Penultimate version; published in Columbus (ed)

The issue of semantic mediation in word and number naming

Marc Brysbaert, Wim Fias, & Bert Reynvoet

University of Gent

Address: Marc Brysbaert
Department of Experimental Psychology
University of Gent
H. Dunantlaan 2
B-9000 Gent
Belgium
Tel. 32 – 9 – 264 64 36
Fax. 32 – 9 - 264 64 96
e-mail: Marc.Brysbaert@rug.ac.be

The issue of semantic mediation in word and number naming

Separating the lexicon from the semantic system in word processing

In current models of word recognition it is customary to make a distinction between a so-called lexical level and a semantic level. At the lexical level, a match is made between the incoming perceptual information and knowledge stored in memory to determine whether a given stimulus (either visual or auditory) refers to a known word or not. At the semantic level, the meaning of a known word is derived. So, when a reader sees the letter string *tree*, s/he first establishes whether this string corresponds to a word that has been mastered (i.e., corresponds with an entry in the mental lexicon), and only then derives the meaning of the word (which, in this case, will be different for an English reader than for a Dutch reader – *tree* in Dutch means *step*).

Several reasons are given for the distinction between the lexical and the semantic level. A first reason is that many researchers believe that the lexical level is much more differentiated than the semantic level. For instance, many authors are convinced that a distinction should be made between a visual and an auditory lexicon. Some reasons for this distinction are related to the nature of the input (e.g., the letters of short written words are probably processed in parallel, whereas there is a clear serial component in the phonemes of spoken words, which typically take hundreds of milliseconds to be pronounced). Other arguments are derived from priming studies. It has been shown that within-modality repetition of a word (e.g. visual-visual) results in larger facilitation effects than cross-modality repetition (e.g., auditory-visual; Morton, 1979). A second differentiation of the lexical level has been suggested within the literature of bilingualism. Many authors (e.g., Kroll & de Groot, 1997) have defended the idea that a bilingual person is characterised by two different lexicons (corresponding to the different languages known), connected to a single meaning system (but see Brysbaert, 1998). So, a first reason for the distinction between the lexical and the semantic system is that there may be several lexicons, all related to the same semantic meaning system.

A second reason for separating lexical from semantic representations is to explain divergences between word processing and picture processing. Although this has been a matter of strong debate (for contrasting views, see e.g. Caramazza, Hillis, Rapp, & Romani, 1990, and Shallice, 1993), evidence is growing that pictures and words address the same semantic system (e.g., Vandenberghe, Price, Wise, Josephs, & Frackowiak, 1996). Pictures have privileged access to this shared store of semantic information, as witnessed by the robust finding that, when pictures and words are presented together, pictures interfere with the semantic processing of a word, whereas the reverse is not true (Glaser, 1992). The fact that pictures have more privileged access to semantics than words, is a strong argument in favour of a lexicon separated from the semantic system. Indeed, if the lexicon and the semantic system were a unitary store, it would be difficult to explain why words are overruled by pictures in gaining access to the semantic system.

A third reason that has been reported for a difference between lexical and semantic representations, has to do with the lack of a one-to-one mapping between words and meanings. For example, the meaning of words to some extent depends on the context. As Harley (1995, p. 176) notes, the word *big* means different things in the phrases *the big ant* and *the big rocket*. Also, some words may have different meanings (polysemy), or different words may have the same meaning (synonymy). It is difficult to explain the resolution of such ambiguities within a single layer of representations.

Finally, a fourth reason for separating the lexical from the semantic system, is that humans can do quite some processing of "words" without understanding them. In this text, we will only discuss the issue of reading aloud visual words. For a start, people can pronounce letter strings that do not have a representation in their lexicon. Ellis and Young (1997, p. 194) give the examples of *pomelo* and *regelate*, which are very infrequent English words. The virtually infinite range of pronounceable non-words constitutes another class of stimuli that can be named without having a meaning. At first sight, this finding suggests that there is a simple letter-sound (grapheme-phoneme) conversion system, which does not depend on meaning. A problem with this account, however, is that in many languages – and certainly in English – the grapheme-phoneme correspondences are ambiguous (e.g. *couch* vs. *touch*, *gave* vs. *have*). So, what would be the pronunciation of the non-word *nouch* according to a simple grapheme-phoneme conversion system? Furthermore, Kay and Marcel (1981) showed that the pronunciation of such non-words depends on the words seen shortly before. After having seen the word *couch*, a participant is likely to pronounce *nouch* as /naʊtʃ/; however, after having seen the word *touch*, the participant is more likely to say /nutʃ/. This seems to indicate that non-words are not pronounced according to a rule-governed grapheme-phoneme conversion system, but by analogy to the pronunciation of known words, a suggestion made for the first time by Glushko (1979). Finally, cases have been published of patients with dementia who did not understand the words they were reading, but who nonetheless pronounced irregular words such as *blood*, *climb*, and *come* correctly (e.g., Schwartz, Saffran, & Marin, 1980). According to many authors (e.g., Ellis & Young, 1997; Harley, 1995), such observations can only be explained by assuming a lexicon separated from the meaning system.

The above considerations have led to the so-called three-route model of visual word naming. A typical example is that of Morton and Patterson

(1980; see Figure 1). In this model, visual letter strings can be named (a) by a simple grapheme-to-phoneme conversion (in later versions of the model, this system could also process larger units than graphemes; see below), (b) by activating an entry in the visual input lexicon, which has direct connections to the phonological output lexicon, where the speech output patterns of known words are stored, or (c) via the visual input lexicon, through the cognitive (semantic) system, to the phonological output lexicon. Only in the last route are semantic variables expected to have an effect on the naming of printed words.

- -
Insert Figure 1 about here
- -

Although most existing models of word processing make a distinction between a lexical and a semantic level, it should be noted that the terminology is not always consistent. Some authors, for instance, consider the lexical and the semantic system as two parts of the mental lexicon. A typical example is Forster's (1976) serial search model of word recognition. In this model of *lexical access*, a distinction is drawn between access files and a master file. There are three different access files: an orthographic (for visual input), a phonological (for auditory input), and a syntactic-semantic (e.g., for the output of thoughts and the naming of pictures). The access files contain nothing else than pointers to the master file in the lexicon, which stores all information to do with the word, *including its meaning*. Another distinction between models is how much information is stored in the lexicon. In the most restricted models, the visual lexicon is nothing else than pointers to the semantic system; in other versions, the lexicon also includes information about derivations (e.g., the plural of nouns), the phonology of visual words (depending on whether a distinction is made between an input and an output lexicon), and/or syntactic information (e.g. the gender of words and the roles words can play in a sentence). Finally, as will be indicated below, currently there are also models that no longer accept the existence of a mental lexicon and the notion of lexical access.

Isolating the semantic system in word naming

In principle, the semantic route of the model depicted in Figure 1 could be of equal (or even more) importance in the naming of visually presented words as the other two routes. A visual word would then rapidly activate its meaning and via the meaning the corresponding speech output codes. However, for a number of reasons this did not happen: The semantic route was only considered as the "third option" in normal word naming. One reason for this view was that models like the one of Figure 1 gave the impression that the semantic route was considerably longer (i.e., required more conversions and activations) than the other two routes. Another reason was the attraction of the modularity idea, which seemed pivotal for the meaning of neuropsychological research (Shallice, 1988). If the functioning of the brain were not differentiated in multiple, more or less independent subsystems, then there would be no point in studying the functional consequences of brain damage for understanding normal function. Or as Shallice (1988, p. 18) put it: "… [In that case,] any form of neurological damage would deplete by a greater or lesser degree the available amount of some general resource, say the mythical *g*. Knowing which tasks a patient could or could not perform would enable us to partition tasks on a difficulty scale. It would tell us little, if anything, about how the system operated."

Fodor (1983) provided an explicit interpretation of a module. For Fodor, a module is a subsystem with the following set of properties: it is domain-specific, innately specified, not assembled from more basic elements, hard-wired, computationally autonomous, and informationally encapsulated. By computationally autonomous, Fodor meant that a module does not share attention, memory, or other general-purpose processes with other modules. By informationally encapsulated, he meant that a module has access to only a very restricted amount of information contained in the system as a whole. Consequently, if the lexical system and the semantic system are two different modules within the language processing system, in the Fodorian view one does not expect a massive interaction of information between the two components during on-line processing. If the mental lexicon is computationally autonomous and informationally encapsulated, one does not expect an exchange of information with the semantic system during the lexical access process. Rather, one would expect a serial, bottom-up flow of information from input to output through the different modules.

Within such a view, the semantic route is indeed one or two steps "longer" than the other two routes. This is why Morton and Patterson's three-route model of visual word naming is less well known than Coltheart's (1978) classical dual-route theory, which capitalises on the non-lexical grapheme-to-phoneme conversion system and on the lexical look-up system. The contribution of the semantic system to printed word naming was reduced to virtually zero, even though none of the authors within the modular tradition denied that people read words in the first place for their meaning.

Re-integrating the semantic system in word naming

The modular view of word processing has been particularly popular among cognitive neuropsychologists (mainly from Europe), who tried to explain the different patterns of lost and preserved functions seen in patients with brain damage (e.g., Ellis & Young, 1997; Shallice, 1988; Shelton & Caramazza, 1999). However, roughly at the same time, an alternative account was developed (initially in the USA) that capitalised extensively on continuous interactions between processing levels: the parallel-distributed-processing or connectionist approach.

The first highly-influential connectionist model of word processing has been published by McClelland and Rumelhart (1981) and was originally developed to explain the word superiority effect (i.e., the finding that letters are identified better when they are part of a word than when they are presented in isolation or in a non-word letter string). The model consists of three layers of processing units: feature detectors, letter detectors, and word detectors. The feature detectors are the horizontal, vertical and oblique lines that constitute the letters. An activated feature detector activates the letter detectors that contain the feature, and inhibits the other letter detectors. Similarly, an activated letter detector activates the word detectors that contain the letter (in that particular position) and inhibits the other word detectors. However, in addition to this bottom-up stream of activation, there are inhibitory connections within the letter and the word level, and facilitatory and inhibitory connections from the word level to the letter level, and from the letter level to the feature level (i.e., top-down influences). Finally, the spread of information between the different levels is continuous: The system does not "wait" until a module has finished its processing before information is passed over, but continuously updates the activation levels. It has been shown that such a model can simulate the word superiority effect and other important empirical results about word and letter perception (Grainger & Jacobs, 1996; McClelland & Rumelhart, 1981). Remark that the model does not include a semantic level either, although the design principles make it easy to imagine an extension to such a level, which would be in continuous interaction with the word level and – hence – all other levels.

A second, major step within the connectionist modelling of word processing was the publication of Seidenberg and McClelland's (1989) distributed model of word naming, thoroughly updated in 1996 (Plaut, McClelland, Seidenberg, & Patterson, 1996). We will discuss the most recent version. The general architecture of the model is shown in Figure 2. The input consists of 105 grapheme units, which describe the structure of virtually every uninflected monosyllabic word in English. These units represent the onsets of words (i.e., the consonants with which words begin), the vowels in the middle of words, and the codas (i.e., the consonants with which words end). Through a layer of 100 hidden units, the grapheme units are connected with 61 phoneme units describing all existing pronunciations of onsets, vowels and codas in monosyllabic words. In addition to the grapheme-to-phoneme conversion system, there is a – hypothesised – second flow of information, going from the grapheme units, through hidden units, to a layer of semantic units, and from there further to the phoneme units. This part of the model was not fully implemented, but simulations were run with the approximate effects this pathway may have on the phoneme units. Note that the model no longer includes a mental lexicon.

- -

Insert Figure 2 about here

- -

For the present purpose, two interesting conclusions emerged from the simulations. First, there is no need for a distinction between a lexical and a non-lexical route to account for the naming times (and errors) of words and non-words; and, second, if the semantic pathway is added to the model, this pathway tends to outperform the direct grapheme-phoneme connection for words with an uncommon pronunciation. As for the first conclusion, before the development of Seidenberg and McClelland's (1989) model, researchers were convinced that two routes were needed to explain the naming of both non-words and irregular words (see above). In addition, a dual-route model seemed to provide a nice account of a robust finding in word naming: the interaction between frequency and regularity. If participants are asked to name aloud printed words, there is virtually no difference in naming times between high-frequency words that follow the grapheme-to-phoneme conversion rules (regular words) and high-frequency words that violate these rules (irregular words). However, for low-frequency words, participants need substantially more time to name irregular words (see Plaut et al., 1996, for a review of the literature). The explanation of the frequency-regularity interaction within the dual-route framework was that, because lexical access time depends on the frequency of the word, the lexical route is particularly interesting for high-frequency words. In this route, a visual word is first recognised and then the pronunciation is "looked-up". Because the look-up process does not take longer for irregular than for regular words, no difference between both types of words is predicted. For low-frequency words, however, due to their slow lexical access, the non-lexical route will be faster, but this route will only be helpful for words with the right grapheme-phoneme translations (i.e., the regular words). For irregular words, it will come up with the wrong pronunciation, which has to be overthrown by the lexical output; hence, the longer naming times for irregular than for regular words in the low-frequency range. What the connectionist model showed, was that the flow of information between grapheme units and phoneme units depended on the spelling-sound consistency (rather than on regularity based on a set of rules) and on the frequency of the word. The phoneme representation of words that consisted of letter sequences with an unambiguous pronunciation (e.g., *best*, *beam*) was retrieved very rapidly, independent of the frequency of the word. However, as soon as there was some ambiguity in the spelling-sound correspondence (e.g. *brown* vs. *blown*), it took the network more and more processing cycles before a stable phoneme representation was reached, the more competitors with a different pronunciation the word had and the less frequent the word was, exactly the pattern of reaction latencies observed with human participants (Plaut et al., 1996).

The second important conclusion Plaut et al. drew on the basis of their model was that when a word was of low frequency and had a less common pronunciation, the semantic pathway tended to be faster than the direct grapheme to phoneme pathway. This is because for this particular class of words it took the model many processing cycles before a stable phoneme representation was achieved on the basis of the graphemic input. In contrast, due to the more straightforward correspondences between the graphemic input and the semantic level and between the semantic level and the phoneme units, the number of processing cycles in the semantic pathway did not differ much between inconsistent, low-frequency words and the other types of words. Therefore, the semantic pathway could contribute to the pronunciation of inconsistent, low-frequency words, whereas for the other words it was outperformed by the direct pathway. Note, however, that the semantic information, due to the continuous interactions with both the grapheme and the phoneme level, is thought to be an integral part of the word recognition process, even though its influences cannot be discerned in the naming times for most words.

Semantic influences on word naming: Empirical findings

In the previous sections, we have described two types of word naming models: a modular one that precludes semantic influences on word naming times in healthy readers, and an interactive one that predicts such influences under particular conditions. At this moment, it may be interesting to see what the empirical data reveal.

At first sight, it seems easy to reject the possibility that the semantic system has little influence on the lexical system, because it is well documented that a word is processed more rapidly when it has been preceded by a semantically related prime. For example, reading aloud the target word *doctor* is facilitated when previously the word *nurse* was shown. This semantic priming effect is not merely due to strategic expectations, as it can be observed with tachistoscopically presented primes that are presented immediately before the target words (e.g., Frenck-Mestre & Bueno, 1999). However, Fodor (1983) argued that such priming effects are not "semantic" but "associative". They are due to the fact that certain words have been frequently linked with one another in our experience (e.g., *mouse* and *cheese*) rather than because the meanings of the concepts are related (e.g. *glove* and *hat*). That is, semantic priming is the result of associations between word representations in the mental lexicon and is not due to influences from the semantic system on the lexical system. Fodor (1990) termed this position the "anti-semantic" modularity view. Subsequent research has indicated that many priming effects are indeed better explained by association strength than by meaning relatedness (e.g., Hino, Lupker, & Sears, 1997), even though many researchers feel association strength does not completely account for the semantic priming effect (e.g., Balota, 1994; Grainger & Frenck-Mestre, 1998). The problem, of course, is how to disentangle meaning relatedness and association strength in a convincing way.

Interestingly, it may be noted that authors sometimes fail to find an effect of semantic priming on word naming latencies. Frost, Katz, and Bentin (1987) showed that word naming was facilitated by the presence of a semantically related prime in English and Hebrew, but not in Serbo-Croatian. They explained this by pointing to the fact that Serbo-Croatian has a transparent, one-to-one mapping from orthography to phonology, so that words in Serbo-Croatian can be read by a non-lexical grapheme-to-phoneme conversion route. Other authors have repeated the absence of semantic priming effects in transparent languages (Baluch & Bester, 1991, for Persian; and Tabossi & Laghi, 1992, for Italian), but only when non-words were included in the list of stimuli to be named.

Other authors have looked directly at the effects of semantic variables on the reading of isolated words (for a review, see Balota, 1994). These variables include concreteness, imageability (see also Strain, Patterson, & Seidenberg, 1995), polysemy (see also Hino & Lupker, 1996; Lichacz, Herdman, LeFevre, & Baird, 1999), and context availability. The general finding is that semantic variables only influence the naming of low-frequency, inconsistent words, as predicted by the Plaut et al. model. However, a problem with this evidence is that none of the reported studies controlled for the age-of-acquisition (AoA) of the stimulus words, a variable strongly correlated with the semantic variables under investigation. It has been shown that the AoA of a word has a significant effect on word naming (Brysbaert, Lange, & Van Wijnendaele, 2000; Gerhand & Barry, 1998) and that, for instance, the apparent effect of imageability on word naming is an artefact of AoA. In particular, both Coltheart, Laxon, and Keating (1988) and Brysbaert et al. (2000) showed that the imageability effect on word naming latencies disappears when the stimuli are controlled for AoA, whereas the influence of AoA remains significant when word imageability is controlled for. In general, the AoA effect is not attributed to the semantic system, but to the speech output system (e.g., Gerhand & Barry, 1998).

In summary, word naming experiments provide suggestive evidence for the influence of semantic variables on word naming. Such evidence is more in line with the interactive models of reading aloud than with the modular models. However, due to the presence of confounding variables, none of the evidence is considered really convincing.

Number naming: The absence of a non-semantic route

The recent attempts to show semantic influences on word naming times should not make us forget that one of the most conspicuous characteristics of word naming is the general absence of semantic effects. Only when the pronunciation of a word is very uncommon (i.e., a low-frequency word with a grapheme sequence that is usually pronounced otherwise) is there some evidence for an effect. This raises the question to what extent other conversions from arbitrary printed input to spoken output occur without semantic mediation. An obvious candidate for such input are the Arabic numerals. After all, there are only 10 digits with a fairly consistent pronunciation. These digits can be combined to form larger numbers, but only a few of these have a non-compound name (i.e., 10, 11, 12, 20, 30, …, 100, 1000, 1000000); the other number names can be assembled on the basis of the constituting digits.

As Deloche and Seron (1987) illustrated, transcoding an Arabic input numeral to a verbal output numeral in principle involves but a few rules, much simpler than the grapheme-phoneme correspondences in most languages. So, a priori there are no reasons not to accept a direct conversion from Arabic numerals to spoken verbal numerals, very similar to the grapheme-to-phoneme conversion module of Figure 1 or the graphemic layer - hidden layer - phoneme layer triad of Figure 2. And indeed, some influential models of number processing have assumed such asemantic conversions (e.g. Campbell, 1994; Cipolotti & Butterworth, 1995; Dehaene, 1992).

However, one of the most important differences between the literature on word processing and the literature on number processing is that whereas it is extremely difficult to find convincing empirical evidence for semantic mediation in word naming, it is virtually impossible to find empirical evidence against semantic mediation in Arabic numeral naming, at least for integer numbers below 100.

The primary meaning of a number is its magnitude information: Two refers to a larger quantity than one, and to a lesser quantity than three. So, magnitude effects are expected in all tasks that involve the meaning of numbers; and this is what has been found. When two numbers have to be compared, reaction latencies are shorter for small numbers (e.g., 1 and 3) than for large numbers (e.g., 51 and 53). In addition, it is more difficult to compare numbers that are close in magnitude (e.g., 1 and 3) than numbers that are further apart (e.g., 1 and 8; for a review of this distance effect, see

Dehaene, Dupoux, & Mehler, 1990). Both findings can easily be accounted for if one assumes a compressed, logarithmic number line, so that the magnitude representations of small numbers are more discernible than those of large numbers. The logarithmic nature of the number line does not only predict the comparison time, but also agrees with the fact that number reading times in a comparison experiment increase as a function of the logarithm of the number magnitude (Brysbaert, 1995, Experiment 1).

However, in a subsequent experiment, Brysbaert (1995) obtained the same logarithmic relation between number magnitude and number reading time when participants were reading Arabic numerals in a Sternberg short-term memory task (i.e., participants first had to read three numbers and then indicated whether a fourth number was one of the preceding three or not). Although this task did not involve any reference to number magnitude, it still had an effect on reading time. Other authors have reported similar magnitude-related effects in non-semantic tasks with Arabic numerals. Duncan and McFarland, 1980), for instance, found a distance effect in a same-different judgement task using pairs of Arabic numerals as stimuli. Pavese and Umiltà (1998) asked their participants to count the number of red items in an array (four or five) and found that reaction latencies were longer when the items were close incongruent digits (e.g., when participants had to count four *3*s) than when the items were far incongruent digits (when participants had to count four *1*s). The distance effect was already present when stimulus arrays were presented for 200 ms only (Pavese & Umiltà, 1999).

With regard to the naming of visually presented Arabic numerals, Brysbaert (1995, Experiment 4) reported that targets are named faster when immediately before a number with a close magnitude was presented than when a number with a more distant magnitude was presented (e.g. *64* was named faster when it was preceded by the number *63* than when it was preceded by the number *61*). Reynvoet and Brysbaert (1999) repeated the distance priming effect with smaller numbers (ranging from *5* to *15*) and tachistoscopic presentation of the primes (see the procedure below). In addition, they found that the priming effect on naming was of the same magnitude as the priming effect on parity judgement. Fias, Brysbaert, Geypens, and d'Ydewalle (1996) showed that small Arabic digits are reacted to faster with the left hand than with the right hand, whereas the reverse is true for large digits. Again, they not only obtained the effect in a parity judgement task (involving semantics) but also when participants had to indicate whether the name of the digit contained an /e/ sound or not. Here too, a semantic effect was obtained in a task involving the transcoding of an Arabic numeral to a spoken output.

Finally, in a review of the neuropsychological literature on numerical cognition, Seron and Noël (1995) noted that no pair of patients has been reported that allows a double dissociation between naming and comprehension of Arabic numerals. As Shallice (1988) argued, convincing neuropsychological evidence for the existence of multiple routes can only be provided by double dissociations. If two routes are postulated from input A to output B, then it should be possible to find (a) a patient with damage to the first route but not to the second, and (b) a second patient with damage to the second route but not to the first. So, if two routes are postulated from Arabic numeral input to verbal output, one semantic and one non-semantic, then ideally it should be possible to describe a patient who still can understand Arabic numerals but no longer name them, and another patient who can name Arabic numerals but does not understand them (just as there are patients who are able to name words without understanding them). It is exactly the absence of the second type of patient in the literature that made Seron and Noël (1995) doubt about the existence of two independent routes for Arabic numeral naming.

As indicated at the beginning of this section, there are no a priori reasons to predict the absence of asemantic naming of Arabic numerals, given the abundant evidence of such naming of words. Post hoc, proponents of lexical models (as in Figure 1) could probably point to the fact that the urges for the creation of a lexicon are much larger in the case of written words than in the case of written Arabic numerals. One of the amazing characteristics of the visual word recognition system is its ability to deal with a complex visual pattern (consisting of very similar characters) in an almost parallel way. It does not take notably longer to read a nine-letter word than a three-letter word (e.g., compare *lucrative* and *rat*, vs. *582617493* and *617*). Second, Arabic numerals only exist in visual form, whereas words can both be written and spoken. And third, words include quite some non-semantic information (e.g., derivations, syntactic roles, gender, number) that does not exist for Arabic numerals. Some authors believe this information is stored in the lexicon. It is not clear what reasons the proponents of alexical models (as in Figure 2) would give to explain why a direct translation from visual input to auditory output exists for words but not for digits.

Pitting Arabic numerals against words

We have seen that there is a remarkable difference between the naming of written words and the naming of Arabic numerals. Whereas the former mainly relies on non-semantic conversion, the latter seems to lack such a possibility. We have further seen that one of the major discussions about word processing concerns the role of the semantic system in word naming. Is it just an epiphenomenon (Figure 1) or does it play an essential role in word recognition (due to the interactions with the grapheme and the phoneme level), but is the onset of its contribution to the phoneme level too slow to influence word naming times (Figure 2)? Because of the processing differences as a function of the input format, numbers may provide an interesting case to investigate this question. Since numbers can unambiguously be described with digits and words, we can examine the consequences of pitting one notation against the other (note that differences in the processing of Arabic and verbal numerals also form a hotly debated issue in mathematical cognition; e.g., Campbell, 1998; Noël, Fias, & Brysbaert, 1997; Noël, Robert, & Brysbaert, 1998).

If words are usually named without semantic mediation and if Arabic numerals do require such mediation, an interesting prediction follows when both notations are presented on the same display. In such a situation, the presence of an Arabic numeral is not expected to interfere with the naming of a verbal numeral, whereas a verbal numeral should interfere with the naming of an Arabic numeral. This is a typical variant of the classical Stroop paradigm. When coloured colour-words are shown, participants name the ink colour of the words faster when the colour is congruent with the word (e.g., the word *red* printed in red) than when the colour is incongruent with the word (e.g., the word *red* printed in green). In contrast, the ink colour has virtually no effect on the word naming (for a review, see MacLeod, 1991). Similarly, it has been shown that incongruence between a word and a picture (e.g., the word *house* and a line drawing of a tree) has little influence on word naming time, but seriously interferes with picture naming (Glaser, 1992; La Heij, Hooglander, Kerling, & van der Velden, 1996). In contrast, the picture strongly interferes with semantic classification of the word, whereas the word hardly interferes with classification of the picture (Glaser, 1992; see above). This has been interpreted as evidence for the fact that pictures directly access an abstract semantic memory (because the essential components are available in the picture), but that words access the semantic memory via a lexicon that carries out a large amount of word processing without semantic interpretation (Glaser, 1992).

Reynvoet, Fias, and Brysbaert (in preparation, Experiment 1) used displays on which an Arabic digit and a verbal numeral (from *zero* to *nine*) were shown one under the other (the notation in the upper part and the lower part was chosen at random). Both numbers were either the same (congruent trials) or different (incongruent trials). In one condition, the task was to name the digit as rapidly as possible; in the other, the word had to be named. Part (a) of Figure 3 shows the main findings. As predicted, reading times for the words did not differ whether the Arabic digit was the same or not; however, digit naming was seriously slower on the incongruent trials than on the congruent trials. To ensure that the asymmetry of the interference effect was not due to the display conditions (the words took more space than the digits), Reynvoet et al. (Experiment 2) repeated the experiment with a parity judgement task instead of a naming task. This time, the incongruency cost was the same for verbal and Arabic numerals (see part (b) of Figure 3), suggesting that both notations have equal access to the semantic information.

- -

Insert Figure 3 about here

- -

The results of Figure 3 are consistent with the idea that words are usually named without semantic mediation, whereas Arabic digits cannot be named without such mediation. However, they still are compatible both with the modular models and the interactionist models. One way to disentangle these types of models is to use priming. As discussed previously, short-term, automatic priming from an Arabic numeral to the naming of a verbal numeral is not expected on the basis of a modular model of word naming. Because the Arabic prime has no direct access to the visual input lexicon, associative priming within the lexicon is not possible, and the semantic system is thought to be rather disconnected from the lexical system. Priming at long time intervals may be possible on the basis of explicit expectations, but short-term, automatic priming is not expected (see Neely, 1991, for a review of these two types of priming). On the other hand, interactive connectionist models, like the one depicted in Figure 2, do predict such priming effects. As soon as semantic units are activated, the flow of information dissipates to the phoneme units and to the grapheme units. Hence, there should be a clear priming effect from Arabic numerals on the naming of verbal numerals.

To investigate automatic priming, Reynvoet et al. (Experiment 4) presented their primes tachistoscopically. That is, first there was a forward mask, consisting of several #-signs, then the prime was presented for 66 ms, followed by a backward mask of #-signs for 66 ms, and the target. The target always was a number word. Participants had to read aloud the word as fast as possible. Primes were either Arabic digits or number words, and the distance between prime and target ranged from 0 (i.e., both pointed to the same magnitude) to +/- 3. Figure 4 shows the priming effects as a function of the distance between the prime and the target, and the notation of the prime (Arabic/verbal). As can be seen, there was a clear distance priming effect, *both for verbal and Arabic primes*. Only the repetition priming effect (distance = 0) was significantly larger for the word-word than the Arabic-word condition; for the other distances, the priming effect was the same in both presentation conditions (the fact that naming latencies in general were faster after an Arabic prime than after a verbal prime, is probably due to the fact that the mask between the prime and the target contained 5 #-signs in the verbal-verbal condition, and only 2 in the Arabic-verbal condition, so that there was less forward masking of the target word in the latter condition). Needless to repeat, the finding that word naming is primed as much by Arabic numerals as by verbal numerals, despite the fact that Arabic numerals do not allow associative priming, is more in line with interactive models of word naming than with modular models.

- -
Insert Figure 4 about here
- -

Conclusion

In this chapter, we have described how a number of observations and considerations made researchers conclude that quite some word processing, and in particular word naming, can be done without semantic mediation. A debate exists, however, about whether this means that the semantic system does not contribute to the word recognition process (i.e., is modulated), or whether word naming times are so fast that the semantic influences cannot be traced in them. Naming Arabic numerals, in contrast, always seems to require access to number magnitude, the major semantic numerical property. For digit naming, there is no evidence in favour of a direct connection between visual input and spoken output. The origin of this contrast between the processing of words and Arabic digits is not known, but probably has to do with requirements limited to the word reading process, as it is generally accepted that other kinds of visual input (in particular line drawings) also require semantic mediation before they can be named (e.g., Glaser, 1992). Placing the verbal and the Arabic format against one another in a Stroop task allowed us to confirm the general picture that words can be read aloud without semantic involvement, whereas Arabic digits require such involvement. When the Arabic digit, however, shortly preceded the verbal numeral, a clear distance priming effect was found on the naming latencies of the target words. Because there are no obvious ways to explain the cross-notational priming effect on the basis of associative priming within a lexical system, this finding argues against Fodor's (1990) anti-semantic modularity view of word naming. In contrast, the finding can easily be integrated within interactive models of word processing.

References

Balota, D.A. (1994). Visual word recognition: The journey from features to meaning. In M.A. Gernsbacher (Ed.), *Handbook of psycholinguistics* (pp. 303-358). San Diego: Academic Press.

Baluch, B., & Besner, D. (1991). Visual word recognition: Evidence for strategic control of lexical and nonlexical routines in oral reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17*, 644-652.

Brysbaert, M. (1995). Arabic number reading: on the nature of the numerical scale and the origin of phonological recoding. *Journal of Experimental Psychology: General, 124*, 434-452.

Brysbaert, M. (1998). Word recognition in bilinguals: Evidence against the existence of two separate lexicons. *Psychologica Belgica, 38*, 163-175.

Brysbaert, M., Lange, M., & Van Wijnendaele, I. (2000). The effects of age-of-acquisition and frequency-of-occurrence in visual word recognition: Further evidence from Dutch. *European Journal of Cognitive Psychology, 12*, 65-85.

Campbell, J.I.D. (1994). Architectures for numerical cognition. *Cognition, 53*, 1-44.

Campbell, J.I.D. (1998). Linguistic influences in cognitive arithmetic: Comment on Noel, Fias and Brysbaert (1997). *Cognition, 67*, 353-364.

Caramazza, A., Hillis, A. E., Rapp, B. C., & Romani, C. (1990). The multiple semantics hypothesis: Multiple confusions? *Cognitive Neuropsychology, 7,* 161-189.

Cipolotti, L. & Butterworth, B. (1995). Toward a multiroute model of number processing: Impaired number transcoding with preserved calculation skills. *Journal of Experimental Psychology: General, 124*, 375-390.

Coltheart, M. (1978). Lexical access in simple reading tasks. In G. Underwood (Ed.), *Strategies of information processing.* London: Academic Press.

Coltheart, V., Laxon, J. J., & Keating, C. (1988). Effects on word imageability and age of acquisition on children’s reading. *British Journal of Psychology, 75*, 1-12.

Dehaene, S. (1992). Varieties of numerical abilities. *Cognition, 44*, 1-42.

Dehaene, S., Bossini, S., & Giraux, P. (1993). The mental representation of parity and number magnitude. *Journal of Experimental Psychology: General, 122*, 371-396.

Dehaene, S., Dupoux, E., & Mehler, J. (1990). Is numerical comparison digital? Analogical and symbolic effects in two-digit number comparison. *Journal of Experimental Psychology: Human Perception and Performance, 16*, 626-641.

Deloche, G., & Seron, X. (1987). Numerical transcoding: a general production model. In G. Deloche & X. Seron (Eds.), *Mathematical Disabilities: A Cognitive Neuropsychological Perspective* (pp. 137-170). Hillsdale, NJ: Erlbaum.

Duncan, E.M., & McFarland, C.E., Jr. (1980). Isolating the effects of symbolic distance and semantic congruity in comparative judgments: An additive factors analysis. *Memory & Cognition, 8*, 612-622.

Ellis, A.W. & Young, A.W. (1997). *Human cognitive neuropsychology: A textbook with readings.* Hove: Psychology Press.

Fias, W., Brysbaert, M., Geypens, F., & d'Ydewalle, G. (1996). The importance of magnitude information in numerical processing: evidence from the SNARC effect. *Mathematical cognition, 2*, 95-110.

Fodor, J.A. (1983). *The modularity of mind*. Cambridge, MA: MIT Press.

Fodor, J.A. (1990) *On the modularity of parsing: A review*. Unpublished manuscript.

Forster; K.I. (1976). Accessing the mental lexicon. In R.J. Wales & E.C.T. Walker (Eds.), *New approaches to language mechanisms* (pp. 257-287). Amsterdam: North Holland.

Frenck-Mestre C., & Bueno S. (1999). Semantic features and semantic categories: Differences in rapid activation of the lexicon. *Brain and Language, 68*, 199-204.

Frost, R., Katz, L., & Bentin, S. (1987). Strategies for visual word recognition and orthographical depth: A multilingual comparison. *Journal of Experimental Psychology: Human Perception and Performance, 13,* 104-115.

Gerhand, S. & Barry, C. (1998). Word frequency effects in oral reading are not merely age-of-acquisition effects in disguise. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24*, 267-283.

Glaser, W.R. (1992). Picture naming. *Cognition, 42*, 61-105.

Glushko, R.J. (1979). The organization and activation of orthographic knowledge in reading aloud. *Journal of Experimental Psychology: Human Perception and Performance, 5*, 674-691.

Grainger, J., & Jacobs, A.M. (1996). Orthographic processing in visual word recognition: A multiple read-out model. *Psychological Review, 103*, 518-565.

Grainger, J., & Frenck-Mestre, C. (1998). Masked priming by translation equivalents in proficient bilinguals. *Language and Cognitive Processes, 13*, 601-623.

Harley, T.A. (1995). *The psychology of language: From data to theory*. Hove: Psychology Press.

Hino, Y., & Lupker, S.J. (1996). Effects of polysemy in lexical decision and naming: An alternative to lexical access accounts. *Journal of Experimental Psychology: Human Perception and Performance, 22*, 1331-1356.

Hino Y., Lupker S.J., & Sears C.R. (1997). The effects of word association and meaning frequency in a cross-modal lexical decision task: Is the priming due to "semantic" activation? *Canadian Journal of Experimental Psychology, 51*, 195-210.

Kay, J. & Marcel, T. (1981). One process not two in reading aloud: Lexical analogies do the work of nonlexical rules. *Quarterly Journal of Experimental Psychology, 33A*, 397-413.

Kroll, J.F. & de Groot, A.M.B. (1997). Lexical and conceptual memory in the bilingual: Mapping form to meaning in two languages. In A.M.B. de Groot & J.F. Kroll (Eds.), *Tutorials in bilingualism* (pp. 169-199). Mahwah, NJ: Erlbaum.

La Heij, W., Hooglander, A., Kerling, R., & van der Velden, E. (1996). Nonverbal context effects in forward and backward word translation: Evidence for concept mediation. Journal of Memory and Language, 35, 648-665.

Lichacz, F.M., Herdman, C.M., Lefevre, J., & Baird, B. (1999). Polysemy effects in word naming. *Canadian Journal of Experimental Psychology, 53*, 189-193.

MacLeod, C.M. (1991). Half a century of research on the Stroop-effect: An integrative review. *Psychological Bulletin, 109*, 163-203.

McClelland, J.L. & Rumelhart, D.E. (1981). An interactive activation model of context effects in letter perception: Part 1. An account of basic findings. *Psychological Review, 88*, 375-407.

Morton, J. (1979). Facilitation in word recognition: Experiments causing change in the logogen model. In P.A. Kolers, M.E. Wrolstad, & H. Bouma (Eds.), *Processing of visible language* (pp. 259-268). New York: Plenum.

Morton, J. & Patterson, K.E. (1980). A new attempt at an interpretation, or, an attempt at a new interpretation. In M. Coltheart, K.E. Patterson, & J.C. Marshall (Eds.), *Deep dyslexia.* London: Routledge and Kegan Paul.

Neely, J.H. (1991). Semantic priming in visual word recognition: A selective review of current findings and theories. In D. Besner & G.W. Hymphreys (Eds.), Basic processes in reading: Visual word recognition (pp. 264-336). Hillsdale, NJ: Erlbaum.

Noël, M.P., Fias, W., & Brysbaert, M. (1997). About the influence of the presentation format on arithmetical-fact retrieval processes. *Cognition*, *63*, 335-374.

Noël, M.P., Robert, A. & Brysbaert, M. (1998). Does language really matter when doing arithmetic? Reply to Campbell (1998). *Cognition, 67*, 365-373.

Pavese, A., & Umiltà, C. (1998). Symbolic distance between numerosity and identity modulates Stroop interference. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 1535-1545.

Pavese, A., & Umiltà, C. (1999). Further evidence on the effects of symbolic distance on Stroop-like interference. *Psychological Research, 62*, 62-71.

Plaut, D. C., McClelland, J. L., Seidenberg, M. S., & Patterson, K. (1996). Understanding normal and impaired word reading: Computational principles in quasi-regular domains. *Psychological Review, 103*, 56-115.

Reynvoet, B., & Brysbaert, M. (1999). Single-digit and two-digit Arabic numerals address the same semantic number line. *Cognition, 72*, 191-201.

Schwartz, M.F., Saffran, E.M., & Marin, O.S.M. (1980). Fractioning the reading process in dementia: Evidence for word-specific print-to-sound associations. In M. Coltheart, K.E. Patterson, & J.C. Marshall (Eds.), *Deep dyslexia.* London: Routledge and Kegan Paul.

Seidenberg, M.S., & McClelland, J.L. (1989). A distributed, developmental model of word recognition and naming. *Psychological Review, 96*, 523-568.

Seron, X., & Noël, M.P. (1995). Transcoding numbers from the Arabic code to the verbal one or vice versa: How many routes? *Mathematical Cognition, 1,* 215-243.

Shallice, T. (1988). *From neuropsychology to mental structure.* Cambridge: Cambridge University Press.

Shallice, T. (1993). Multiple semantics: Whose confusions? *Cognitive Neuropsychology, 10*, 251-261.

Shelton, J.R., & Caramazza, A. (1999). Deficits in lexical and semantic processing: Implications for models of normal language. *Psychonomic Bulletin & Review, 6*, 5-27.

Strain, E., Patterson, K., & Seidenberg, M.S. (1992). Semantic effects in single-word naming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21*, 1140-1154.

Tabossi, P., & Laghi, L. (1992). Semantic priming in the pronunciation of words in 2 writing systems: Italian and English. *Memory & Cognition, 20*, 303-313.

Vandenberghe, R., Price, C, Wise, R., Josephs, O, & Frackowiak, R. S. J. (1996). Functional anatomy of a common semantic system for words and pictures. *Nature, 383,* 254-256.

Figure 1 : Morton and Patterson's three-route model of word naming. Note that although there are double arrows between the input lexica and the cognitive system, within the modular models these are not interpreted as an indication of continuous and symmetric exchange of information (see the text for more details).

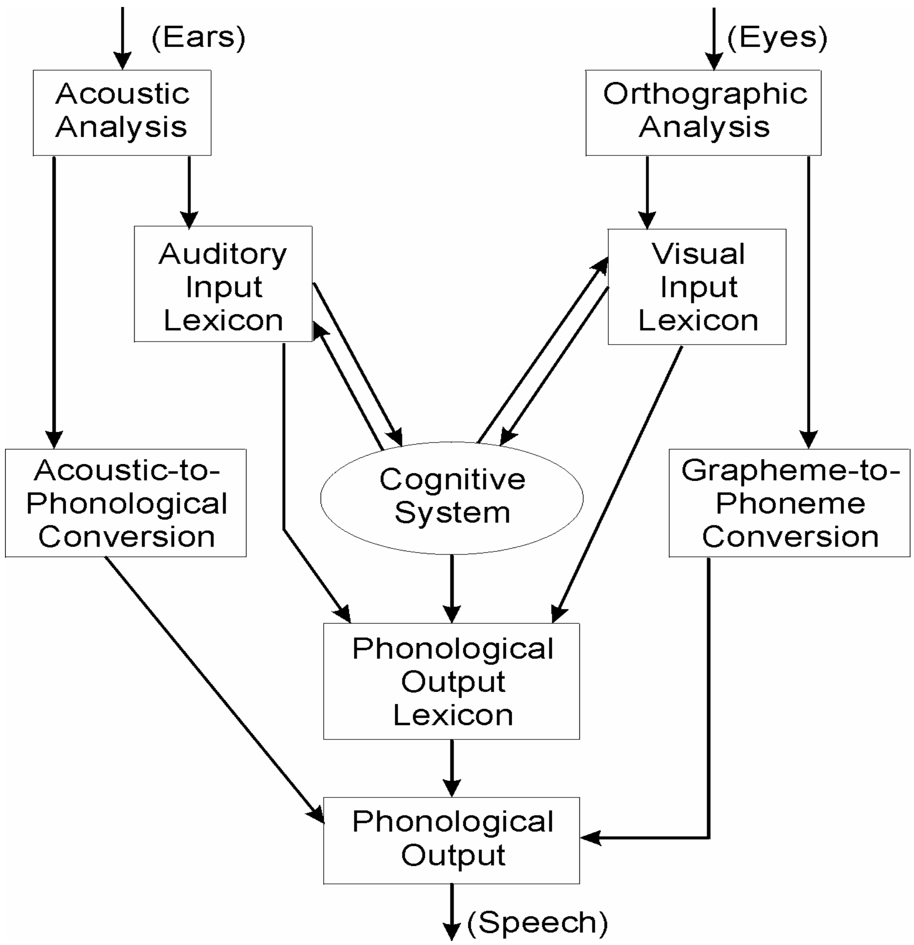


Figure 2: Plaut et al.'s model of word naming.

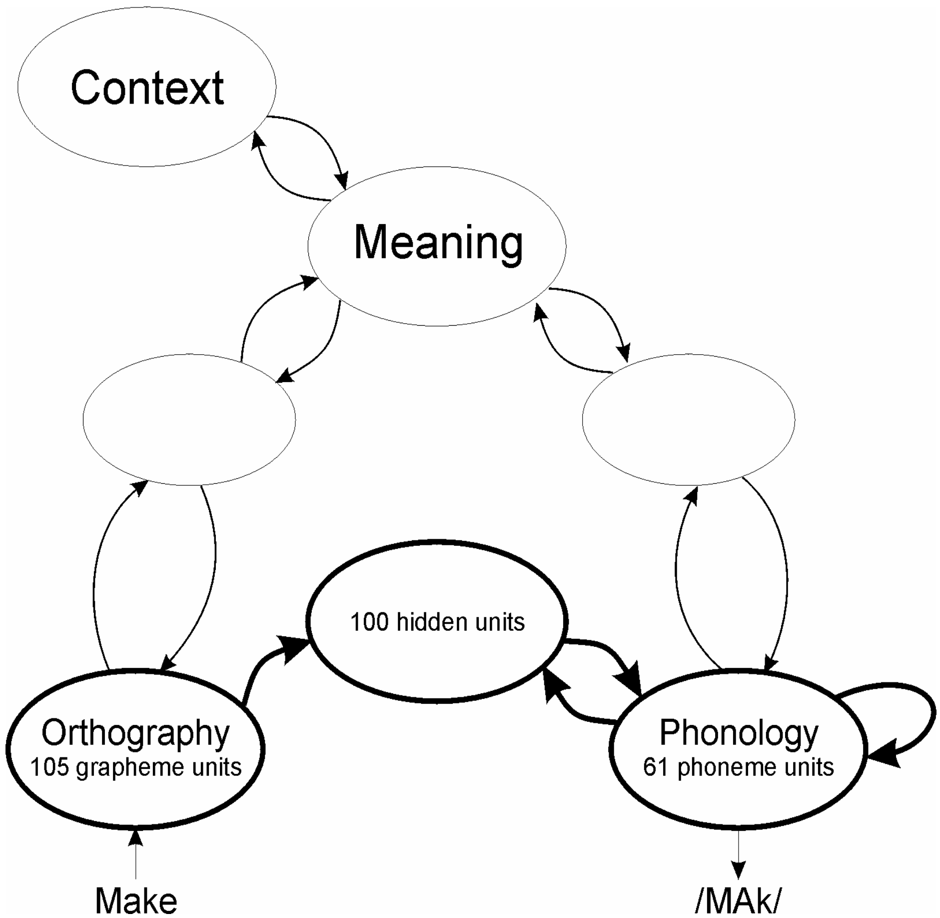
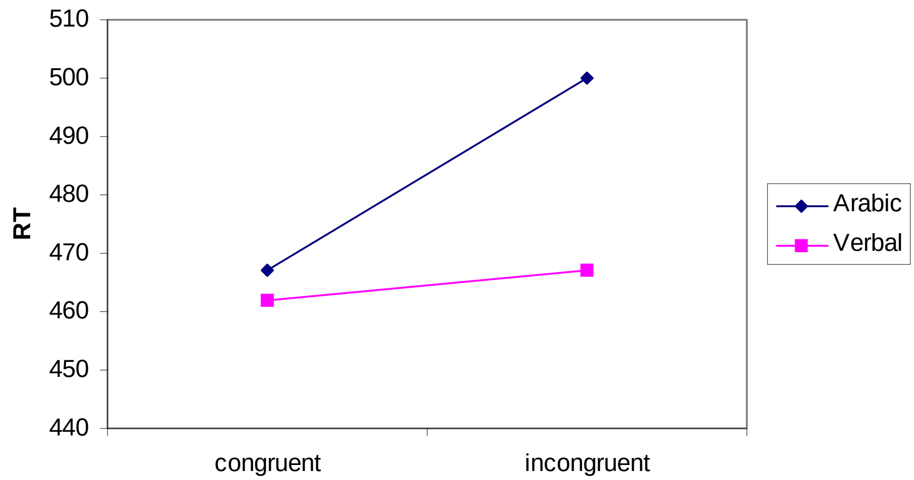


Figure 3: Response latencies in a Stroop-task with digit/word targets/distracters (Reynvoet et al., in preparation). (a) Naming latencies for words and digits as a function of congruency with the distracter presented in the other modality. (b) Parity judgement times for words and digits as a function of congruency with the distracter.

a)



b)

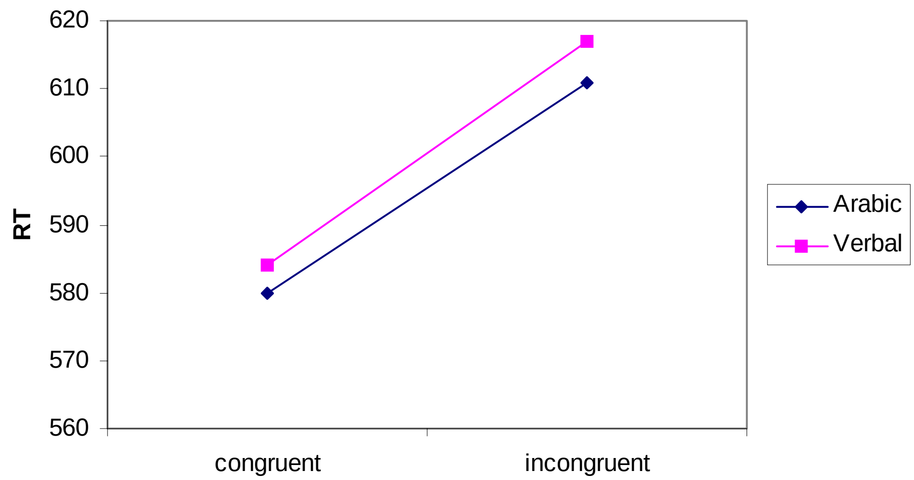


Figure 4 : Naming latencies of number words preceded by a tachistoscopically presented Arabic or verbal prime with a magnitude close to the target (Reynvoet et al., in preparation).