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Automatic semantic activation of embedded words: Is there a "hat" in "that"?[☆]

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Abstract

Participants semantically categorized target words that contain subsets (Experiment 1; e.g., target = *hatch*, subset = *hat*) or that are parts of supersets (Experiment 2; e.g., target = *bee*, superset = *beer*). In both experiments, the targets were categorized in a congruent condition (in which the subset–superset was associated with the same response, e.g., Does *hat*ch refer to a human body part?) and an incongruent condition (in which the subset–superset was associated with a conflicting response, e.g., Does *hat*ch refer to a piece of clothing?). Responses were slower and less accurate in the incongruent conditions, suggesting that subsets and supersets were processed to the level of meaning. Congruency effects occurred regardless of the position of the subset or superset (e.g., *hat*ch, d*ram*a, h*owl*), and in Experiment 1, were obtained for subsets that maintained (e.g., *car*d) and changed their pronunciation (e.g., *crow*n). Congruency effects were only found when the subsets were of higher frequency than the target. The implications for theories of word identification are discussed.

Keywords: Embedded; Cascaded; Word identification; Subset; Superset

All languages are characterized by extensive lexical embedding. That is, s horter words are often embedded within longer words (e.g., "seat" in the spoken word "conceit," or *crow* in the written word *crown*). Despite the prevalence of embeddedness, relatively few studies have considered its impact on word identification, and the majority of these have been carried out in the auditory domain. Indeed, within the visual domain, only a handful of studies have sought to test whether reading a word like *e.g., clamp* results in automatic activation of its embedded subsets (i.e., *clam* and *lamp*), and even fewer studies have assessed whether reading a target like *clam* results in the automatic activation of its supersets (e.g., *clamp*). This is somewhat surprising given the large number of studies that have examined the effect of orthographic neighbours on word identification, which are formed by the substitution of a single letter (e.g., *dare* is an orthographic neighbour of *care*).

Word neighbours play an important role in many models of visual word recognition. For example,

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according to the interactive activation model of McClelland and Rumelhart (1981), processing of the word *lamp* should automatically result in the partial activation of the high frequency word *camp*. Under some circumstances, activation of this neighbour can impair recognition relative to words like *urge* that have no higher frequency neighbours; under other circumstances, automatic activation of neighbours can facilitate identification (for discussion of the conditions in which facilitation and inhibition occur in network models, see Davis, 2003). Grainger and colleagues have reported evidence supporting this prediction in experiments with French and Spanish stimuli, with impaired identification of words with higher frequency neighbours (e.g., Carreiras, Perea, & Grainger, 1997; Grainger, O'Regan, Jacobs, & Segui, 1989). Corresponding experiments with English language materials have provided mixed evidence on this issue, with all possible results reported (e.g., Forster & Shen, 1996; Perea & Pollatsek, 1998; Sears, Hino, & Lupker, 1995, 1999).

The conventional definition of an orthographic neighbour—as a word that is formed by the substitution of a single letter—restricts neighbours to words of identical length. For example, *camp* is a neighbour of *lamp*, whereas *clamp* is not, as it involves the addition—rather than the substitution—of a letter. It seems likely that the popularity of this definition is due more to its simplicity rather than to any theoretical claim that the perceptual similarity of *camp* and *lamp* is greater than that of *clamp* and *lamp*. Indeed, given that *clamp* contains all of the letters of *lamp* (plus an initial letter *c*), whereas *camp* contains only three of the four letters in *lamp* (plus an initial letter *c*), it might be argued that subset–superset similarity is greater than neighbour similarity.

In fact, there is some evidence that orthographic similarity extends to subset–superset relations. Drews and Zwitserlood (1995) assessed priming in Dutch for superset primes (e.g., *kerst*) followed by a subset target (*KERS*) and reported an inhibition effect, both for masked and unmasked primes. Similarly, employing the masked priming paradigm, De Moor and Brysbaert (2000) reported inhibitory priming between superset–subset and subset–superset prime-target pairs in Dutch, with similar results obtained when items overlapped at the beginning (e.g., prime = *boord*, target = *BOOR*) or end (e.g., prime = *eeuw*, target = *GEEUW)*. These priming results lend support to the claim that superset and subset items are orthographically similar and compete with one another for identification. It is interesting to note that these inhibitory priming effects turn facilitatory when the supersets and supersets are morphologically related (Rastle, Davis, & New, in press; Stanners, Neiser, Hernon, & Hall, 1979). That is, facilitation results when orthographically similar word forms activate the same (as opposed to different) root morphemes.

In light of these considerations, it seems plausible that subsets and supersets are activated during the normal course of identifying words, and this may in turn impact on the identification of the target words. Consistent with this possibility, Taft and Forster (1976) and Andrews (1986) presented participants with familiar compound words that contained embedded words of differing frequencies (e.g., *headstand* and *loincloth* contain high- and low-frequency embedded words, respectively). RTs in a lexical decision task were faster to targets when their subsets were higher in frequency, suggesting that subsets were activated and facilitated lexical decisions—at least for compounds. More recently, Davis and Taft (submitted) reported two lexical decision experiments that provide evidence for the automatic activation of subset and superset words in non-compound items. In the first experiment, the number of subset and superset neighbors affected the speed and accuracy of "No" decisions to nonwords (e.g., *droe* which has the superset neighbors *drove* and *drone* and the subset neighbor *doe* were more difficult to classify than matched nonwords like *skoe* which has no subset or superset neighbors). In Experiment 2, the presence of an embedded higher-frequency subset word (e.g., *come* in *comet*) resulted in slower and less accurate "Yes" decisions to words, relative to control words that did not contain embedded subset words.

A weakness of the above studies, however, is that different sets of targets were included across the subset–superset conditions. For example, Davis and Taft (submitted) compared words like *tablet* (containing the subset *table*) with control words like *tumble* (which does not contain an embedded word). Although items were matched in terms of frequency, word length, etc., they may not have been matched on all relevant factors. For instance, none of the above studies matched on age-of-acquisition or imageability, variables known to influence RTs in the lexical decision task (e.g., Stadthagen Gonzalez, Bowers, & Damian, 2004). Thus, it is always possible that the results reflect the impact of these or some other uncontrolled variables rather than the impact of the supersets or subsets on target identification.

In the present study, we attempted to determine whether subsets and supersets are activated during the course of identifying non-compound words using a methodology that avoids these matching issues. In order to achieve this, we adapted a procedure introduced by Forster and Hector (2002). The authors found that nonwords (e.g., *turple*) that are neighbours of animal words (in this case, *turtle*) are slower to reject in an animal categorization task (responding that *turple* is not an animal) compared to matched nonwords without animal neighbours (e.g., *cishop*). Presumably this is due to the semantics of the neighbour being accessed in the case of *turple*. Rodd (2004) recently extended this finding to word targets, showing that words that are neighbours of animals (e.g., *leotard*) are also difficult to reject as animal terms (also see Pecher, Zeelenberg, & Wagenmakers, in press).

In the present experiments, we extended this logic to subset and superset words. In Experiment 1, participants were presented with target words that contain subsets that are members of a specific semantic category (e.g., *hatch*, in which the subset *hat* is a member of the "item of clothing" category). In Experiment 2, target words were subsets of longer words that were members of a semantic category (e.g., *bee*, where the superset word *beer* is a member of the "alcoholic drink" category). The question of interest is whether participants are slower to make semantic categorizations when the subset–superset and target are associated with a different (incongruent) compared to the same (congruent) response. For example, are people slower to reject *hatch* as a piece of clothing (a condition in which the subset demands a YES answer and the target a NO answer) compared to rejecting *hatch* as a human body part (a condition in which the subset and target both demand a NO answer)? The critical advantage of this procedure is that the same target (e.g., *hatch*) is presented in both conditions and the same NO response is required; accordingly, any differences would likely reflect the impact of the subset or superset on target categorization rather than any uncontrolled differences between targets across conditions.

In addition, this procedure—which we call the *semantic competition task*—allows us to assess whether or not the spread of activation from orthography to semantics is cascaded. That is, any congruency effect would not only indicate that the orthographic (or phonological) forms of the subsets/supersets and targets were activated in parallel, but also, that these co-activated word forms activated their corresponding semantic representations during the course of identifying the target. It is the co-active semantic representations that would impair performance in a semantic categorization when responses are incompatible. In discrete or "modular" stage models, by contrast, access to semantics occurs only after a word is identified orthographically or phonologically. Accordingly, only the meaning of one word (presumably the target) should be contacted, which should eliminate any semantic congruence effects (but see Forster & Hector, 2002, for a modular account of congruency effects obtained with nonword targets—e.g., the difficulty in rejecting *turple* as non-animal). Perhaps the best evidence to date for cascaded processing is the congruence effect reported by Rodd (2004) and Pecher et al. (in press) for neighbours in the semantic categorization task. The present studies also provided an opportunity to replicate these findings, but with subset and supersets.

Experiment 1

Method

Participants

Forty-six undergraduate students from the University of Bristol participated in return for course credit or £5. All were native English speakers, and had normal or corrected-to-normal eyesight.

Materials

One hundred and nineteen words were selected that contained a total of 59 subset items belonging to one of the following categories: Human Body Part (22 supersets, 10 subsets); Animal (29 supersets, 14 subsets); Clothing (16 supersets, eight subsets); Vehicle (14 supersets, seven subsets); Animal Body Part (nine supersets, six subsets); Household Item/Furniture (13 supersets, six subsets); Alcoholic Drink (seven supersets, three subsets); and Food Item (nine supersets, five subsets). Superset words comprised the subset word plus one, two, or (occasionally) three additional letters. In the case of a superset item with two or three extra letters, the subset item could be positioned at the initial, middle, or final embedding positions. Fifty-three items belonged to the initial embedded position, 21 to the middle embedded position, and 45 to the final embedded position.

A constraint in selecting these supersets was that their subsets were good exemplars of their category (e.g., for the superset *hatch*, *hat* must be a good exemplar of clothing). In order to ensure this, a set of 35 independent participants from the same population were asked to categorize the subsets of a large number of potential supersets with respect to the subset category. Supersets were only included in the main experiment if the mean YES latency for their subsets was less than 800 ms and the mean error rate was less than 20%. The mean RTs and error rates of the 59 items included in the experiment were 594 ms and 4.3%, respectively.

Each target word was categorized with regards to whether its embedded subset maintained its pronunciation within the context of the superset. Congruency of pronunciation was assessed by comparing the CELEX phonetic transcription for each target word and its superset: the pronunciations were deemed to be congruent if the phonological nucleus of the subset matched that of the superset (e.g., *hat*ch; 73 items collapsing across condition), and different-sounding if not (e.g., *leg*al; 46 items). Finally, each superset was categorized with regards to the relative frequency of the superset and its embedded word. Eighty-two supersets contained subsets that were more frequent, and 37 less frequent. See Appendix A for the full list of items, and their corresponding classifications.

One hundred and nineteen filler items were also selected as members of the relevant categories, and these were matched in length with the superset items. This ensured that there were an equal number of YES and NO responses for each category. Stimuli were displayed in 20 point Times New Roman font, using the DMDX software package (Forster & Forster, 2003).

Design

Each superset was presented in the Incongruent and Congruent conditions. This was achieved by constructing two experimental files, and counterbalancing items between the following categories: Human Body Part vs. Animal; Clothing vs. Vehicle; Animal Body Part vs. Household Item/Furniture; and Alcoholic Drink vs. Food Item. For example, for the 22 superset items that contained a subset referring to a human body part (e.g. "army"), 11 of these items were categorized with respect to the human body part category and 11 with respect to the animal category in one counterbalanced condition, and the categorizations were reversed in the second counterbalanced condition. Each block of semantic categorizations included an equivalent number of filler items (that demanded a YES response). In addition to these eight blocks of categorization, a ninth block was included for the sake of practice. Items in this block were categorized with respect to the category *Fruit*. The eight experimental blocks, along with the items within each block, were presented in a random order.[1]

Procedure

Participants were tested individually or in small groups. They were instructed to categorize each word as quickly and accurately as possible by pressing the right shift key if they thought the item belonged to the category, and the left shift key if not. Each item was preceded by a plus sign that was displayed for 800 ms and acted as a fixation point. A blank screen then appeared for a duration of 350 ms, followed by the presentation of the target for a duration of 500 ms. Following each response, participants received feedback, and were required to press the spacebar to proceed to the next trial. The relevant category label (e.g., "Item of Clothing?") was displayed in the centre of the screen prior to the first trial in each categorization block, and on remaining trials was presented on the top-left corner of the screen. On completion of a block of trials the next category was presented in the centre of the screen, and remained on the top-left corner for the following trials within the block. A single practice block preceded the eight blocks of experimental trials in order to familiarize participants with the task.

Results

Participants and items with an error rate greater than 20% in the congruent condition were dropped from the RT and Error analyses (two participants and four items). In addition, participants and items were excluded from the RT analysis when their overall error rate (averaged across incongruent and congruent conditions) was greater than 20% (five items). For the correct RTs, we removed responses that were greater than 1500 ms or less than 300 ms (<1% of the data).

There was a main effect of congruence, with longer correct RTs in the incongruent (660 ms) compared to congruent (640 ms) condition, $t1(44) = 4.1$, $t2(109) = 3.1$, $ps < .001$. A similar pattern was found for the errors, with 8% errors and 4% errors in the two conditions, respectively, $t1(44) = 4.5$, $t2(114) = 3.4$, $ps < .001$. This shows that the semantics of the subsets were indeed contacted and interfered with the categorizations of the supersets in the incongruent condition. Inspection of the data revealed a clear effect of relative frequency. When the subset word was of higher frequency than the superset there was a large congruence effect (26 ms in the RT data and 4.5% in the accuracy data). By contrast, when the subset word was lower in frequency than the superset there was little evidence of an effect (9 ms in the RT data and 1.4% in the accuracy data), $t1(44) = 1.2$, $p > .05$, $t2(34) = 1.0$, $p > .05$. This parallels various neighbourhood frequency effects reported by Grainger and colleagues (Grainger, 1990; Grainger & Jacobs, 1996; Grainger et al., 1989; Grainger & Segui, 1990) who report that higher but not lower-frequency neighbours interfere with target identification. For this reason, subsequent analyses were restricted to the set of items in which the subset was of higher frequency than the superset.

Table 1 shows the mean correct RTs and error scores for the targets with higher-frequency subsets. As can be seen, congruence effects were obtained across most conditions. A 2 × 3 ANOVA performed on the RT congruence scores showed no main effect of pronunciation, $F1$ and $F2 < 1$, nor of embedding position, $F1$ and $F2 < 1$. A 2 × 3 ANOVA performed on the congruence error scores showed no significant effect of pronunciation, $F1 < 1$, $F2(1,77) = 1.2$, $p = .28$, whereas a main effect of embedding position was observed in the participant analysis, $F(1,88) = 6.9$, $p < .01$, but not by item analysis, $F(1,76) = 2.0$, $p = .15$. This latter finding reflects the larger congruence effects in the first position for errors. Overall, however, these analyses highlight that interference extended across pronunciation and position conditions.

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[1] For one of the counterbalanced files there were only two items in the interference condition for the subject analysis, and one subject made errors on both items. In order to run this analysis we entered the mean RT over the other participants for this subject.

Table 1
Mean RTs (ms) and error rates (%) for targets with higher frequency subsets in Experiment 1, as a function of embedding position (initial, medial, or final), semantic congruence (congruent or incongruent), and pronunciation congruence (same or different)

Embedding position	Pronunciation	Example item	Congruence	RT	ER
Initial	Same	*hat*ch	Congruent	651	3.6
			Incongruent	678	9.6
			Difference	*−27*	*−6.1*
	Different	*ear*n	Congruent	631	4.0
			Incongruent	656	13.0
			Difference	*−25*	*−9.1*
Middle	Same	s*cow*l	Congruent	616	3.3
			Incongruent	645	4.6
			Difference	*−29*	*−1.3*
	Different	c*rat*e	Congruent	611	0.0
			Incongruent	620	2.9
			Difference	*−9*	*−2.9*
Final	Same	h*owl*	Congruent	652	4.4
			Incongruent	668	6.6
			Difference	*−16*	*−2.2*
	Different	w*arm*	Congruent	658	7.8
			Incongruent	698	6.4
			Difference	*−40*	*1.3*

Discussion

The results provide clear-cut evidence that subsets are activated during the course of visual word identification, consistent with Davis and Taft (submitted). Indeed, subsets were activated whether embedded in the initial, medial or final positions of the target. In the present study, however, conclusions are not compromised by any concerns regarding stimulus matching, as stimuli were compared to themselves across conditions. Experiment 1 also provides evidence that subset activation extends to semantics. This parallels the Rodd (2004) and Pecher et al. (in press) findings with neighbours, and thus provides further evidence in support of cascaded semantic processing. Finally, the present study provides evidence that subsets can be activated to the level of semantics even when their pronunciation changes within the context of the target.

It should be noted that our claim that congruency effects reflect the automatic activation of subset words per se might be challenged in some cases. In particular, two alternative possibilities can be considered. The first is that the activation of the subset depends on it sharing a syllable with the presented word (e.g., *rug* and *rugby* share the same initial syllable). There is some evidence that syllabic neighbors are activated during the process of identifying written Spanish words (Carreiras & Perea, 2002; Perea & Carreiras, 1998). However, relatively few of our subset words shared a syllable with the presented word (and this never occurred in the middle embedding condition, which showed robust congruency effects), and so it is unlikely that syllabic activation was responsible for the congruency effects. A second possibility is that the activation of the subset depends on it sharing a body with the presented word (e.g., *clamp* and *lamp* share the body *amp*, and are therefore *body neighbors*, e.g., Forster & Taft, 1994). Again, this is only the case for a subset of the items (i.e., those in the final embedding condition) and hence it cannot explain the robust congruency effects observed for initial and middle embedding conditions. Nevertheless, we cannot rule out the claim that body neighbour similarity played a role in the final subset condition. It is interesting to note that this would lead to the following strong prediction. That is, the identification of *clamp* should activate not only the subset *lamp*, but also the body neighbours *damp*, *ramp*, *tramp*, etc., producing similar size congruence effects in all cases. Although it is beyond the scope of this paper to test this alternative hypothesis, it seems unlikely to us that the semantic codes for all these body neighbours are activated to the same extent as those for an embedded subset word. In any case, the important point is that the current study clearly shows that embedded words are activated to the level of form and semantics (i.e., the semantic congruency effects cannot be satisfactorily explained as simply reflecting the activation of sublexical units).

Experiment 2

In the second experiment, we assessed whether congruence effects are obtained when target words are subsets of longer words (e.g., target = *bee*, superset = *beer*).

Method

Participants

Forty-six undergraduate students from the University of Bristol participated in return for course credit. All were native English speakers, and had normal or corrected-to-normal eyesight.

Materials

Thirty-six target words were selected, each of which could be embedded within supersets belonging to one of the following categories: Human Body Part, Animal, Clothing, Vehicle, Animal Body Part, Household Item/Furniture, Alcoholic Drink, Food Item, Colour, Dwelling, and Part of a vehicle. The 36 target words were associated with 34 different supersets (the supersets 'plane' and 'ship' were repeated). Target words were one letter shorter than their supersets. There were three position conditions, each consisting of 12 targets: Initial embedding, e.g., *fee* (superset = *feet*); Final embedding, e.g., *lane* (superset = *plane*); and Outer embedding, where the superset is formed by the insertion of a medial letter, e.g., *sip* (superset = *ship*).

All targets maintained a similar pronunciation within the context of their supersets. Congruency of pronunciation was again assessed by comparing the CELEX phonetic transcription for each target word and its superset: the pronunciations were deemed to be congruent if the phonological nucleus of the subset matched that of the superset. Finally, targets were only included if their superset was more frequent (mean frequency of target = 8 per million; superset = 56 per million).

To ensure that the supersets of the selected subset items were good exemplars of their category, a set of 20 independent participants from the same population was asked to categorize the supersets of a large number of potential targets with respect to a superset category. Supersets were only included in the main experiment if the mean YES latency for their subsets was less than 800 ms and the mean error rate was less than 20%. The mean RTs and error rates of the 34 items included in the experiment were 523 ms and 4.3%, respectively. See the Appendix A for the full list of items, and their corresponding classifications.

Thirty-six filler items were also selected as members of the relevant categories, and these were matched in length with the subset items. This ensured that there were an equal number of YES and NO responses for each category. Stimuli were displayed in 20 point Times New Roman font, using the DMDX software package (Forster & Forster, 2003).

Design

Each target was presented once, and two counterbalanced experimental files were constructed such that the target was presented in the incongruent (e.g., rejecting *lane* as a type of vehicle, with its superset *plane*) and congruent (e.g., rejecting *lane* as a type of fruit). When possible, half of the items from a given category were presented in the incongruent context, and half in the congruent context.[2] Each block of semantic categorizations included an equivalent number of filler items (that demanded a YES response). In addition to these eleven blocks of categorization, a twelfth block was included for the sake of practice. Items in this block were categorized with respect to the category *Fruit*. The 11 experimental blocks, along with the items within each block, were presented in a random order.

Procedure

The procedure was identical to that in Experiment 1.

Results

Participants and items with an error rate greater than 20% in the congruent condition were dropped from the RT and Error analyses (two participants and two items). In addition, the participants and items were excluded from the RT analysis when their overall error rate (averaged across incongruent and congruent conditions) was greater than 20% (one item). Again, we removed correct RTs greater than 1500 ms and less than 300 ms (<1% of trials).

Table 2 shows the mean correct RTs and error scores across embedding position in both congruence conditions. There was a significant main effect of semantic congruence, with longer RTs in the incongruent (660 ms) compared to the congruent condition (626 ms), $t1(43) = 5.0$, $t2(32) = 3.2$, $ps < .01$. Similarly, errors were more frequent in the incongruent condition (8%) compared to the congruent condition (3%), $t1(43) = 3.8$, $p < .001$, $t2(33) = 2.1$, $p < .05$.

An ANOVA of the congruence scores across the three embedding positions showed no effect of position in the RT data, $F1(2,84) = 1.3$, $p = .28$, $F2(2,33) = 1.2$, $p = .33$, nor in the error data, $F1(2,86) = 1.5$, $p = .23$, $F2 < 1$. This finding shows that interference effects extended across all embedding positions.

Discussion

The key result of this experiment is that the incongruent supersets interfered with target categorizations across all three embedding positions. Indeed, the overall

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[2] It was not possible to counterbalance items between category pairs, as in Experiment 1, given the limited number of items per category and the odd number of categories. Accordingly, each target was categorized in the incongruent condition and randomly assigned to one of the other categorization conditions in the congruent condition, counterbalanced across files.

Table 2
Mean RTs (ms) and error rates (%) for targets in Experiment 2, as a function of subset position (initial, final, or outer) and semantic congruence (congruent or incongruent)

Subset position	Example item	Congruence	RT	ER
Initial	brand(y)	Congruent	613	3.8
		Incongruent	655	5.7
		Difference	*−42*	*−1.9*
Final	(b)louse	Congruent	636	3.2
		Incongruent	650	10.3
		Difference	*−14*	*−7.1*
Outer	s(h)eep	Congruent	628	2.3
		Incongruent	675	6.8
		Difference	*−47*	*−4.5*

size of the interference generated by supersets was very similar to that generated by subsets that maintained the same sound in Experiment 1. Accordingly, orthographic similarity appears to extend to subsets and supersets of targets, regardless of the relative position of the subset–superset to the target.

General discussion

The key result of this investigation is that the semantic categorization of targets was slower and less accurate when their higher-frequency subsets (Experiment 1) or supersets (Experiment 2) were associated with a conflicting response (e.g., Does *hatch* refer to a piece of clothing?) compared to a congruent response (e.g., Does *hatch* refer to a human body part?). This strongly suggests that the subsets and supersets of target words are activated to the level of form and meaning. Although previous studies have provided evidence that subsets and supersets are activated at the level of form (e.g., Andrews, 1986; Davis & Taft, submitted; Taft & Forster, 1976), this conclusion relied on comparing responses to different sets of words in the various subset–superset conditions. Accordingly, it is possible that the effects reflected uncontrolled differences between the targets, rather than the activation of their subsets/supersets. This concern does not extend to the present studies given that the *same* target items were presented in the congruent and incongruent conditions.

The present findings highlight the fact that measurements of orthographic similarity need to be extended to words of different lengths, and that the practice of measuring similarity based on the standard N metric (Coltheart, Davelaar, Jonasson, & Besner, 1977) is insufficient. The importance of neighbours that vary in length has previously been noted by Carreiras and Perea (2002) and Forster and Taft (1994). The current finding that congruence effects extend to supersets containing initial, middle, and final subsets shows that all these subset–superset relations are orthographically similar as well. This is problematic for a number of orthographic letter coding schemes. For instance, according to the DRC model (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), letter position is coded by a set of position-specific letter units, e.g., the word *clamp* is coded by activating the units C_1, L_2, A_3, M_4, and P_5. This type of coding scheme explains why initial subsets should be automatically activated; for example, the code for *clam* (C_1, L_2, A_3, and M_4) is present within the code for *clamp*. However, it cannot explain the automatic activation of middle-embedded and final-embedded subsets, because the common letters in the subset and superset words will be coded by different letter units (e.g., the word *lamp* is coded by the letter units L_1, A_2, M_3, and P_4, none of which are present in the code for *clamp*). A variation of slot-coding, in which letters are assigned to slots relative to the position of the vowel (e.g., Harm & Seidenberg, 1999), could explain the similarity of *clamp* and *lamp*. However, this scheme does not explain the similarity of our outer embedded subsets in Experiment 2 (e.g., *tale* and *table* share only two units in this scheme—the vowel and *A* and the preceding *T*). Slot coding schemes (whether vowel-centred or based on absolute position) are also unable to explain the orthographic similarity of transposed-letter word pairs (e.g., *calm–clam*; e.g., Perea & Lupker, 2003), and words that differ in a letter substitution and a position change (e.g., *soap–shop*), so-called *neighbours once-removed* (Davis & Bowers, 2004). Although these similarity relations are lost in the slot-coding schemes used in most models of word identification, they are captured in some letter coding schemes (e.g., Davis, 1999; Davis & Bowers, 2004; cf. Bowers, 2002).

The subset interference effect also provides evidence against a key assumption of the original interactive-activation model and those models derived from it (e.g., the DRC and M-ROM models; Coltheart et al., 2001; Grainger & Jacobs, 1996); namely, that the word selection process depends on the existence of inhibitory bottom-up connections between letter nodes and incompatible word nodes. For example, in these models the input stimulus *hatch* is prevented from activating the *hat* word node, because the C_4 and H_5 letter units send strong inhibitory signals to this node.

Another important conclusion that can be drawn from these semantic congruence effects is that semantic activation from print is characterized by cascaded processing; that is, word identification not only involves the co-activation of the orthographic (or phonological) forms of the target and its subsets/supersets, but also, these co-activated word forms activate their corresponding semantic representations in parallel. As noted in the introduction, a modular staged processing account predicts that the semantics of only one item is contacted (presumably the target), in which case no congruency effects should have been observed (but see Forster & Hector, 2002). Although cascaded processing is widely assumed in activation models of word identification, the current data provide some of the first direct evidence in support of this assumption (see also Bourassa & Besner, 1998; Pecher et al., in press; Rodd, 2004).[3]

The finding that congruence effects were obtained when subsets changed their pronunciation suggests that access to meaning from print can be direct, without phonological mediation, as is sometimes claimed (e.g. Lukatela & Turvey, 1994; Van Orden, 1987). If access to meaning from print was only phonologically based, it might have been expected that congruence effects for these items would have been greatly reduced or eliminated; phonologically, there is no "crow" in "crown." Of course, the findings could reflect the fact that the phonology of both /kraUn/ (rhymes with "town") and /krUn/ (rhymes with "groan") was activated from *crown* (given the inconsistency with which the letter sequence "ow" maps onto vowels in English), and that /krUn/ in turn activated the meaning of *crow*. In our view, however, it is more straightforward to assume that the orthographic subsets themselves directly activated their semantic representations.

It is interesting to compare the present results to findings obtained with spoken words. As noted in Introduction, there is a small but more substantial literature concerned with the impact of embedding on spoken word identification. This work makes it clear that initial embeddings are co-activated to the level of form and meaning, but results with final embeddings are somewhat mixed. On the one hand, Prather and Swinney (1977) found that auditory presentation of *boycott* primed a visual target related to *boy*, but not a visual target related to *cot*, suggesting that embedded words at the start but not the end of supersets are activated to the level of form and meaning (similar results were obtained by Marslen Wilson & Zwitserlood (1989) and Pitt (1994)). A similar conclusion is suggested by the findings of Luce and Lyons (1999). The authors reported reduced latencies in lexical decision and shadowing tasks for superset words containing beginning subsets (e.g., "cherish," which contains "chair") compared to matched control words without any embedding (e.g., "flourish"), but no corresponding differences between supersets that contained end subsets (e.g., "chloride," which contains "ride") and control words ("chlorine").

On the other hand, Luce and Cluff (1998) obtained evidence that final subsets can also be activated to the level of meaning using a semantic priming paradigm; for example, the spoken word *hemlock* primed the written word *key* (for similar results, see Shillcock, 1990; Vroomen & De Gelder, 1997). More generally, the claim that spoken word identification involves co-activating the form and meaning of words with similar endings was supported by Allopenna, Magnuson, and Tanenhaus (1998). Participants were presented with spoken words (e.g., "beaker") and were required to point to a corresponding picture. The authors found that the participants' eye movements were distracted by pictures that rhymed with the target ("speaker"), suggesting these latter words were also activated to the level of meaning. Indeed, these findings suggest that the cohort of co-activated words that differ in their onsets extends beyond final embeddings to include neighbours.

The basis of the inconsistent findings in the spoken domain is unclear, but part of the problem may be methodological. As noted by Allopenna et al. (1998), the commonly used cross-modal semantic priming procedure may not be sufficiently sensitive to reliably detect the weak activation of embedded words, resulting in a mixed set of findings when the embedded words were in the final position. And the failure to obtain evidence that final embeddings are activated when shadowing or making lexical decisions to supersets (Luce & Lyons, 1999) suffers from the same problem common in past studies in the visual domain—that is, it is difficult to match words on all relevant dimensions other than the embedding. In this case, the authors did not match on age-of-acquisition or imageability, for example.

The semantic competition task may overcome both of these limitations. With regards to the sensitivity of the technique, it might be expected that the semantic activation of the subset itself (e.g., the activation of *lock* from *hemlock*) would be greater than the semantic activation

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[3] It is interesting to note that in the speech production literature there is an active debate concerning whether processing should be characterized as cascaded or staged; cf. Levelt, Roelofs, and Meyer (1999). The current findings bear on this debate indirectly, in that it is unparsimonious to advocate a discrete staged processing model of speech production in the face of evidence that input systems access semantics in a cascaded fashion.

of an associate of the subset (e.g., the activation of *key* from *hemlock*), in which case, congruence effect in the semantic competition task should provide a better measure of subset activation than the cross-modal priming technique described above. With regards to the stimulus-matching problems, they do not arise in the semantic competition task as the same target words serve as their own controls. Recently we have assessed congruence effects for spoken words in the semantic competition task using the items from Experiment 1, and we found large congruency effect for words containing initial subsets, and only small effects for words with final embeddings.

Before concluding, it is important to note that the present congruency effects cannot be used to support the claim that lexical competition (orthographic, phonological, or semantic) plays a role in word identification. Although the current findings provide direct support for the claim that subsets and supersets are coactive during the course of word identification, the congruency effects could simply reflect the fact that co-active semantic representations delay responding when they are associated with different responses. According to this account, the delayed response to the target reflects a response conflict, rather than a delay in its identification. Nevertheless, given the inhibitory effects of higher frequency subsets (Davis & Taft, submitted) and neighbours (e.g., Grainger et al., 1989; Pollatsek, Perea, & Binder, 1999) on target categorization in the lexical decision task, we would endorse the view that lexical competition between form-similar words delays identification as well.

In sum, the present study provides strong evidence that subsets and supersets of target words are activated to the level of form and meaning. This highlights the orthographic similarity between words of different lengths, and suggests that semantic access from print is characterized by cascaded processing.

Appendix A

Stimuli used in Experiment 1

Superset	Subset	Semantic category	Pronunciation	Embedding position	Relative subset frequency	IS RT[a]	IS ER[b]
alert	ale	alcoholic drink	different	initial	lower	96	0.20
drum	rum	alcoholic drink	same	final	lower	97	−9.09
grump	rum	alcoholic drink	same	middle	higher	−26	4.55
porter	port	alcoholic drink	same	initial	higher	94	13.04
sport	port	alcoholic drink	same	final	lower	−52	−3.95
tale	ale	alcoholic drink	same	final	lower	46	−9.09
valet	ale	alcoholic drink	different	middle	higher	41	9.09
abate	bat	animal	different	middle	higher	−10	0.00
antic	ant	animal	same	initial	higher	−37	4.55
apex	ape	animal	same	initial	higher	51	−4.55
bath	bat	animal	different	initial	lower	−60	−8.70
baton	bat	animal	same	initial	higher	15	4.35
beer[c]	bee	animal	different	initial	lower	—	23.32
bowl	owl	animal	different	final	lower	−74	0.20
brat	rat	animal	same	final	higher	109	0.00
cape	ape	animal	same	final	lower	12	4.55
catch	cat	animal	same	initial	lower	−13	−9.29
cater	cat	animal	different	initial	higher	−104	0.00
cower	cow	animal	same	initial	higher	21	18.18
cram	ram	animal	same	final	higher	−84	4.55
crate	rat	animal	different	middle	higher	83	4.35
crown	crow	animal	different	initial	lower	13	−18.18
drama	ram	animal	different	middle	lower	−87	−4.35
frame	ram	animal	different	middle	lower	8	−0.20
harem	hare	animal	different	initial	higher	86	4.35
howl	owl	animal	same	final	higher	204	3.56
paper	ape	animal	same	middle	lower	30	−13.64
pigmy	pig	animal	same	initial	higher	45	22.73
ramp	ram	animal	same	initial	higher	81	0.00
rant	ant	animal	same	final	higher	−3	13.64
rate	rat	animal	different	initial	lower	21	4.55
scowl	cow	animal	same	middle	higher	82	−4.55

(*continued on next page*)

Appendix A (*continued*)

Superset	Subset	Semantic category	Pronunciation	Embedding position	Relative subset frequency	IS RT[a]	IS ER[b]
share	hare	animal	same	final	lower	−41	9.29
stage	stag	animal	different	initial	lower	11	−0.20
steel	eel	animal	same	final	lower	−38	−0.20
want	ant	animal	different	final	lower	99	4.35
fine	fin	animal body part	different	initial	lower	−14	0.00
fury	fur	animal body part	different	initial	higher	287	30.43
pawn	paw	animal body part	same	initial	higher	29	27.47
retail	tail	animal body part	same	final	higher	−12	0.00
spawn	paw	animal body part	same	middle	higher	238	17.19
swing	wing	animal body part	same	final	higher	—	—
tailor	tail	animal body part	same	initial	higher	−41	−9.09
thor[c]	horn	animal body part	same	final	higher	—	30.04
twinge	wing	animal body part	same	middle	higher	−72	0.00
address	dress	clothing	same	final	higher	43	8.70
brag	bra	clothing	different	initial	higher	−11	−4.35
braid	bra	clothing	different	initial	higher	137	8.70
caper	cape	clothing	same	initial	higher	−59	4.55
chat	hat	clothing	same	final	higher	13	4.55
escape	cape	clothing	same	final	lower	36	−4.55
hatch	hat	clothing	same	initial	higher	−32	4.55
hate	hat	clothing	different	initial	lower	−23	0.00
invest	vest	clothing	same	final	lower	37	9.09
pursuit	suit	clothing	different	final	higher	47	9.09
socket	sock	clothing	same	initial	lower	68	21.54
suite[c]	suit	clothing	different	initial	higher	—	54.55
suitor	suit	clothing	same	initial	higher	59	4.15
tier	tie	clothing	different	initial	higher	−29	4.55
vestry	vest	clothing	same	initial	higher	99	4.35
zebra	bra	clothing	different	final	higher	−56	−5.14
breadth	bread	food	same	initial	higher	34	−4.55
champ	ham	food	same	middle	higher	58	−13.83
peat	pea	food	same	initial	lower	−10	13.64
pier	pie	food	different	initial	higher	29	−9.09
price	rice	food	same	final	lower	87	4.35
sham	ham	food	same	final	higher	−53	−8.70
speak	pea	food	same	middle	lower	−35	4.74
spiel	pie	food	different	middle	higher	−34	0.00
tricep	rice	food	different	middle	higher	11	9.09
barbed	bed	household item	different	final	higher	170	−0.20
blood[c]	loo	household item	different	middle	lower	—	—
bloom	loo	household item	same	middle	lower	43	−4.55
clamp	lamp	household item	same	final	higher	65	−4.74
drug	rug	household item	same	final	lower	13	0.20
embed	bed	household item	same	final	higher	−4	0.00
igloo	loo	household item	same	final	higher	204	−0.20
look	loo	household item	different	initial	lower	−94	−4.35
notable	table	household item	different	final	higher	−3	−8.70
rugby	rug	household item	same	initial	lower	39	26.09
stable[c]	table	household item	same	final	higher	103	−5.14
tablet[c]	table	household item	different	initial	higher	—	36.96
woven	oven	household item	different	final	higher	63	4.94
army	arm	human body part	same	initial	lower	10	13.64
barmy	arm	human body part	same	middle	higher	34	4.35
chair	hair	human body part	same	final	higher	52	12.85
china	chin	human body part	different	initial	lower	21	−13.64
clip	lip	human body part	same	final	higher	−64	0.00
earn	ear	human body part	different	initial	higher	27	13.64

Appendix A (*continued*)

Superset	Subset	Semantic category	Pronunciation	Embedding position	Relative subset frequency	IS RT[a]	IS ER[b]
flung	lung	human body part	same	final	lower	−88	0.00
gear	ear	human body part	same	final	higher	32	−13.64
harm	arm	human body part	same	final	higher	67	4.35
hearth	heart	human body part	same	initial	higher	−42	4.55
hearty	heart	human body part	same	initial	higher	42	−4.74
hippy	hip	human body part	same	initial	higher	−12	9.09
learn	ear	human body part	different	middle	lower	26	0.00
legal	leg	human body part	different	initial	higher	−25	−8.70
lipid	lip	human body part	same	initial	higher	149	3.95
lunge	lung	human body part	same	initial	higher	64	12.85
plunge	lung	human body part	same	middle	higher	−25	0.00
sliver	liver	human body part	same	final	higher	−25	−0.20
swear	ear	human body part	different	final	higher	−13	4.55
urchin[c]	chin	human body part	same	final	higher	—	—
warm	arm	human body part	different	final	higher	25	4.55
whip	hip	human body part	same	final	higher	−10	−4.94
abuse	bus	vehicle	different	middle	higher	−61	0.00
bush	bus	vehicle	different	initial	higher	−34	−9.29
busk	bus	vehicle	same	initial	higher	42	−8.50
cabin	cab	vehicle	same	initial	lower	101	14.03
card	car	vehicle	same	initial	higher	51	−13.64
care	car	vehicle	different	initial	higher	−103	9.09
jetty[c]	jet	vehicle	same	initial	higher	—	25.69
scab	cab	vehicle	same	final	higher	−28	0.00
scare	car	vehicle	different	middle	higher	−16	0.00
strain	train	vehicle	same	final	higher	−63	0.20
struck	truck	vehicle	same	final	lower	24	−0.40
trainer[c]	train	vehicle	same	initial	higher	—	—
vane	van	vehicle	different	initial	higher	−24	13.83
vicar	car	vehicle	different	final	higher	2	9.49

[a] Interference score reaction time (incongruent RT − congruent RT).

[b] Interference score error rate (incongruent ER − congruent ER).

[c] Items excluded from analyses.

Stimuli used in Experiment 2

Subset	Superset	Semantic category	Embedding position	IS RT[a]	IS ER[b]
louse	blouse	clothing	final	−5	9.1
hark	shark	animal	final	164	22.7
hale	whale	animal	final	−11	4.6
hip	ship	vehicle	final	−29	−4.6
lane	plane	vehicle	final	16	4.6
ail	tail	animal body part	final	58	−9.1
oat	coat	clothing	final	15	0.0
ace	face	human body part	final	45	9.1
hack	shack	dwelling	final	2	4.6
heel	wheel	part of a vehicle	final	99	9.1
utter	butter	food	final	−20	4.6
ion	lion	animal	final	−34	0.0
bee	beer	alcohol	initial	3	4.6
brand	brandy	alcohol	initial	107	0.0
scar	scarf	clothing	initial	109	0.0
pin	pink	colour	initial	−66	−4.6
fee	feet	human body part	initial	−1	9.1
whisk[c]	whisky	alcohol	initial	—	63.6
brow	brown	colour	initial	−7	−13.6

(*continued on next page*)

Appendix A (*continued*)

Subset	Superset	Semantic category	Embedding position	IS RT[a]	IS ER[b]
bee[c]	beef	food	initial	—	—
rabbi	rabbit	animal	initial	108	4.6
bat[c]	bath	household	initial	—	—
tan	tank	vehicle	initial	−22	4.6
rave	raven	animal	initial	−1	−4.6
seep	sheep	animal	outer	2	−4.6
salon	salmon	animal	outer	91	0.0
pane	plane	vehicle	outer	18	4.6
vet	vest	clothing	outer	12	−9.1
wig	wing	animal body part	outer	95	4.6
caste	castle	dwelling	outer	88	4.6
tale	table	household	outer	−16	9.1
lap	lamp	household	outer	164	13.6
sin	skin	human body part	outer	−3	0.0
sip	ship	vehicle	outer	54	0.0
tuck	truck	vehicle	outer	77	27.3
lab	lamb	animal	outer	−66	13.6

[a] Interference score reaction time (incongruent RT − congruent RT).

[b] Interference score error rate (incongruent ER − congruent ER).

[c] Items excluded from analyses.

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