed as much as their stems and as much as each other.

There are several possible interpretations of these findings. If inflected verbs need to map on to the stem to activate verb semantics this mapping may occur so quickly and effectively that it does not interfere with priming. The degree of phonological similarity to the stem does not seem to affect the efficiency of this mapping. The irregular past tense has less phonological similarity to associated stems than the regular past tense yet this does not delay access to verb semantics. If the regular and irregular past tense are processed differently this does not seem to have consequences for semantic activation as measured in this experiment.

Another alternative is that inflected verbs do not need to map on to the stem in order to activate verb semantics. All forms might be equally associated with verb semantics. However, if the stem is not the most basic form associated with verb semantics, why should past tense inflections have led to slower responses? It is not the case that there was no effect of words being inflected in this experiment, just that this did not interact with semantic priming.

To summarize, this experiment found that past tense inflection, whether regular or irregular, did not affect semantic priming, although it did increase response latencies to targets.

Experiment 2: Cross-modal semantic priming.

It is already established that intramodal presentation of the regular and irregular past tense facilitates responses to associated verb stems (Marslen-Wilson and Tyler, 1997) and Experiment 1 established that they also facilitate responses to semantically related verbs. However, when primes and targets are presented in different modalities the irregular past tense no longer facilitates responses to associated stems (Marslen-Wilson, Hare and Older, 1993). This contrasts with the regular past tense, which continues to show morphological priming. As modality seems to affect morphological priming from the irregular past tense the second experiment tested whether it also affects semantic priming.

Cross-modal presentation also allows us to probe semantic activation earlier in its time course. The first experiment might have failed to detect effects of tense or verb regularity on semantic activation if these had dissipated in the 200 millisecond inter-stimulus interval between the prime and target. In addition, reducing available processing time allows us to assess whether the tense effect found in the first experiment reflected the impact of inflected words on initial semantic activation or a possible post-lexical effect arising in the interval between hearing primes and responding to targets.

The second experiment used the design and materials from Experiment 1 but this time a visual target presented for 500 milliseconds followed the immediate offset of the auditory prime. Reaction times were recorded from target onset as before. 51 participants took part (native speakers of UK English, aged between 18 and 40, with no language disorders). 12 to 14 participants were randomly assigned to each version of the experiment.

Results

The data from four participants were discarded due to unusual and/or variable reaction times. The items involving 5 target words were also removed because of high error rates. This left a total of 47 participants and 99 test items.

For the analysis of reaction times, all errors (2%) and extreme values (0.1%, defined as ≥ 1350 msec) were removed from the data. Mean reaction times were then calculated over participants and items. These were

Table 2 Mean item reaction times and standard deviations for cross-modal semantic priming.

	STEM PRIMES			PAST TENSE PRIMES		
	Test	Control	Diff	Test	Control	Diff
REGULAR	516 (51)	525 (54)	9	511 (46)	538 (63)	27 ***
IRREGULAR	517 (50)	536 (60)	19 **	512 (44)	531 (59)	19 *

* p < .05, ** p < .01, *** p < .001

entered into two analyses of variance on participant (F_1) and item (F_2) means, with the same factors as experiment 1. Item means are shown in Table 2.

There was a main effect of prime type (F_1 (1,43) = 28.62, $p < .001$; F_2 (1,91) = 24.59, $p < .001$), due to faster reaction times following related (mean RT = 514 msec, sd = 48 msec) compared to unrelated (mean RT = 532 msec, sd = 59 msec) primes. There were no main effects of verb tense or regularity and no interactions between priming, tense and regularity.

Planned comparisons on item means in individual conditions indicated that regular stems did not prime significantly (t (48) = -1.23, p = .225) due to an unexplained interaction between priming and version (F_2 (3,45) = 6.49, $p <.001$). One version showed reduced latencies following semantically unrelated regular stems. The remaining three versions showed a significant effect of priming (F_2 (1,33) = 9.62, p = .004) and no interaction with version (F_2 (2,33) = 2.39, p = .107) with semantically related regular stems (RT = 510 msec) facilitating responses by 21 msec relative to unrelated regular stems (RT = 531 msec). All other conditions produced significant priming across all four versions.

Discussion

This experiment confirmed the main effect of priming, with semantically related primes facilitating responses to targets as before. Priming did not interact with tense or verb regularity. The amount of priming shown by regular stems is smaller than the other conditions when all four versions are analyzed. The main effect of priming, however, indicates that regular stem priming is not significantly different to other conditions when version-related variance is partialled out.

Past tense primes facilitated semantically related targets despite cross-modal presentation and reduced processing time. As the irregular past tense fails to act as a morphological prime under these conditions, one might have expected to see an interaction between prime, tense and verb regularity, such that the irregular past tense failed to prime despite priming in all other conditions. This was not found. Again there seem to be no consequences for semantic activation, as indexed by semantic priming, of words being inflected or having different degrees of phonological similarity to their stems.

In addition, the lack of a tense effect, when processing time is reduced, suggests that the effect found in the earlier experiment did not reflect the impact of inflected words on initial semantic activation but a post-lexical effect arising in the interval between hearing primes and responding to targets. This might be a consequence of the irrelevance of the past tense inflection to the subsequent stem target.

Thus in this second experiment, once processing time was reduced, there was no effect of words having past tense inflections on semantic activation. This suggests that all forms of a verb access its semantic representations equally rapidly.

General discussion.

Research on the English past tense has concentrated on issues relating to phonological or orthographic form. A central question has been whether the predictable similarity in form between verb stems and the regular past tense engages specialized rule-based processes to compute the past tense rather than storing it in full. However, theoretical models answering this question have made implicit, largely untested assumptions about the activation of verb semantics from verbs in the past tense.

Most models assume that verbs in the past tense access the same semantic representations as their verb stems and are processed as modified forms of their verb stems. We assume that the form, not the semantics, of the verb is modified as a result of syntactic constraints. These assumptions lead us to expect some effect of this modification of form on the activation of verb semantics. Single route accounts suggest that inflected words will have patterns of phonological activation that are highly similar, but not identical, to those of their stems. Dual route accounts suggest that inflected words must map onto underlying morphemic representations, accessed via the verb stem. Therefore, we might expect not to see semantic priming from inflected forms, or to see reduced priming reflecting the time taken to map onto semantics via the verb stem. However, both the experiments reported here show that this is not the case. Activation of verb semantics did not show any effects of verb inflection. The only consequence of verbs being inflected, i.e. the increase in response latencies to auditory targets following past tense primes, did not interact with semantic priming and appeared to be a post-lexical integration effect, as it was not present when processing time was reduced in the second experiment.

It is also commonly assumed that the amount and predictability of phonological similarity between stems and past tense, which is greater in the regular past tense, will have processing consequences, and might even engage different types of processing. The results reported here, however, suggest that these factors have no effect on the activation of verb semantics in comprehension.

Thus both stem and past tense, regular and irregular verb primes all accessed verb semantics equally in the same time frame. Activation of verb semantics seems insensitive to morphological complexity and inflectional regularity. The surprising aspect of this is

that verb stems are assumed to be the most basic form of verbs and processing of the regular and irregular past tense has been found to dissociate in development (Berko, 1958) and to doubly dissociate following neurological damage (Marslen-Wilson and Tyler, 1997; Tyler, deMornay-Davis, Anokinah, Longworth, Randall, & Marslen-Wilson, in press; Ullman, Corkin, Coppola, Hicock, Growdon, Koroshetz, and Pinker, 1997).

In particular these results might seem surprising given the dissociations between processing the regular and irregular past tense even in the normal adult. Both the regular and irregular past tense act as morphological primes when presented intramodally but with cross-modal presentation the irregular past tense no longer primes stem targets (Marslen-Wilson, Hare and Older, 1993). However, the current results show that the irregular past tense does facilitate responses to semantically related verbs, both cross-modally and intra-modally. This is consistent with the complete equivalence of regular and irregular forms in terms of their linguistic and communicative function.

In summary, these experiments suggest that past tense forms activate the same semantic representations as their stems, priming related words to the same extent. There is no evidence that morphophonological processing delays semantic activation. There was no reduction in semantic priming to suggest a processing cost for inflected verbs and no regularity differences to suggest that degree of phonological modification affects the time course of access to semantics. This suggests a lexical architecture permitting either direct mapping of all verb forms onto semantics, or the mapping of all verb forms, regular and irregular, stem and past tense, onto an abstract root morpheme providing access to semantics. If, on either view, separate processing routes are indeed involved in the perceptual analysis of regular and irregular forms, then they deliver their output to higher-order interpretive systems with essentially the same time-course. Theoretical models explaining the processing of the regular and irregular past tense therefore need to bear in mind that access to verb semantics seems to be insensitive to both morphological complexity and inflectional regularity.

Acknowledgements

This research was supported by an MRC post-graduate research studentship (number G78/6297), and an MRC programme grant to LKT.

References

Baayen, R. H., Piepenbroek, R. and Gulikers, L. (1995) The CELEX Lexical Database (CD-ROM). Linguistic Data Consortium, University of Pennsylvania, Philadelphia, PA.

Berko, J. (1958) The child's learning of English morphology. *Word, 140*, 150-177.

Butterworth B. (1983) Lexical Representation. In B. Butterworth (ed.) *Language Production volume 2: Development, writing and other language processes.* Academic Press.

Coltheart, M. (1981) MRC Psycholinguistic Database. *Quarterly Journal of Experimental Psychology*, *33A*, 497-505.

Forster, K.I., and Forster, J.C. (1990) The DMASTR display system for mental chronometry. Tucson, Arizona: University of Arizona.

Joanisse, M.F., and Seidenberg, M.S. (1999) Impairments in Verb Morphology Following Brain Injury: A Connectionist Model. *Proceedings of the National Academy of Sciences, USA. 96*,7592-7597.

Marslen-Wilson, W.D., Hare, M. and Older, L. (1993). Inflectional morphology and phonological regularity in the English mental lexicon. In Proceedings of the 15th Annual Conference of the Cognitive Science Society. London.

Marslen-Wilson, W.D., Tyler, L.K., Waksler, R. and Older, L. (1994) Morphology and meaning in the English mental lexicon. *Psych. Rev. 101 (1),* 3-33.

Marslen-Wilson, W.D., and Tyler, L.K. (1997) Dissociating types of mental computation. *Nature, 387,*592-594.

Marslen-Wilson, W.D., and Tyler, L.K. (1998) Rules, representations and the English past tense. *Trends in Cognitive Sciences, 2 (11),*428-435.

Pinker, S. (1991) Rules of Language. *Science, 253,* 530-535.

Plaut, D.C., and Gonnerman, L.M. (2000) Are non-semantic morphological effects incompatible with a distributed connectionist approach to lexical processing? *Lang. Cognitive Proc. 15 (4-5),* 445-485.

Plunkett, K., and Marchmann, V. (1993) From rote learning to system building: acquiring verb morphology in children and connectionist nets. *Cognition, 48,* 21-69.

Rumelhart, D., and McClelland, J. (1986) On learning the past tense of English verbs. In McClelland, J.L., Rumelhart, D.E., and the PDP Research Group, (Eds.) *Parallel Distributed Processing: Explorations in the Microstructure of Cognition, Vol.2. Psychological and Biological Models*), MIT Press.

Tyler, L.K., deMornay-Davies, P., Anokhina, R.A., Longworth, C.E., Randall, B., & Marslen-Wilson, W. D. (in press) Dissociations in processing past tense morphology: Neuropathology and behavioral studies. *Journal of Cognitive Neuroscience*.

Ullman, M.T., Corkin S., Coppola M., Hicock, G., Growdon, J.H., Koroshetz, W.J., and Pinker, S. (1997) A neural dissociation within language: evidence that the mental dictionary is part of declarative memory, and that grammatical rules are processed by the procedural system. *Journal of Cognitive Neuroscience, 9,* 266-276.