

DOTTORATO IN COTUTELA

**The effects of a concomitant distractor on word reading
aloud and picture naming tasks**



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Abstract of Thesis

The aim of this thesis was to investigate properties of the human reading and speech production systems using picture naming or word reading tasks in four paradigms, all involving to-be-ignored distractors: 1) Picture-Nonword Interference, PNWI 2) Picture-Word Interference, PWI 3) Word-Word Interference, WWI 4) Word-Nonword Interference, WNWI. The dual route theory of reading was the theoretical framework for discussing the results. Human data and DRC simulations, using a new Semantic version of the DRC model, are reported. Paper 1 of the thesis investigated the effects of nonword distractor length, target length, and initial and final target-distractor phonological relatedness on the PNWI effect. Furthermore, it reports the first attempt in the psycholinguistic literature to disambiguate between the role of the number of phonemes or the number of syllables in the nonword distractor length effect observed in PNWI. Paper 2 explored the role of target picture frequency on the PNWI and PWI effects. Comparisons between human data and simulations led to the suggestion that the phoneme level of the human system possesses a relative-position coding scheme rather than the absolute-position coding scheme postulated by the DRC model. Paper 3 used the WWI and WNWI paradigms to investigate the interplay between the lexical and nonlexical routes by varying nonword distractor length, nonword distractor pronounceability and word target frequency. Overall the results reported in the thesis emphasize the interplay between the lexical, nonlexical and semantic routes together with the inability of the human speech production and reading system to ignore the distractors in these four paradigms. More importantly the results demonstrate that in the human speech production system position coding at the phoneme level does not use an absolute-position coding scheme.

Introduction

In daily life humans are typically faced with performing multiple tasks at the same time: reading silently while drinking coffee, listening to music while studying or running, walking while speaking to a friend, cooking while watching TV and so on. These are just a few very common examples. Usually performance on each of these tasks is affected by the concurrent tasks. The size of the interference or facilitation, though, depends on the demands of all the other concurrent tasks. For instance it has been shown that performance in a simulated driving task is affected by a word production task and the size of this interference increases as the difficulty of the driving task increases (Strayer & Johnston, 2001; Strayer, Drews & Johnston, 2003).

Issues concerning processing resources in attention, dual task performance and workload assessment have been widely studied in psychology, especially cognitive psychology. Efforts have been made to establish what the nature of dual task interference is. Does it reflect a functional limit of the cognitive system, or a structural limit? Does it reflect an overlapping in sharing the same process or an overlapping in time? Are there multiple resources available to the human system or is there one unique resource of attention that is limited? A major aim of cognitive science research over the last 60 years has been to address questions concerning the dynamics of the timing of the tasks that are performed and questions concerning the cognitive processes responsible for the interference. Certainly, what these interference effects suggest is that some cognitive components required for concurrent task resolution depend upon shared processing mechanisms.

One of the human abilities apparently based on dedicating processing mechanisms is our linguistic ability. Linguistic processes may be specialized, as they may be based on a substrate that is cognitively, anatomically and genetically distinct from that of other, nonlinguistic processes (Pinker, 1994). Furthermore, language skills are widely practiced during one's lifetime, which might be the reason why language tasks are performed quite automatically in adults and why the processes that govern linguistic tasks are specific, dedicated and modular (modular processes as defined by Sternberg (1969, 1998b)). For example, in spontaneous speech and conversation humans are able to utter about three words per second while producing only about one error every 1000 words (Levelt, 1981).

Processing mechanisms that instead of being task-specific are drawn upon by distinct unrelated tasks could be termed as central processing mechanisms (as in Ferreira & Pashler (2002)). In their work Ferreira & Pashler (2002) investigated the modular vs. central nature of linguistic processing, looking at spoken word production. They specifically avoided complex

linguistic tasks such as sentence comprehension or sentence production, which might not solely require language-dedicated processes. Spoken word production instead is discrete as it is thought to be served by a modular linguistic system, which is highly specific and independent from other mechanisms. Ferreira & Pashler's rationale behind, it is as follows: if in a spoken word production task they obtained an interference effect from a concurrent nonlinguistic task then the word production task is not purely domain specific but involves other more nonspecific central cognitive processes. On the other hand, if they obtained no effects on the performance of a spoken word production task of a concurrent and irrelevant nonlinguistic task, then this result would support the view that word production is carried out by a domain specific process that works as a module, functionally independent and specialized.

Ferreira & Pashler (2002) report two Psychological Refractory Period (PRP) studies (for a detailed description of this paradigm see Pashler (1994)). In summary, they showed that the durations of the word-production stages of lemma selection and phonological word-form selection (early word production stages) are subject to a central processing bottleneck, whereas the later stage of phoneme selection is not, implying that lemma selection and phonological word-form selection stages require cognitive attentive resources that are not specifically dedicated to language but serve other cognitive tasks.

Following this study, much other PRP work has been conducted to characterize the effect of psycholinguistic variables in the PWI paradigm. In this work, the word "central" refers to the requirement of general cognitive attentive resources. For instance 1) the effect of Age of Acquisition (AoA) in PWI (faster picture naming latencies for pictures whose names have been acquired early in life) has been shown to be pre-central (Dent, Johnston & Humphreys, 2008); 2) the semantic interference effect in PWI (slower picture naming latencies for picture paired with semantically related distractors) has been shown to be pre-central (Ferreira & Pashler, 2002; Dell'Acqua, Job, Peressotti & Pascali, 2007; Dent et al., 2008); 3) the frequency effect in PWI (faster target naming latencies for picture whose names are high frequency names) has been shown to be central (the target frequency effect in PWI is an effect occurring at lexical access, at the stage of accessing the word-form rather than the lemma (Levelt, Roelofs & Meyer (1999), p. 18); 4) the phonological facilitation effect in PWI (faster naming latencies for pictures paired with onset phonological related distractors) has been shown to be post-central (Ferreira & Pashler, 2002).

The experimental paradigms used in this thesis can be seen as dual task paradigms (and are thus analogous to the PRP paradigm) because the instructions given to the participants are twofold in that they imply an overt task (naming pictures or reading words aloud) and a covert task (disregarding written distractor stimuli). Hence, in a similar way we

can explore - with the paradigms of this thesis - how the execution of each task affects performance of the other. This allows us to seek an understanding of which processes of the word production and reading aloud task are common and shared between these two tasks.

Differences between reading aloud and picture naming

It is well accepted that reading aloud and picture naming tasks are different in many aspects and involve different language stages and mechanisms. Picture naming latencies are much slower than latencies for reading aloud words (Potter & Faulconer, 1975). A major reason for this difference is the fact that accessing the name of a picture requires accessing the conceptual system and the semantic system, in order to activate the meaning (abstract concept) of the visual representation. This is required for access to the phonological representation of the picture's name (see e.g. Roelofs (2002a), Friedmann, Biran & Dotan (2012) for a generic model of word production and picture naming or Strijkers & Costa (2011) for a schematic model of object naming). Reading a word aloud instead can happen by direct communication between orthography and phonology, without requiring the involvement of the conceptual and semantic systems (Morton & Patterson, 1980; McCann & Besner, 1987; Coltheart, Rastle, Perry, Langdon & Ziegler, 2001), which is essential for picture naming tasks. In other words, in reading aloud the phonology of a written word is directly activated from its orthography and the activation of semantics from print proceeds in parallel with the activation of phonology from print, rather than constituting a mandatory step in the activation of phonology from print (Coltheart et al., 2001). In contrast, in picture naming the activation of semantics is a mandatory step toward the activation of the phonology (Roelofs, 2004; Dell'Acqua, Sessa, Peressotti, Mulatti, Navarrete & Grainger, 2010; Mulatti, Peressotti, Job, Saunders & Coltheart, 2012).

Current literature on the brain regions and neural circuits involved in these two tasks also suggests that there are different neural substrates subserving different forms of processing.

Fiez, Balota, Raichle & Petersen (1999) used functional neuroimaging to investigate three factors that affect reading performance 1) the lexicality of the stimuli (words *vs.* nonwords), 2) frequency (high frequency words *vs.* low frequency words) and 3) consistency (whether the pronunciation has a predictable spelling-to-sound correspondence). A left frontal region showed effects of consistency and lexicality, indicating a role in orthographic to phonological transformation. Motor cortex showed an effect of consistency bilaterally, suggesting that motoric processes beyond high-level representations of word phonology influence reading performance.

Other studies using functional neuroimaging indicate that a region in the left frontal operculum (FO) is more active when subjects read pronounceable nonwords as compared to words. Fiez, Tranel, Seager-Frerichs & Damasio (2006) tested the prediction that subjects with left FO damage would have impaired reading of pronounceable nonwords but relative undamaged performance on reading words aloud i.e. the form of acquired dyslexia known as “phonological dyslexia”. Subjects with left FO damage were found to have significant problems on a set of tasks that measured nonword reading. These results support the view that some forms of phonological dyslexia reflect a deficit in phonological processing (Farah, 1996; Patterson & Ralph, 1999; Harm & Seidenberg, 2001) rather than a specific disorder of orthographic to phonological transformation.

Fiez et al. (2006) advanced three hypotheses about the role of the FO, on the basis of broader evidence that links the inferior frontal gyrus to speech production (Greenlee, Oya, Kawasaki, Volkov, Kaufman, Kovach, Howard & Brugge, 2004; Hickok & Poeppel, 2004; Watkins & Paus, 2004). The first hypothesis was that the left FO specifically supports tasks that target sublexical or phonological segmentation processes (Lesch & Martin, 1998; Burton, Small & Blumstein, 2000). The second hypothesis was that the FO helps to control phonological representations and processes supported by posterior language regions (Harm & Seidenberg, 1999). The third hypothesis was that the left FO might support articulatory processes that are engaged by the rehearsal of information in verbal working memory and the blending of phonological information during nonword reading and some form of nonword repetition (Patterson & Marcel, 1992; Burton et al., 2000; Patterson, 2000). Jobard, Crivello & Tzourio-Mazoyer (2003) reported the results of a meta-analysis conducted on 35 neuroimaging studies of word and pseudoword reading. They did not obtain evidence for any cluster of activation more recruited by word than by pseudoword reading, suggesting that the first stage of orthographic processing for reading aloud may be common to words and pseudowords and would take place within a left occipitotemporal region (the visual word form area - VWFA) situated in the ventral route, at the junction between inferior temporal and fusiform gyri. In contrast, there are regions which are predominantly involved in specific components of the human reading system: graphophonological conversion seems to rely on left lateralized brain structures such as superior temporal areas, supramarginal gyrus and the opercular part of the inferior frontal gyrus (the last two regions imposing a greater load in working memory). The lexical–semantic route is served by the coactivation of the VWFA and the semantic areas, namely the basal inferior temporal area, the posterior part of the middle temporal gyrus and the triangular part of inferior frontal gyrus. These results confirm the suitability of the dual route framework to account for activations observed in subjects with no language impairments in reading tasks (see Figure 1, Jobard et al. (2003), Fig. 5).

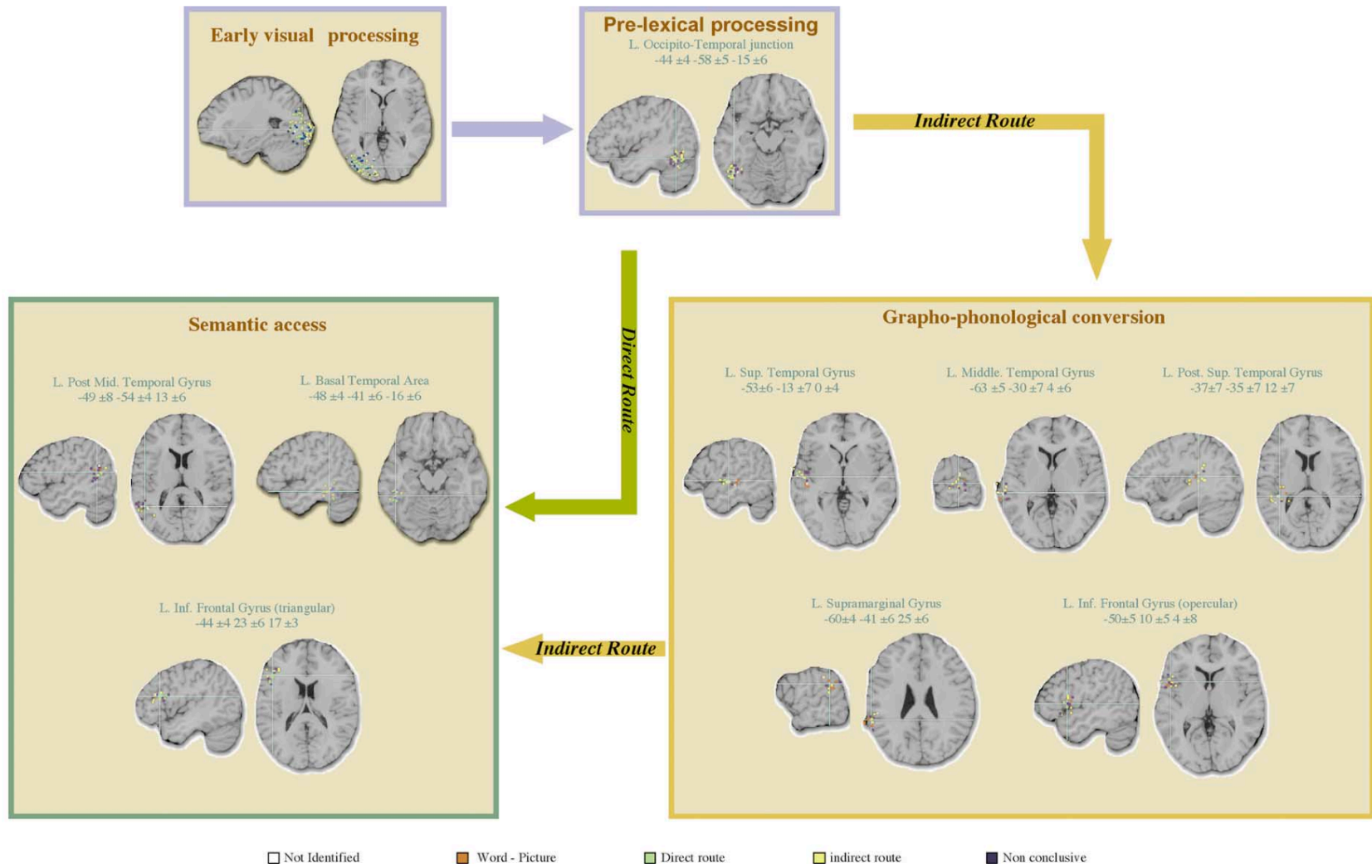


Figure 1. Jobard et al. (2003), Fig. 5. Dual route model of reading as suggested by the meta-analysis of results published in neuroimaging studies.

Concerning picture naming, in a PET study Murtha, Chertkow, Beauregard & Evans (1999) showed that the activation of the fusiform gyrus is most likely related to visual perceptual semantic processing. Additionally, Sebastian, Gomez, Leigh, Davis, Newhart & Hillis (2014) reported an MRI study with participants having an acute left hemisphere ischaemic stroke. In their study the Brodmann's area (BA) 37 – the occipitotemporal area – was shown to have two important functions: a) the computation of case, font, location and orientation-independent grapheme descriptions for written word recognition and production (reading and spelling), function carried out by the left midfusiform gyrus; and b) assessing modality-independent lexical representations for output (naming pictures and reading and spelling of irregular or exception words). This role may depend on the lateral part of BA 37 in inferior temporal cortex.

Price (2000) has proposed a model illustrating how functional neuroimaging can contribute to cognitive and anatomical models of language and reconcile the different perspectives, the anatomical ambitions of the 19th century neurologists and the cognitive finesse of the 20th century cognitive models (see Figure 2, Price (2000), Fig. 12).

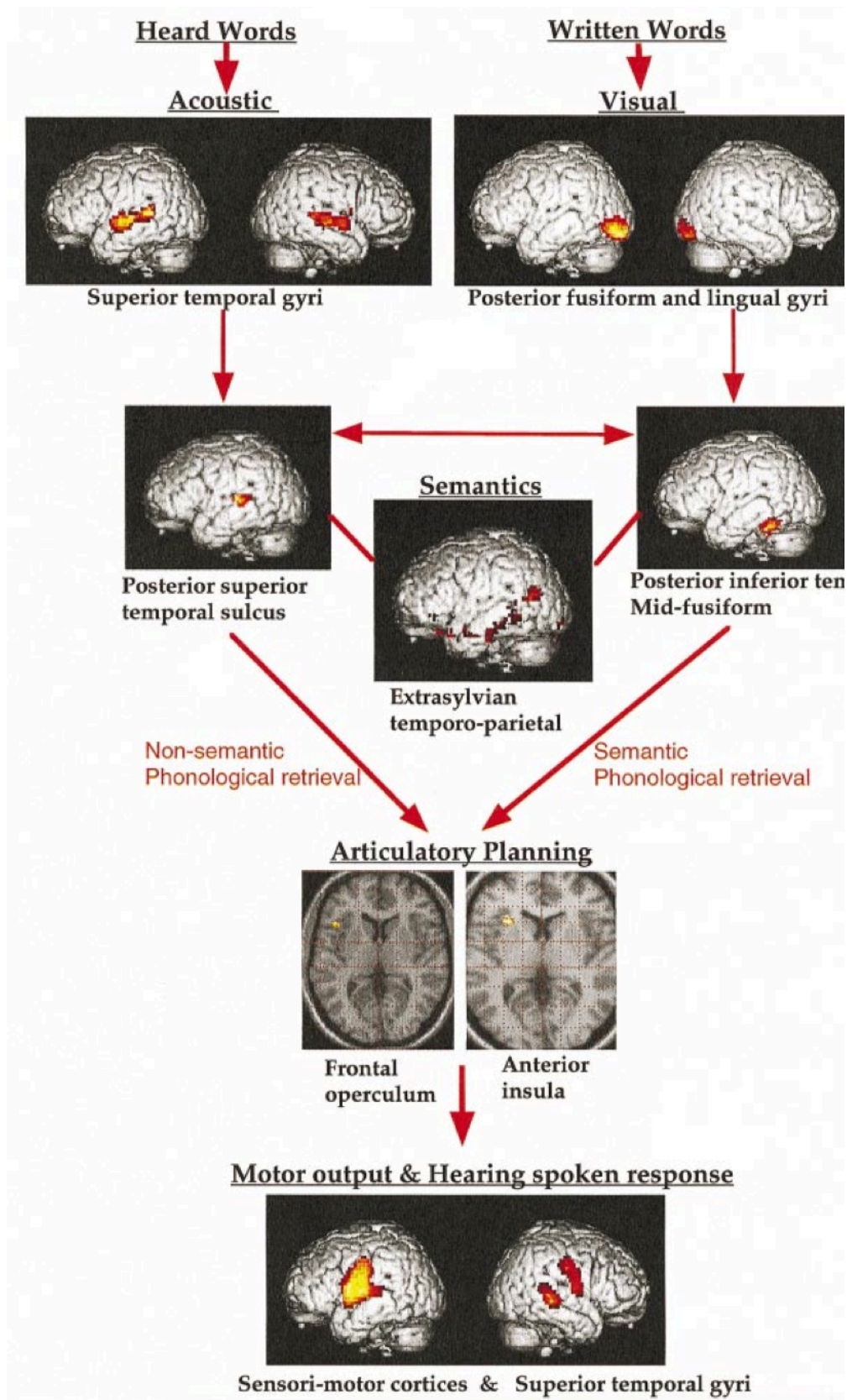


Figure 2. Price, 2000, Fig. 12. Proposed neurological and cognitive model of language.

Recently Duffau, Moritz-Gasser & Mandonnet (2014) proposed instead a dynamic distributed model of language processing realized by means of brain stimulation mapping

during picture naming (see Figure 3, Duffau et al. (2014), Fig. 2).

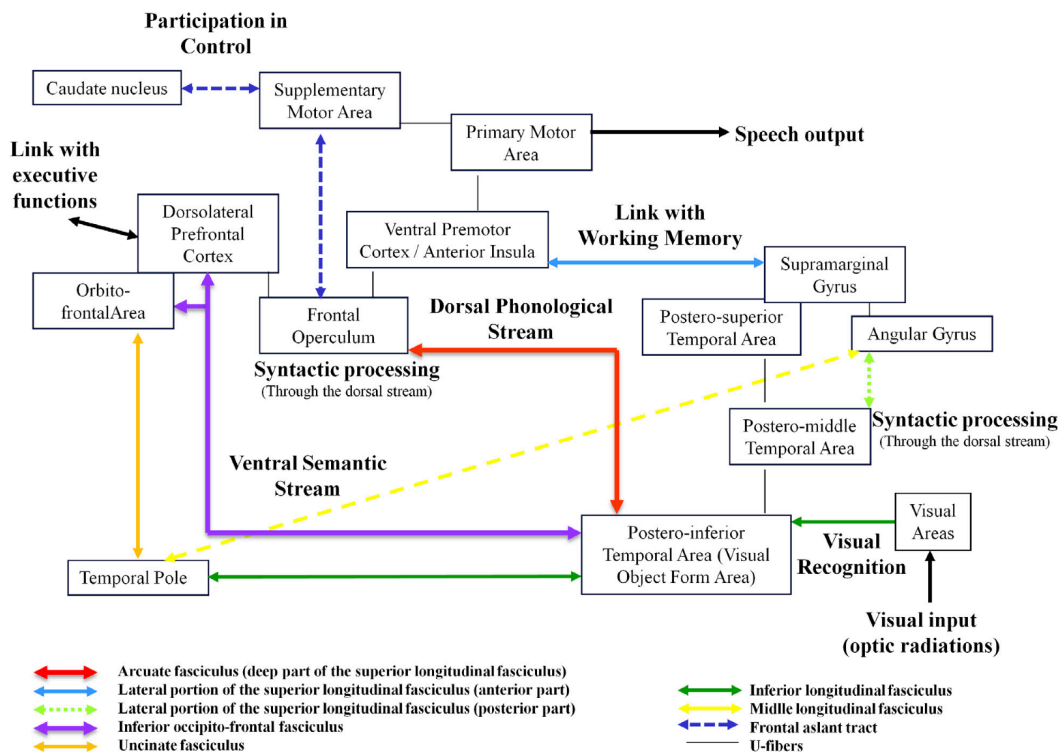


Figure 3. Duffau et al., 2014, Fig 2. Proposal of a hodotopical¹ model of language, with incorporation of anatomic constraints, elaborated on the basis of structural–functional correlations provided by intraoperative direct electrical stimulation.

This model has the advantages of explaining double dissociations observed in lesion studies such as those between comprehension and picture naming disorders, between semantic and phonemic paraphasia, between syntactic and naming disturbances, and between multimodal (visual/auditory) integration disorders and naming disorders. Furthermore, it takes into account the anatomic constraints both at cortical and axonal levels. It also explains the mechanisms of compensation underlying brain plasticity and recovery of aphasia following a permanent lesion. Finally, it establishes links with amodal cognitive functions such as working memory and executive control.

Hickok (2012) instead formulated a model of speech production that integrates theoretical constructs from linguistic and motor control views and he linked the model to underlying neural circuits. This integration led to the identification and proposal of new features: parallel activation of phonological forms, a computational architecture that integrates motor selection, forward prediction, error detection and error correction into one

¹ A revisited model of language, not modular, in which language is conceived as resulting from parallel processing performed by distributed groups of connected and synchronized neurons, rather than by individual centers (Duffau, 2008). In this framework, language is underlain by large-scale sub-networks interacting together and able to compensate themselves after brain lesion (at least to some degrees), opening the door to brain plasticity (Duffau, H., Moritz-Gasser, S. & Mandonnet, E., (2014). A re-examination of neural basis of language processing: proposal of a dynamic hodotopical model from data provided by brain stimulation mapping during picture naming. *Brain and language*, 131 1-10.).

mechanism. Furthermore, the model encompasses the idea that there is a rough correspondence between linguistic notions such as phonemes and syllables and motor control circuits involving somatosensory and auditory systems. All in all, this model incorporates processing levels identified in psycholinguistic research and the ones identified in the motor control approaches to speech production (see Figure 4 Hickok (2012), Fig. 4, for a schematic architecture of the state feedback control model).

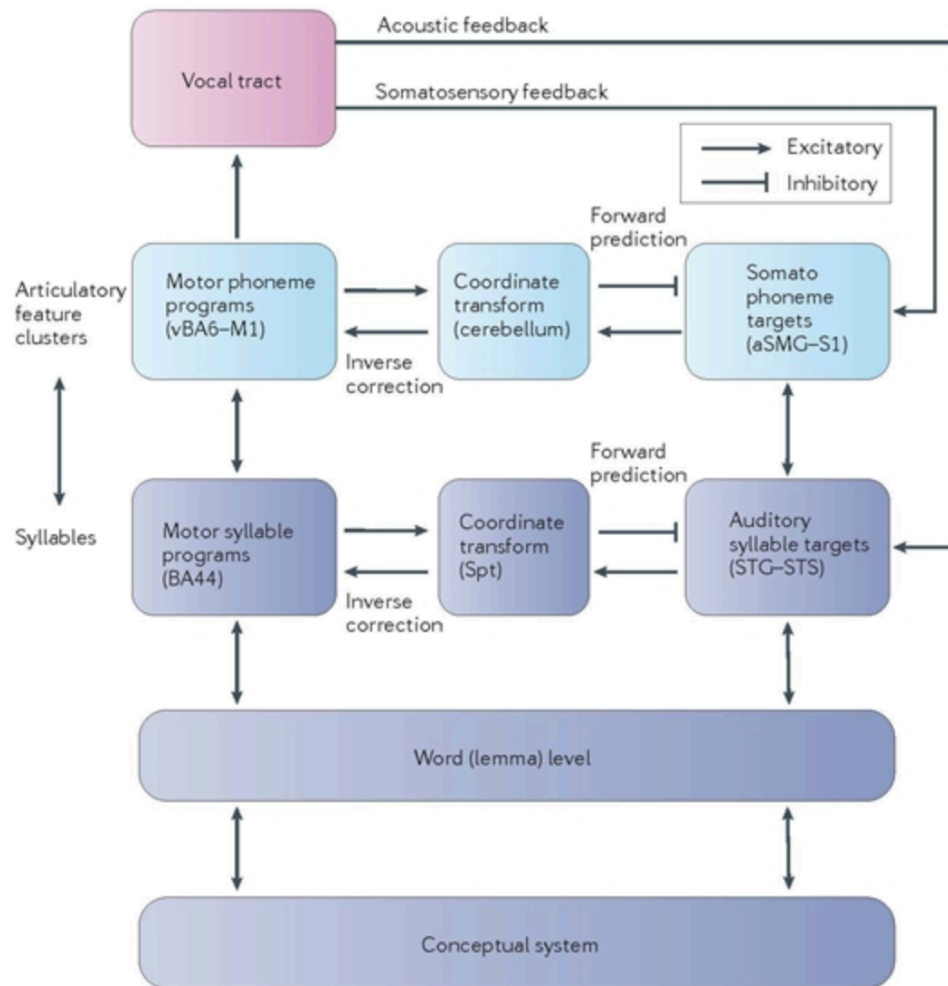


Figure 4. Hickok 2012, Fig. 4. A schematic architecture of the state feedback control model.

Returning to the issue of picture naming, Friedmann et al. (2012) reported that conceptual processing was found to involve activation in the posterior inferior parietal lobe, middle temporal gyrus (MTG), the fusiform and parahippocampal gyri, the dorsomedial prefrontal cortex and the posterior cingulate gyrus, primarily in the language dominant (usually left) hemisphere.

The mid section of the left MTG is active during word generation and picture naming but not in reading. Indefrey (2011) concluded that this region subserves “conceptually-driven lexical selection”. Maess, Friederici, Damian, Meyer & Levelt (2002) showed that the MTG is activated around an early time window of 175–250ms, the time window during which the

selection of the entry in the semantic lexicon is assumed to occur.

MEG studies of the left superior temporal gyrus (STG) show activation in time windows starting at 275ms after the presentation of the stimulus and onwards, which is assumed to be the period at which the phonological output lexicon is accessed (Indefrey, 2011). Data from a patient with an impairment in the phonological output buffer suggest that the left posterior inferior frontal gyrus serves post lexical stages while the right supplementary motor area (SMA) and the left anterior insula were suggested to be post buffer phonetic areas, related to articulatory processing (Indefrey & Levelt, 2004).

Concerning the phonological level, which is the major level of interest of this thesis, studies of impairments in the phonological output buffer in conduction aphasia have consistently indicated that phonological buffer impairments are related to lesions in the STG and inferior parietal cortex (Baldo, Klostermann & Dronkers, 2008), in the left posterior STG (Hickok & Poeppel, 2000) and in the anterior supramarginal gyrus (Damasio & Damasio, 1980).

Several models were mentioned in this section with the purpose to give an overview of the current literature and the most recent approaches used in the study of language, reading and picture naming. These models cannot be adopted in simulating our behavioural results since none of them is a computational model but instead they are theoretical models that link the functional architecture of language with its neural and neuroanatomical substrates.

Word planning and executive control.

Following Miyake, Friedman, Emerson, Witzki, Howerter & Wager (2000), executive control is assumed to include updating, shifting and inhibiting abilities. As pointed out by Roelofs (2008), attentional influences in cortical pathways of word planning need to be distinguished from the brain structures that exert control over those influences (see Figure 5, Roelofs (2008) Fig.1, for an illustration of the cortical anatomy of attention to word planning).

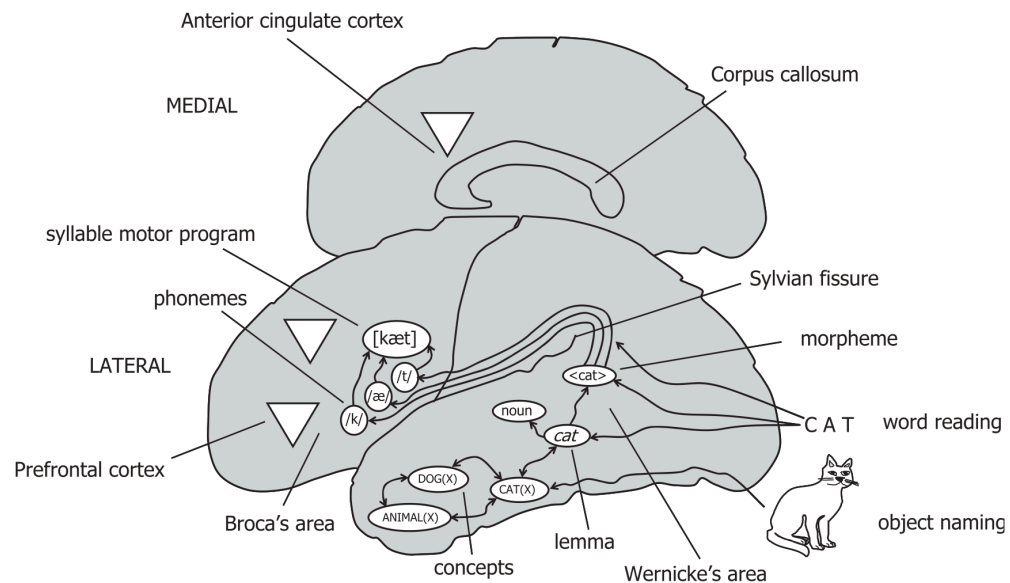


Figure 5. Roelofs 2008, Fig.1. Cortical anatomy of attention to word planning illustrated by medial and lateral views of the human brain.

According to neuroimaging studies, the anterior cingulate cortex (ACC) and the lateral prefrontal cortex (LPFC) are more active in word generation, when the executive control demands are high, than in word reading, when the demands are much lower. The increased activity in the frontal areas shows the following properties:

1. It disappears when word selection becomes easy after repeated generation of the same word (Petersen, Van Mier, Fiez & Raichle, 1998).
2. It is higher for objects with multiple candidate lexical entries (Kan & Thompson-Schill, 2004).
3. Frontal areas are more active when retrieval fails and words are on the tip of the tongue than when words are readily available (Maril, Wagner & Schacter, 2001).
4. Frontal areas are more active also in the PWI task with semantically related distractors superimposed, than when there are no word distractors (de Zubicaray, Wilson, McMahon & Muthiah, 2001).

Thus ACC and LPFC are involved in executive aspects of attention to word planning, though these areas seem to play different roles. ACC activity seems to reflect the detection of response conflict and acts as a signal that engages executive control processes subserved by LPFC. Furthermore, ACC is engaged in the regulation of response selection (Roelofs, van Turennout & Coles, 2006). Aarts, Roelofs & van Turennout (2009) reported an fMRI study that examined which areas in frontal cortex, included medial frontal cortex (MFC), are implicated in response conflict, task conflict or both. The imaging data revealed activity in

both the ACC and a more dorsal region in the MFC (the medial superior frontal gyrus) related to response conflict as well as to task conflict. In LPFC response conflict was associated with activity in ventral LPFC, whereas task conflict activated both ventral and dorsal regions. Whilst the type of conflict (response *vs.* task) was differentiated in LPFC, no such differentiation was found in MFC, including the ACC.

Piai, Roelofs, Acheson & Takashima (2013) suggests that the dorsal anterior cingulate cortex (ACC) is activated in the performance of three different tasks (Stroop, PWI and Simon tasks) – specifically for the incongruent trials. What its activation suggests is that in all these three tasks – which are attentional demanding tasks but in which the amount of linguistic processing is varied – regulatory and monitoring processes are involved for the solution of the task. This region might thus subserve a domain-general attentional control function. Moreover, the two tasks in which language was mostly involved (the Stroop and the PWI task) elicited the activity of the anterior STG. This substrate might instead be language specific.

Taking into consideration the results of Piai et al. (2013), one would expect that during the performance of experimental tasks like the PWI, PNWI, WWI and WNWI paradigms, some language specific substrate will be active together with areas of the brain that have a role in inhibiting the written distractor stimulus. Note that the distractor was presented 1) upon the target picture - when the picture stimulus is the target stimulus – or 2) centrally in the visual field (when the written word stimulus is the target stimulus presented either above or below the distractor one). The last mentioned areas govern attentional control and attentional filtering (Marini, Chelazzi & Maravita, 2013), processes which allow the selection of the relevant stimulus for the correct solution of the primary task (naming the target picture or the target word), (but see Shao, Meyer & Roelofs (2013) for evidence supporting the distinction between selective and nonselective inhibition of competitors in picture naming).

Picture-Nonword Interference and Picture-Word Interference tasks

These two paradigms represent two ways in which a researcher can explore and study 1) how the cognitive system deals with a dual task situation in which a picture name has to be activated and produced while ignoring the written stimulus presented upon the picture; 2) how the reading system faces this situation: since reading a written stimulus demands few resources, and since written word distractors are presented foveally, how is the instruction to ignore the distractor word obeyed?; 3) how the human speech production system can obey the instruction of naming the picture while ignoring or suppressing the output that belongs to the reading system which computes or activates the phonology of the distractor; 4) the interplay

between the semantic, lexical and nonlexical routes.

The PWI paradigm has been used to explore the stages of lexical access (see Figure 6, Roelofs (2002a) Fig. 2, for a frequently-used model of lexical access).

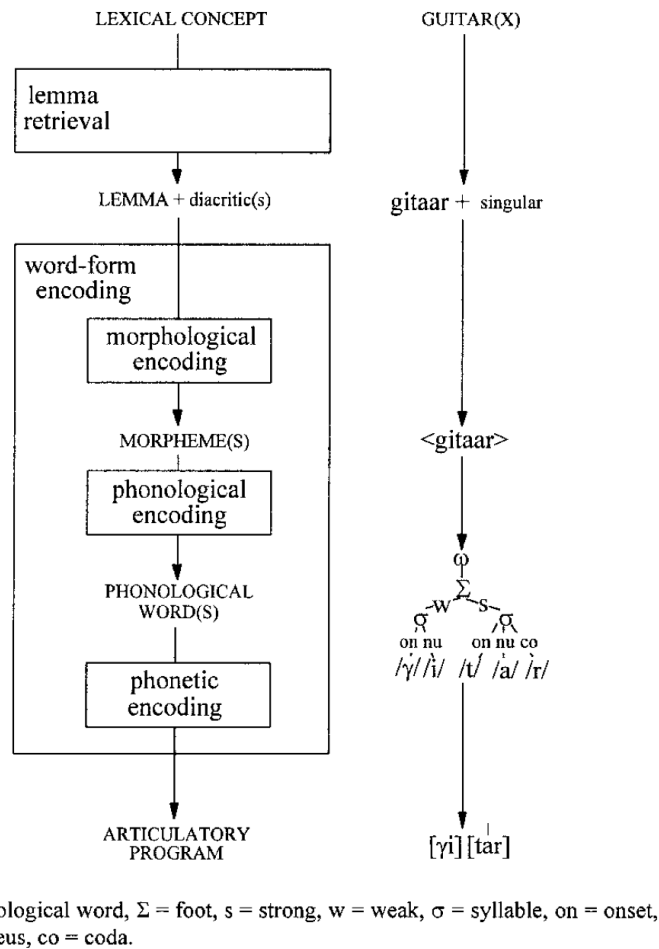


Figure 6. Roelofs 2002, Fig. 2. Stages of lexical access in Weaver++.

The main results obtained in the PWI literature, which are critical for the research conducted and reported in this thesis, are as follows:

The semantic interference effect (Schriefers, Meyer & Levelt, 1990; Roelofs, 1992). Naming latencies of pictures paired with semantically-related distractors (e.g. DOG *target* – giraffe *distractor*) are longer than picture naming latencies of pictures paired with semantically unrelated distractors (e.g. DOG *target* – jumper *distractor*). The locus of this effect is commonly assumed to be at the lemma selection level according to the lexical-competition account, (Glaser & Glaser, 1989; Starreveld & La Heij, 1996a; Starreveld & La Heij, 1996b; La Heij, Kuipers & Starreveld, 2006).

The phonological facilitation effect (Lupker, 1982; Damian & Martin, 1999). Picture naming latencies of pictures paired with phonologically-related distractors (onset phonological relatedness or end phonological relatedness) are longer than picture naming

latencies of pictures paired with phonologically unrelated distractors. This effect has been located at the phoneme retrieval stage (Meyer & Schriefers, 1991).

Target frequency effect (Miozzo & Caramazza, 2003; Costa, Alario & Caramazza, 2005; Mahon, Costa, Peterson, Vargas & Caramazza, 2007; Mädebach, Oppermann, Hantsch, Curda & Jescheniak, 2011). Naming latencies of pictures with a high frequency value are shorter than naming latencies of pictures with a low frequency value. This effect has been proposed to arise at the level of phonological representation activation between the lemma representation and the lexeme representation, because of a stronger link connecting these two representations when the name of the picture is a high frequency name (e.g. Barry, Morrison & Ellis (1997)).

The last two effects mentioned are particularly relevant because we investigated in two separate experiments – Experiment 2 in paper 2 and Experiment 3 in paper 3 – the target-distractor phonological relatedness effect (onset phonological overlap) and the target frequency effect, in order to study the dynamics of activation of the corresponding lexical representations, phonological representations and the constituent phonemes of both the target and distractor strings. In one of these experiments, the target was presented as a picture and in the other it was a written word. This allowed us to investigate possible differences arising from the route used to activate/retrieve the target name.

Concerning the PNWI literature (pronounceable nonword distractors), it has been shown that picture naming is slower when there is a pronounceable nonword distractor superimposed upon the picture, compared to when the picture-name is superimposed (Rosinski, Golinkoff & Kukish, 1975). Picture naming is faster when there is a pronounceable nonword distractor superimposed upon the picture, compared to when a word semantically related to the picture name is superimposed (Rosinski et al., 1975; Rosinski, 1977). Importantly, the pronounceability of nonword distractors makes a difference: Guttentag & Haith (1978) found that superimposed visual noise (?%&\) leads to faster picture-naming RTs than superimposed unpronounceable distractors, and superimposed unpronounceable nonword distractors lead to faster picture naming RTs than superimposed pronounceable distractors.

However, when nonword distractors are unpronounceable Posnansky & Rayner (1977) did not observe any differences when the distractor was a word that preserved some visual features of the picture name as compared to an unpronounceable nonword that shared the shape and letters (initial/final) with the target name. All conditions yielded faster picture naming latencies than picture naming when no distractors were present (Experiment 4). Lupker (1982), in contrast, found no facilitation from the sharing of some visual features

between unpronounceable nonword distractors and the picture names.

Underwood & Briggs (1984) (Experiment 1) failed to find any differences between picture naming latencies when pictures were paired with unpronounceable nonword distractors, word distractors that shared graphemic properties or phonemic properties with the target and semantically unrelated word distractors. On the whole all these conditions were faster than when a distractor word was a semantic associate of the picture name. As mentioned in the Introduction section of paper 1 of this thesis (which contains a more detailed review), the results we described should be taken with caution since they stem from a paradigm that was not systematically explored.

A length effect on reading pronounceable nonwords aloud has been documented by Weekes (1997): reading latencies of long nonwords are slower than those for the short nonwords. This length effect is smaller or absent when the stimuli are words (see Barton, Hanif, Eklinder Björnström & Hills (2014) for a review of the word length effect in reading aloud). The nonword length effect is well established to be a pointer of nonlexical translation of print to speech.

Given the inconsistent pattern of results reported in the PNWI literature and given our interest in studying the phonological properties of nonword strings and how these properties and the nonword phonemic computation could affect the retrieval and activation of the picture's lexical entry and its final production, we carried out six PNWI experiments in total. We explored the interaction between the human reading system and the speech production system, manipulating the phonemic length of nonword distractors, their phonological relatedness with the target picture's name (especially varying the position of the shared phonemes), and the target frequency, in order to shed further light on the lexical-semantic route and the nonlexical translation of print to speech.

Word-Word and Word-Nonword Interference Tasks

La Heij, Happel & Mulder (1990) were the first to use WWI task. In this paradigm, participants are first presented with a fixation point at the center of their visual field. At its offset, two words are simultaneously presented, a distractor word and a target word. The distractor word always appears at the center of the screen. The target word appears either above or below the distractor so is defined as a function of its position (either above or below) that it occupies with respect to the position of the centrally-presented distractor. Participants are instructed to read the target word aloud and to ignore the distractor. In the WNWI paradigm, used for the first time in paper 3 of this thesis, the distractors were written nonwords instead of words. This is the only difference between the WWI and WNWI paradigms.

In the WWI study of La Heij et al. (1990) the distractors were semantically related to the target word or unrelated, and members of the target response set or not member of the target response set. A control condition was adopted in which a row of XXXXXs was presented as the distractor stimulus. The experiment failed to reveal any effects of the varied factors investigated.

However, different results were reported by Mulatti, Ceccherini & Coltheart (2014), who reported four WWI experiments in which word–word interference effects were found. In the first experiment low frequency distractors interfered more than high frequency distractors in target naming. In the second experiment distractor frequency and target frequency (high *vs.* low values of stimuli's frequency) exerted additive effects. In the third experiment an effect due to the case status of the target (same *vs.* AlTeRnAtEd) interacts with the type of distractor (word *vs.* string of # marks). Finally, in the fourth experiment a target–distractor semantic facilitation effect was reported: target naming latencies were shorter when targets were simultaneously presented with semantically related distractor words compared to unrelated distractor words. Mulatti et al. (2014) used the WWI paradigm in order to investigate a mechanism for binding the lexical representations of the stimuli with the corresponding visual, precategorical features - that is, to explain how a link is constructed between the identities of the items and the positions that those items occupy. In that study a model of visual attention to multiple words was proposed which borrows two principles governing processing dynamics from the dual-route cascaded model of reading: cascaded interactive activation and lateral inhibition. Three mechanisms deal with the distinctive feature of the WWI task where two words are presented simultaneously: identification, tokenization, and deactivation.

Paper 3 of this thesis follows and builds on these results but aims to deepen our understanding. We thus seek:

- a) to clarify the nature of the nonword length effect obtained in the previous papers of this thesis with PNWI (Experiment 1 and Experiment 2);
- b) to investigate how the frequency of the lexical representation of target words affects the influence of nonlexical processing of nonword distractors (Experiment 1 and 2);
- c) to offer a proposal concerning how the reading and the speech production systems deal with two concomitant stimuli (one of the two is the target stimulus, and the other needs to be suppressed in order to perform as instructed) and whether other cognitive mechanisms are implied;
- d) to explore the dynamics of activation between the phonemic and phonological representation of the target stimulus and the distractor, within the reading system;

e) to study how and when the position information is available to the reading system both for word and nonword stimuli;

f) to investigate to which point nonword distractors are phonologically computed, how they can be disregarded or inhibited and whether they can be identified; and

g) to investigate which dynamics are going on when the reading and the speech production systems are presented with two concomitant words in which the target frequency is varied orthogonally with the phonological relatedness between target and distractor word pairs.

We adopted as our theoretical framework the dual route theory of reading aloud and its corresponding computational model: the Dual Route Computational (DRC) model of visual word recognition and reading aloud (Coltheart et al., 2001).

Some changes in the Mulatti et al. (2014)'s model were proposed in order to account for the obtained behavioural data, and new challenges for future research investigations were discussed.

Theory evaluation, module discovery & computational modelling

As mentioned in Coltheart (2011) there are two methods widely used in cognitive science to study what parts some particular mental process is composed of: a) the additive factor method and b) the method of cognitive neuropsychology. Both methods share the *attitude* they take with regard of the relationship between data and theory. A two-way relationship is adopted by both of the methods. One type of relationship is defined as *theory evaluation* and the other type of relationship is called *module discovery*. In theory evaluation the form of inference used to derive predictions is the deductive inference one: the theory offers the premises and the predictions are deduced from the premises.

Adopting the additive factor method, if the theory is correct, one should observe additive effects in the data manipulating a pair of particular variables whereas some other variables should interact. Adopting the neuropsychological approach instead one should encounter a patient with a particular pattern of impairment but never a patient with another pattern of cognitive impairment.

The form of inference to be used when inferring a theory from the data is the abductive inference or inference to the best explanation (Lipton, 2004). For instance it claims that given a theory, a pattern of data should be observed if the theory is true. Or better, the data could accommodate more than one theory but there are some specific reasons why one should believe in the main theory proposed.

A third approach to study the cognitive system and specifically the human reading

system is the computational modelling approach. Existing models of reading are verbal models (described informally) or models that are described formally. The formal model description can be mathematical or computational. A computational model of any cognitive activity is a computer program that not only performs the output of the humans but it does it in the same way the human cognitive system does (Coltheart, 2006).

One of the existing computational models in reading aloud is relevant for the reported research work. It is a Semantic version of the well-known DRC model (Coltheart et al., 2001). We used this version of the DRC model to simulate picture naming and all the PWI and PNWI experiments reported, using experimental stimuli in English.

DRC–SEM

The semantic version of the DRC model is fully described in the Introduction section of paper 1 of this thesis (p.47). Coltheart, Woollams, Kinoshita & Perry (1999) added a minimal semantic system to the DRC model to simulate colour naming, where the basic architecture of the DRC model (fig. 7, Coltheart et al. (2001) p. 214) was extended by adding a Semantic System containing the three colour concepts used in their experiment (i.e. red, green and blue). The model we used to simulate our data extended this work: we constructed a semantic version of the DRC model (DRC–SEM, see Figure 2 of paper 1 of this thesis) in which the model's Semantic System contained a semantic unit for each of the words in the DRC model's vocabulary. DRC–SEM is based on DRC 1.2.1 as used by Mousikou, Coltheart & Saunders (2010b) and it is available for download at <http://www.cogsci.mq.edu.au/~ssaunder/DRC/drc-sem/>.

This thesis represents the first attempt to simulate a picture naming task and moreover the first attempt to simulate tasks as PWI or PNWI that provide the concurrent presentation of two stimuli, one imperative and one a distractor. Furthermore, the whole reading and speech production system is involved in the solution of such tasks, with the intervention of other non-language specific mechanism such as visual attention, selection of the relevant information, inhibition of the irrelevant ones and cognitive control on the task. The simulations reported all in all suggest that in order to compute the human reading and the speech production system's functioning correctly, the DRC model has to be modified concerning the way it codes the phonemes position at the level of the phoneme system. This proposal has been discussed deeply throughout this thesis.

Neuropsychological evidence

Temporary word retrieval failures in language-unimpaired speakers are the tip of the tongue (TOT) and the slip of the tongue phenomena. When a person tries to retrieve the word that it is in the TOT state, semantic information is fully available, and some phonemes, typically the initial ones, can be retrieved. Grammatical gender information is also typically available and sometimes even the number of the syllables and the stress position (Friedmann et al., 2012). The features of the TOT phenomenon suggest that phonological information is retrieved separately from semantic and syntactic information and that the intention to produce a word in a sentence context provide a grammatical encoding and a phonological one (Vigliocco, Antonini & Garrett, 1997).

When instead an incorrect word or nonword is produced instead of the target word, a slip of the tongue phenomenon happens (Fromkin, 1971).

One of the most frequent deficits in lexical retrieval (i.e. the process of getting from a concept to a spoken word) is anomia. The types of anomia can be distinguished in terms of the multiple ways in which lexical retrieval can fail: at the conceptual level, in the semantic lexicon, in the syntactic lexicon, in the phonological output lexicon, and in the connections between these components (see Figure 7 Friedmann et al. (2012), Figure 19.3).

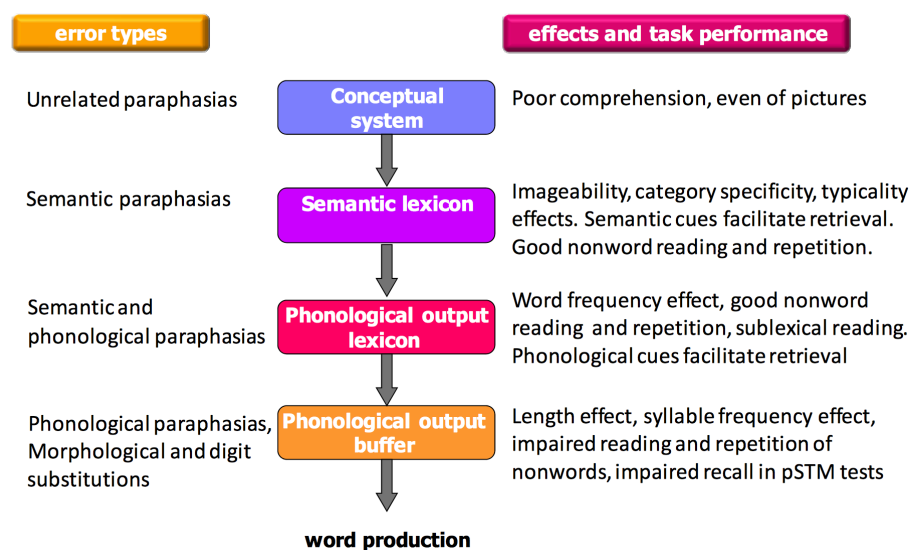


Figure 7. Friedmann et al., 2012, Figure 19.3. Errors that characterize each of the type of anomia.

We will briefly describe phonological buffer anomia since it involves the phonological output buffer, a critical level in the speech production and human reading system studied in the research work reported in this thesis.

Phonological buffer anomia is characterized by errors in speech production, which are nearly always phonological errors (no semantic errors such as producing a name of an item in the same semantic category, or circumlocutions). Patients with this deficit have no problems in

comprehension tasks with pictures, written or spoken words. However, they have difficulty with nonwords repetition tasks. Indeed the phonological output buffer is responsible for holding and composing phonemes of nonwords in reading and repetition tasks and since it is a phonological short-term component, it is affected by the length of the phonemic string it holds (Franklin, Buerk & Howard, 2002). Furthermore, patients with this type of anomia make more errors with infrequent syllables than frequent ones (Goldrick & Rapp, 2007).

Moreover, since the phonological output buffer composes words from phonemes and metrical information and morphologically complex words from morphemes, words could be produced with an incorrect order of phonemes, or with substitution/omission or addition of morphemes. Finally numbers could be produced with digit substitutions. Individuals with conduction aphasia are typically impaired in the phonological output buffer (Franklin et al., 2002). As reported by Damasio & Damasio (1980) conduction aphasics show the following features:

1. Conversation includes runs of normally articulated words, with generically preserved use of grammatical inflections and syntactic structures. The speech is characterised by errors in the selection and sequencing of phonemes and syllables. These may be omitted, substituted or transposed.
2. Auditory comprehension is well preserved.
3. The task of repeating words or sentences after the examiner may be particular deficient, in comparison with the level of fluency observed in conversation.

Picture naming has been widely used as a treatment technique for patients with acquired aphasia. Picture naming treatments could be divided essentially in to three types: 1) phonological treatment, 2) orthographic treatment and 3) semantic treatment. Hickin, Best, Herbert, Howard & Osborne (2002) reported a study where both phonological and orthographic cues were effective in improving word retrieval. Previous studies reported instead an advantage for a semantic treatment over a phonological one (Howard, Patterson, Franklin, Orchard-lisle & Morton, 1985a; Howard, Patterson, Franklin, Orchard-Lisle & Morton, 1985b). Howard et al. (1985a) showed that auditory word-to-picture matching, visual word-to-picture matching and semantic judgements are found to have effects lasting for up to 24 hours. The durable facilitation of word retrieval has been adjudged to access the semantic representation corresponding to the picture name, opposite to the short-term effects of techniques that provide patients with information about the phonological shape of the name. Howard et al. (1985b) reported a day-by-day improvement specific to the actual items treated in semantic and phonological treatments. Additionally, he reported a significant improvement

in naming after one week the end of the treatments, with a small, but significant advantage for the semantic treatment.

This section highlights the important role of the phonological output buffer as the level where the phonological and syllabic information are combined and composed in a specific order (for instance in nonword repetition tasks). As mentioned above this is a short-term storage that can be affected by the length of the string to be retained (Franklin et al., 2002). This buffer is particularly relevant because we suggest throughout the thesis that the nonword length and the phonological facilitation effects we report in PNWI occur within the existing connections that link this buffer to the phoneme system. The latter stage represents the level where the lexical, lexical-semantic and nonlexical routes cooperate to produce one unique output to the primary task required (i.e. name the picture/read the target word).

Moreover, the picture naming task has been used and is still used as a rehabilitation technique for phonological and semantic aspects of language. It has been shown to be effective at least in a short-term range time. These evidences overall suggest that this task requires the access/activation/retrieval of semantic and phonological information, all impaired processes in patients with acquired aphasia.

Thesis outline

Paper 1 investigates the nonword distractor length effect in picture naming, the phonological relatedness between the picture name and the nonword distractor, and the position of the shared segments. The last experiment reported in paper 1 aims to disambiguate between the role of syllables and phonemes in the nonword distractor length obtained in PNWI.

Paper 2 investigates issues of the dynamics between the semantic–lexical and the nonlexical routes, by means of the manipulation of nonword distractor length, phonological relatedness and target frequency. In a second experiment we studied how the reading and the speech production systems deals with two lexical concomitant stimuli (the name of the target picture and the written word distractor).

In these two papers the DRC–SEM model was used to simulate the results and hence to test the model and to better understand our behavioural effects.

Paper 3 addresses the issues of the dynamics of activation, inhibition when the reading and human speech production systems have been presented with two simultaneously stimuli. Only one, the imperative stimulus, needed to be read aloud (always a written word), and the other one, a distractor, could be a nonword (Experiment 1 and 2) or a written word (Experiment 3).

The role of later stages in the speech production process (articulation, motor programs planning) and general cognitive mechanisms (selective attention, visual attention, strategies) are discussed.

In the General Discussion chapter all the behavioural results of this thesis and the respective simulations are linked each other and discussed all together, highlighting the main experimental questions this thesis addresses and the critical issues arisen from the behavioural data and the DRC-SEM's simulations comparisons.

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**PAPER 1: Experimental and computational studies using
the picture-nonword interference task: implications for models of
reading and speech production**

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Abstract

The picture-word interference paradigm refers to the task in which participants are required to name the picture, disregarding a written word distractor presented upon the line drawing (Glaser & Dungenhoff, 1984). We investigated via five experiments how written pronounceable nonword distractors affect picture naming latencies, investigating the effects of picture-nonword phonological relatedness and nonword distractor length. Our aim is to improve the current knowledge on the phoneme system of the human reading system when two different sources of physical stimulation concur to be named, the picture and the nonword. We ran five simulations with a Semantic version of the DRC model (Coltheart et al., 2001), corresponding to the first four analysis of the human data. We highlight 1) a different phoneme position coding from that implemented in the DRC model and 2) the importance of the number of syllables in picture naming (Experiment 5).

Keywords:

Word production

Picture naming

Reading Aloud

Picture-word interference paradigm

Nonword length

Target-Distractor phonological relatedness

Phoneme System

Computational Modelling

Introduction

A Stroop-like paradigm widely used to investigate the nature of reading and word production processes is the picture–word interference (PWI) task paradigm. In this paradigm a picture is presented with a superimposed distractor word. Participants are asked to name the picture aloud as quickly and accurately as possible while ignoring the word.

It is well established that naming a picture with a superimposed distractor word takes longer than naming the picture when it is presented alone (Potter & Faulconer, 1975; Lupker, 1979). This is because the written distractor taps into the phonological system and this activated phonology competes with the phonology of the picture name, resulting in picture naming latencies being delayed in comparison to the condition in which the picture is presented alone. Various factors affecting the degree of this delay have been investigated, by varying properties of the name of the target or of the distractor word. Among the several effects found with the PWI technique, the semantic interference effect and the phonological facilitation effect have shown the usefulness of the PWI technique as a tool for studying word production and reading processes. We briefly describe both of these effects.

Picture naming latencies of pictures paired with distractor words that belong to the same semantic category of the picture name (e.g. WHALE *target* – fly *distractor*) are slower than the picture naming latencies of the same pictures paired with distractor words that do not belong to the semantic category of the picture’s name (e.g. WHALE – ribbon), (Schriefers et al., 1990; Roelofs, 1992). This is the semantic interference effect. Its locus is commonly assumed to be at the lemma selection level, during the selection of the picture’s lemma, which is part of the process of producing the picture’s name. We refer to this account as the lexical-competition account (Glaser & Glaser, 1989; Starreveld & La Heij, 1996a; Starreveld & La Heij, 1996b; La Heij et al., 2006). Since the lemma representation of the semantically related distractor word receives activation from both the target – through a spreading activation process at the semantic level – and the distractor, it is more strongly activated than the lemma representation of an unrelated distractor. In this way a semantically related distractor word competes more strongly with the lemma representation of the picture’s name than does a semantically unrelated distractor word.

Another variable that has been investigated in the PWI paradigm is the phonological relatedness between the target picture’s name and the written distractor word. When pictures are paired with printed word distractors sharing the first two phonemes/letters, picture naming latencies are faster than under the phonologically/orthographically unrelated condition, e.g. Damian & Martin (1999), Experiment 1; Starreveld & La Heij (1996a)¹. In addition, pictures

paired with distractor words that share the last two phonemes with the picture name are named faster in comparison to the same pictures paired with distractor words that do not share any phonemes. These findings illustrate the phonological facilitation effect (Lupker, 1982). The usual interpretation of this effect is that the phonological representations of the picture name and the distractor word receive activation (to some extent) at the same time, and that the shared phonemes accumulate a greater amount of activation, resulting in faster naming latencies than when the distractor word is phonologically unrelated with the target picture name. This effect has been located at the phoneme retrieval stage (Meyer & Schriefers, 1991).

The PWI paradigm has been widely used to study different aspects of lexical access and the additivity or interactivity of the processing stages involved. In contrast, very little work has been reported in the literature concerning the picture-nonword interference paradigm (PNWI), in which the letter string superimposed upon the picture is a nonword rather than a word. We next review what work has been done on the PNWI effect.

Picture-nonword interference effects

For our purpose, we consider only work with adult skilled readers. First, we review studies where the distractors are pronounceable nonwords. What has been found here is as follows:

1. Picture naming is slower when a pronounceable nonword distractor is superimposed upon the picture, compared to when the picture name is superimposed, Rosinski et al. (1975)².

¹ In their experiment 1 Starreveld and La Heij (1996b) used the PWI paradigm in which visual distractors are used. The target-distractor relationship that we are interested in is defined by the Authors as *orthographic* according to which both targets and distractors started with the same consonant(s)-vowel combination (CAR written upon the picture of a cat). In this sense we can consider this manipulation as a phonological target-distractor relatedness. They obtained a phonological facilitation effect when the first two segments overlapped between the target and the distractor stimuli.

² Trigrams. They refer to all the possible three letters combinations in the form Consonant – Vowel – Consonant (CVC) of the Roman alphabet, with the restrictions that two consonants are different and neither is a y when y is a vowel (this pair of restrictions results in a total of 2480 trigrams). All these stimuli have been tested for their association values (see Archer, 1960; Glaze, 1928; Krueger, 1934). These values express the extent in which each trigram is associated with meanings or ideas. In this paper the work of Rosinsky et al., 1975, Golinkoff & Rosinsky, 1976 and Rosinsky, 1977 are mentioned who all used pronounceable CVC trigrams with association values ranging from 35% to 65% (Archer, 1960).

2. Picture naming is faster when there is a pronounceable nonword distractor superimposed upon the picture, compared to when a word semantically related to the picture name is superimposed (Rosinski et al., 1975; Rosinski, 1977).
3. Picture naming latency is faster when there is a pronounceable nonword distractor superimposed upon the picture, compared to when a word semantically unrelated to the picture name is superimposed (Guttentag & Haith, 1978; Rayner & Posnansky, 1978; Lupker, 1979; Briggs & Underwood, 1982; Lupker, 1982). However, Rosinski (1977) found that picture naming latency was no different in these two conditions.
4. Phonologically-related distractor nonwords lead to faster picture naming latencies than phonologically unrelated distractor words, with both conditions being slower than when the picture name is superimposed (Posnansky & Rayner, 1977)³. But Rayner & Posnansky (1978) found no difference between a phonologically-related distractor nonword condition and a superimposed picture name condition (with both being faster than picture naming with semantically unrelated distractors). When nonword distractors share some phonological features with the target name, there is facilitation compared to other nonword conditions (shape shared⁴, both pronunciation and shape shared, none of these two shared; Rayner and Posnansky, 1978⁵).
5. The pronounceability of nonword distractors makes a difference: Guttentag & Haith (1978) found that superimposed visual noise (?%&\) leads to faster picture naming RTs than superimposed unpronounceable

³ Posnansky & Rayner (1977) used a visual mask made up of superimposed Xs or Is or even Os. It lasted for 300 ms and covered the area of the visual angle occupied by the picture. This mask display procedure was used also in Rayner & Posnansky, 1978, and Rayner & Springer, 1986.

⁴ Shape of label (Posnansky & Rayner, 1977). This variable is manipulated in the way that the letters of the picture label (often those that occupy the middle position in the string) were substituted with letters having high values of letter confusability (Bouma, 1971) with the original ones (i.e. for instance ascenders were replaced by descenders and descenders by ascenders). In the Posnansky & Rayner, (1977) paper however, the following implication is given: the label of the picture name possesses an orthographic representation which matches the distractor orthographic representation concerning some visual features such as to be represented in lower case, as the distractor is visually presented upon the picture. The authors did not consider this implication as erroneous.

⁵ It is worth to point out that the only phonetic feature the authors have investigated is vocalic quality. Further, some confounds are due to the selection of the experimental stimuli: for instance Rayner & Posnansky (1978) considered the sharing of the initial letters of the picture label as a visual feature only.

distractors, and superimposed unpronounceable nonword distractors lead to faster picture naming RTs than superimposed pronounceable distractors.

6. Distractor shape and sharing the initial letter between picture and distractor nonword have an influence. When nonword distractors share both overall shape and also the initial letter with the target name, picture naming RTs are faster than when the nonword distractors do not share these properties (Rayner & Springer, 1986).

When nonword distractors are unpronounceable (i.e. are consonant strings), the following has been found:

1. When unpronounceable nonword distractors share both the shape and the extreme letters with the picture label, picture naming RTs are faster than when only one of these properties is shared; the latter condition is in turn faster than when neither property is shared (Posnansky & Rayner (1977) - Experiment 1). In addition, RTs are faster when distractors share shape and initial letters with picture names compared to when the shared letters are in the middle of the distractors (and scrambled), with RTs being even slower when the only property shared is shape (Posnansky & Rayner, 1977, Experiment 3).
2. Posnansky & Rayner (1977, Experiment 4) did not observe any differences between the following conditions: (a) the distractor was the name of the picture; (b) the distractor was a word that preserved some visual features of the picture name; and (c) the distractor was an unpronounceable nonword that shared the shape and letters (initial/final) with the target name. All three conditions yielded faster picture naming RTs than picture naming when no distractors were present. But Lupker (1982) - Experiment 1 - found no facilitation from the sharing of some visual features between unpronounceable nonword distractors and the picture names.
3. Underwood & Briggs (1984, Experiment 1) failed to find any differences between the following conditions: (a) unpronounceable nonword distractors; (b) word distractors that shared graphemic properties or phonemic properties with the target; and (c) semantically unrelated word distractors. On the whole all these conditions were faster than when a distractor word was a semantic associate of the picture name.

We note that many of these experiments are subject to several confounds⁶ so the results we describe should be taken with caution. We also note that we have considered only the most conventional PNWI paradigm in which pictures and distractors are presented simultaneously and their durations or stimulus-onset asynchronies are not manipulated. We finally note that the most recent paper on the PNWI we have reviewed was published in 1986; to the best of our knowledge, no work on the PNWI effect has been published since then. Thus, work on this effect has been unsystematic, subject to confounds, and not recent.

Since we want to use the PNWI paradigm to investigate processes of picture naming and reading, we have carried out experimental and computational work on the PNWI effect with a well-controlled experimental procedure and method, an adequate selection of the experimental stimuli avoiding confounds, and computational modelling using a development of the DRC computational model of reading aloud (Coltheart et al., 2001). Specifically our aim is to investigate what occurs in the phoneme system during the activation of a picture name's phonemes, in particular how this is influenced by the phonemes of the distractor nonword.

A well-known phenomenon in reading aloud is the length effect on reading aloud of pronounceable nonwords (Weekes, 1997): reading latencies of long nonwords are slower than those of short ones. This length effect is much smaller or absent when the stimuli are words. This is typically attributed to a property of the nonlexical reading-aloud route, namely, that this route works on letter strings serially and left-to-right, activating phonemes from the left most grapheme to the rightmost one. Given that the length effect is a key indicator of the operation of the nonlexical route, in our first experiment we manipulated nonword distractor length in the PNWI paradigm to test the interplay between the nonlexical route and the picture naming process at the specific stage of the phoneme level of the speech production system.

⁶ For instance a) in Rosinsky et al., (1975) and Golinkoff & Rosinsky, (1976) semantically related distractors appeared in the same sheet as the target pictures. La Heij, (1988) obtained the response set membership effect showing that in order to obtain a pure effect in PWI, it is necessary that distractors never belong to the target pictures response set. b) In Guttentag & Haith (1978) the nonword distractor neutral condition shared one letter or one phoneme with the picture label, and in some cases they coincided. Since our aim is to investigate the role of the phonemes, this represents a crucial confound.

Experiment 1

Method

Participants

Twenty-three students of the Università degli Studi di Padova participated in the study as volunteers. They all had normal or corrected-to-normal vision. Participants were all native speakers of Italian.

Design

A within-subject design was employed with the length of pronounceable nonword distractors (short distractors: 4-5 phonemes *vs.* long distractors: 7-8 phonemes) as a factor.

Materials

Fifty pictures were selected as target stimuli from the database of Dell'acqua, Lotto & Job (2000). Their average number of phonemes was 6.0 (ranging from 4 to 9), counting geminate consonants as in GONNA as two phonemes. These pictures had a high name agreement value. The mean frequency of the target pictures was 1.86 (range: 0.70 – 2.94) - frequencies were taken from the database of Dell'acqua et al. (2000).

One hundred nonword distractors were constructed; fifty were long distractors (7-8 phonemes) and the other fifty were short distractors (4-5 phonemes). Context-sensitive graphemes and multi-letter graphemes were avoided, so that the number of the phonemes in each distractor stimulus was also the number of its letters. None of the distractors had any orthographic neighbors. Each target picture was presented twice, once with a long superimposed distractor and once with a short superimposed distractor. All phonological overlaps between the name of the target and the phonology of the distractor were avoided.

Twenty-three experimental lists were created in which stimuli were presented in a different order for each list with the restriction that one particular target could not have been followed by itself in the next 3 items. Furthermore, each list began with three practice trials. Appendix 1 reports the stimuli used in Experiment 1.

Apparatus

The experiment took place in a sound-attenuated and dimly lit room. The stimuli were

displayed on a 17" cathode-ray tube monitor controlled by a 686 IBM-clone and E-prime software. The onset of vocal responses was detected using a high-impedance microphone to which a voice-key was connected.

Procedure

Participants were tested individually. They were instructed to name the target picture aloud as quickly and accurately as possible while disregarding the superimposed distractor nonword. On each trial, a fixation point (+) appeared in the center of the screen for 500ms. Following the fixation point's offset, a blank screen was displayed for 100ms, followed by the presentation of a picture-nonword pair, which remained visible until a vocal response was detected or 3s elapsed. The ITI was fixed at 1000ms. When projected on the screen, pictures occupied an ideal square of about 6×6 cm. The nonword distractors were shown in capital letters in Geneva font, bold, 20-point. Pictures were centered at fixation, and word position varied randomly in the region around fixation to prevent participants from systematically fixating the portion of the picture not containing the distractor (La Heij, Van der Heijden & Schreuder, 1985; Glaser & Glaser, 1989). The viewing distance was 60cm. Target/distractor pairs were presented in a different random order for each participant. The experimenter recorded each response as correct or incorrect. The experimental session was preceded by a practice session of 8 trials and a familiarization session in which subjects saw all the pictures of the experiment (practice, trial and experimental pictures) for a total of fifty-seven pictures, with their corresponding names presented beside them.

Results

Naming errors and apparatus failures (6.2%) were removed prior to analysis. Correct RTs were submitted to Van Selst & Jolicoeur (1994) outlier removal procedure, resulting in the elimination of 0.6 % trials. The factor of length of nonword distractors (long distractor: 7-8 letters *vs.* short: 4-5 letters) was treated as a within-subject factor in both the by-subject (F1) and the by-item (F2) analyses.

RTs

Target pictures were named aloud faster when presented paired with short distractor (773ms) than when paired with long distractors (799ms), a difference that was significant: $F(1, 22) = 5.75, p < .05, F(1, 49) = 7.56, p < .05$.

The effect of distractor length effect was not significant, $F_1(1, 22) = .22, p > .05$, $F_2(1, 49) = .28, p > .05$. Accuracy reached the value of 98% for pictures paired with long distractors and 99% for pictures paired with short nonword distractors.

Discussion

We observed a distractor length effect in the PNWI paradigm: picture naming latencies are longer when pictures are paired with long distractor nonwords than when the same pictures are paired with short distractor nonwords. How might we explain this distractor length effect? We suggest the following explanation.

After the onset of the picture, all the phonemes of the picture name will begin to rise in activation in parallel at the same time. Meanwhile, the non-lexical procedure will be computing the phonology of the distractor and activating its constituent phonemes, one phoneme at a time, proceeding from left to right. In order for the picture to be named, its phonemes have to win the competition with the distractor phonemes for the position they occupy in the string, and they must reach the naming threshold. The strength of the competition will vary across the position of the string because of the serial nature of the computation by the nonlexical route. The strongest competition between the two candidate phonemes will be at the first phoneme position, and the strength of this competition will decrease along the phoneme string.

Our short distractors had 4 or 5 phonemes. These distractors will produce competition for the first 4 or 5 phonemes of the picture names; there will be no interference with later phonemes of the picture names and so pictures whose names had 6 to 9 phonemes will have 1, 2, 3 or 4 phonemes receiving no interference. Our long distractors had 7 or 8 phonemes. These distractors will produce competition for the first 7 or 8 phonemes of the picture names; pictures whose names had 8 to 9 phonemes will have 0, 1 or 2 phonemes receiving no interference. There will be more phonemes of the picture name receiving no interference from the distractor phonemes in the short-distractor condition than in the long-distractor condition.

It follows from this explanation that the more phonemes a target picture has, the greater the distractor length effect should be. Consider, for example, pictures with 4-phoneme names. Here it should not matter at all whether the distractor is short (4-5 phonemes) or long (7-8 phonemes) because the additional phonemes in the long distractors are in positions not used by the picture's phonemes. In contrast, for pictures with long names, a higher proportion of their phonemes will receive competition from the distractor when that distractor is long than when it is short. Following this reasoning one would predict an interaction between the

number of the phonemes of the target picture and the distractor length.

Figure 8 shows how the distractor length effect changes as a function of the number of the phonemes constituent the picture names.

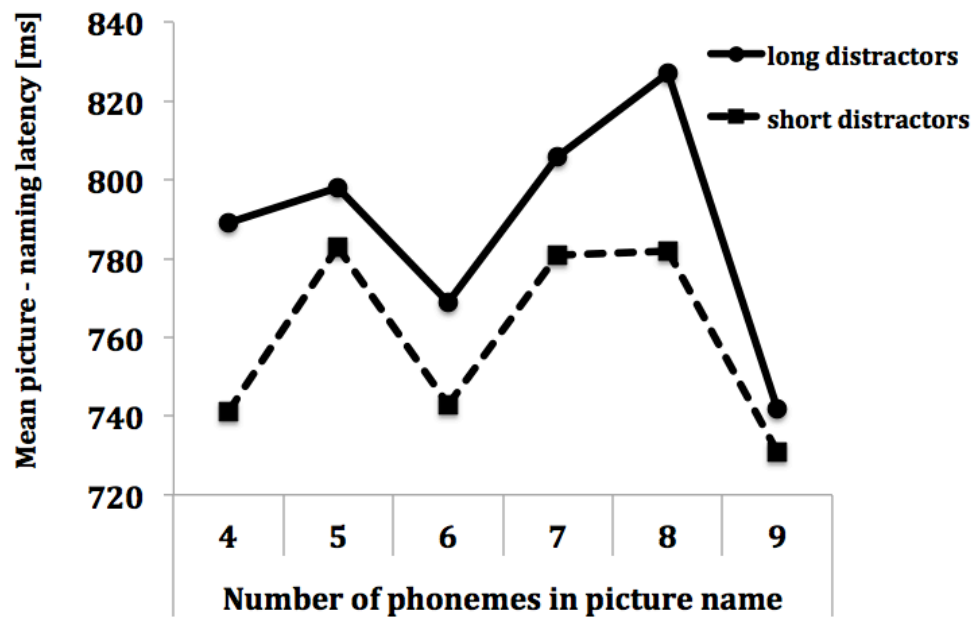


Figure 8. Means of picture naming latencies [ms] according to the nonword distractor length and the target distractor length. Length is considered as number of constituent phonemes of the name of the stimuli.

We investigated this with a post-hoc analysis of our data: the target length factor has been created grouping the pictures in two levels, long pictures were those with 7, 8 or 9 phonemes and short pictures those with 4, 5 and 6 phonemes resulting in two groups of 25 item each. The mean reaction times for each condition considered in the post-hoc analysis are reported in Table 1 (data by subjects).

Target Length	Distractor Length		Difference (RTs)
	Long (7-8 ph.) RTs	Short (4-5 ph.) RTs	
Long (7-8-9 ph.)	807	786	21
Short (4-5-6 ph.)	792	760	32
Difference	15	26	

Table 1. Means of the picture naming latencies [ms] of Exp 1 as a function of target length and distractor length factors. Length is considered in terms of the number of the constituent phonemes.

We conducted a repeated measures ANOVA for the analysis by subjects (F1) and by items (F2), considering the distractor length as a within-subject factor in both F1 and F2 and the target length as a within-subjects factor in F1 and as between subjects factor in F2.

The analysis reveals a distractor length effect both in the analysis by subjects $F_1(1,22) = 5.6$, $MSE = 2972$, $p < .05$, and in the analysis by items $F_2(1,48) = 7.4$, $MSE = 2429$, $p < .05$. The interaction was not statistically significant $F_1(1,22) = .34$, $MSE = 2106$, $p > .05$, $F_2(1,48) = .16$, $MSE = 392$, $p > .05$, nor was the target length factor $F_1(1,22) = 3.4$, $MSE = 2854$, $p = .07$, $F_2(1,48) = 0.9$, $MSE = 11016$, $p > .05$. The predicted interaction between distractor length and target length is clearly absent, a result which is inconsistent with the explanation we offered for the distractor length effect we found in this experiment.

Thus, what needs to be explained is the additive pattern of results: the presence of the distractor length effect concomitant with the absence of the target length effect, with no interaction between these two factors. As we have already discussed, a phoneme system is required for both picture naming and reading aloud (Figure 9). Printed stimuli have a faster access to the phoneme system than do pictorial stimuli because of the nonlexical reading route. Thus, in the picture-nonword and picture-word paradigms, information from the print will reach the phoneme system earlier from the distractor than the target. What participants need to do in order to name aloud the picture name is to ignore information from the print distractor held in the phoneme system.

We further investigated the target-distractor properties explored in the first two reported data sets, by means of computational modelling. We did this by simulations using a version of DRC model of visual word recognition and reading aloud (Coltheart et al., 2001) that was equipped with a semantic system that allowed simulation by the model not only of reading aloud but also of picture naming.

Simulations

Coltheart et al. (1999) added a minimal semantic system to the DRC model to simulate colour naming, where the basic architecture of the DRC model (Coltheart et al., 2001, fig. 7, p. 214) was extended by adding a Semantic System containing the three colour concepts used in their experiment (namely red, green and blue). The model we have used to simulate our data extended this work: we constructed a semantic version of the DRC model (DRC-SEM, see Figure 9) in which the model's Semantic System contained a semantic unit for each of the words in the DRC model's vocabulary. DRC-SEM is based on DRC 1.2.1 as used by Mousikou et al. (2010b) and it is available for download at <http://www.cogsci.mq.edu.au/~ssaunder/DRC/drc-sem/>.

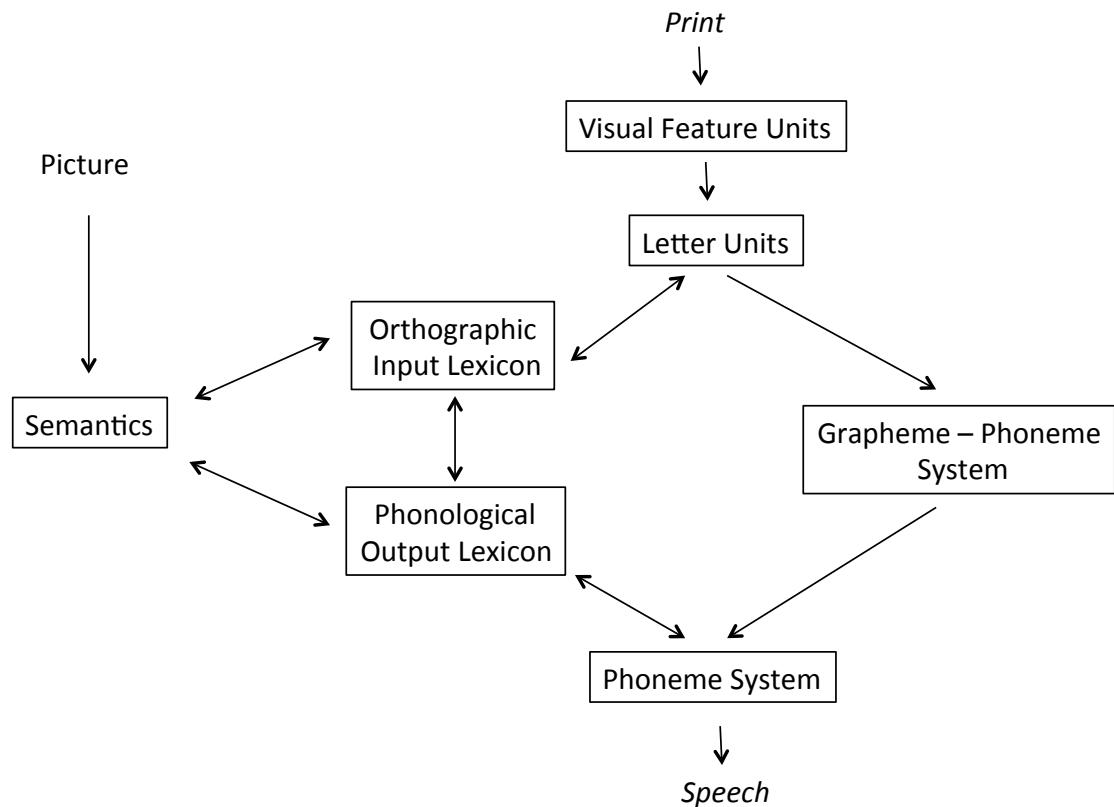


Figure 9. Semantic version of the DRC model (Coltheart et al., 2001) with the inclusion of a picture recognition route (on the left).

Our simulations used the default parameters of DRC 1.2.1, with the additional parameter values reported in Table 2.

Parameters	Values
SemanticsOnset	60
SemanticsOrthlexExcitation	0.25
SemanticsPhonlexExcitation	0.25
SemanticsExternalExcitation	0.5
Letter Decay (at cycle 120)	1.0
PhonemeUnsupportedDecay	0.05

Table 2. Parameters used in the DRC-SEM simulations of reading aloud.

Picture naming was simulated by switching on the unit in the Semantic System corresponding to the picture. This was done after processing by DRC-SEM had proceeded for the number of cycles specified by the SemanticsOnset parameter.

DRC-SEM is capable of producing a picture name or of converting print to phonology. When both a picture and a printed stimulus are presented to it, the model must be capable of producing the picture name or of reading aloud the printed stimulus, just as people are when they are given a picture with a superimposed printed stimulus. One of the ways to simulate the instruction “name the picture and ignore the written stimulus” is to weaken the connection between the letter level and the orthographic representation. This is the reason we choose to assign at the parameter Letter Decay the maximum possible value of 1.0 at cycle number 120, the idea being that when the system detects that a printed stimulus is present (we imagine that this happens at 120 cycles after the initiation of processing), it immediately switches off all activations at the letter level (that is the effect of instituting a decay of 1.0 at that level).

Simulation 1

Properties of the stimuli for the complete list of stimuli see Appendix 2.

The dependent variable in this simulation was distractor length (short *vs.* long). Thirty words from the DRC English vocabulary were selected to serve as picture names; they had an average written frequency of 16.1 and an average spoken frequency of 0.97; the number of phonemes in the distractor ranged from 4 to 7 with an average of 5.6 phonemes - values were from the CELEX database (Baayen, Piepenbrock & van Rijn, 1993). Short and long pronounceable nonword distractors (30 for each condition) were selected. The distractors were selected to have one-to-one mappings of letters to phonemes; long distractors had 7 phonemes and letters and short ones had 4 phonemes and letters. Targets and distractors never had shared phonemes in the same position. Each target was run through DRC-SEM with a short distractor and a long distractor.

Results

Long distractors interfered more than short distractors in terms of the number of cycles the model requires to name the given picture, 224 cycles *vs.* 222 cycles. An analysis using McNemar’s test revealed a significant effect of distractor length, $p < .001$.

Discussion

DRC-SEM correctly simulates the nonword distractor length effect found in the behavioural data. Where does this effect come from in the model? It arises as a function of the inhibitory and excitatory connections between the phoneme system and the phonological

output lexicon.

When the distractor is long, the phonological target representation has always a lower activation level than when it is paired with a short distractor. This is because the total amount of inhibition a picture name unit in the phonological output lexicon receives via feedback from the phoneme system is greater when the distractor is long (has many phonemes) than when it is short (has few phonemes). As a consequence the phonemes activated by the target's phonological output lexicon representation will possess a lower level of activation when the distractor is long than when it is short, and so the time needed for target phonemes to reach their critical response threshold (i.e. DRC-SEM's picture naming latency) will be greater with long distractors than with short distractors.

Also, the level of activation of the first phoneme of the target becomes greater than the level of activation of the first phoneme of the distractor earlier (in terms of number of cycles) when the distractor is short than when it is long. From that cycle on, the target phonological representation exhibits an exponential rate of activation, in both cases.

Furthermore, the last phoneme of the picture name to reach the naming threshold is the phoneme in the first position. This occurs for the following reason. The non-lexical procedure starts working on the leftmost grapheme of the distractor nonword, activating its phoneme. Only when this first phoneme reaches a certain activation level does the nonlexical procedure move on to the second grapheme, and so on across the input letter string. So the first phoneme of the target picture name receives stronger lateral inhibition from the corresponding phoneme of the distractor than is the case for other target phonemes, and the later a phoneme is in the target picture name the weaker will be the competition from the corresponding distractor phoneme.

Simulation 2

Properties of the stimuli (for the complete list of stimuli see Appendix 3).

In this simulation there were two dependent variables: distractor phonemic length (short vs. long) and target phonemic length (short vs. long). The human data reported earlier showed that picture naming latencies were longer when distractors were long than short, and that neither the main effect of target length nor its interaction with distractor length were significant. This is the pattern of results to be explored in Simulation 2.

Thirty-two target words were selected. Half of them were long targets (6.18 phonemes on average) and half were short targets (3 phonemes). The two groups of targets were matched on spoken frequency value from CELEX (Baayen et al., 1993). Thirty-two distractors were selected; half of them were long distractors (7 phonemes) and half short (4

phonemes). Targets and distractors pairs could share one phoneme but never in the same absolute position.

Results

Table 3 shows the average number of cycles the model required to name the pictures as a function of target length and distractor length.

Target Length	Distractor Length		Difference (cycles)
	Long (7 ph.)	Short (4 ph.)	
	n.Cycles	n.Cycles	
Long (6 ph.)	223,87	222,93	0,94
Short (3 ph)	222,93	222,93	0
Difference	0,94	0	

Table 3. Means of the number of DRC-SEM cycles of Simulation 2 as a function of target length and distractor length factors. Length is considered in terms of the number of the constituent phonemes.

For each target we calculated the value of the distractor length effect for both the long target condition and the short target condition. We then have subtracted the former obtained values to the latter ones obtaining a measure of the interaction for each target. We then tested whether this set of values was significantly different from zero with a sample t test, $p < .05$. An analysis using McNemar's test revealed the effects of target length and distractor length were not significant. However, McNemar's tests indicated that the effect of the distractor length variable (long vs. short nonword distractors) within the long targets condition and the effect of the target length variable (long vs. short picture names) within the long distractors condition were both statistically significant difference ($p < 0.001$ in both cases).

Thus the model failed to simulate the human data, which showed no interaction between target length and distractor length and a main effect of distractor length.

Discussion of Experiment 1 and its simulations.

With DRC-SEM, when the name of the picture is long, there is a nonword distractor length effect such that long nonword distractors produce slower picture naming latencies than superimposed short distractors. When instead the name of the picture is short there is no trace of distractor length effect, the latest phonemes of long distractors cannot have any effect when targets are short. The interaction occurs as a consequence of the DRC-SEM reading (and picture naming) system having the following properties: position-specific phoneme

representations in the phoneme system and left-to-right operation of the nonlexical reading route.

In order to explore deeply the functioning of the human reading system we decided to investigate the phonological relatedness between the picture and the nonword distractor. The phonological facilitation effect has been previously reported in PWI literature (Lupker, 1982; Meyer & Schriefers, 1991; Starreveld & La Heij, 1996a; Damian & Martin, 1999).

Within the DRC-SEM framework and considering the PNWI paradigm, we can make two predictions:

- 1) A phonological relatedness effect, if the overlap is in the first positions;
- 2) A distractor length effect, if targets are long;
- 3) An additive pattern between picture-distractor onset phonological relatedness and nonword distractor length.

The first prediction is driven out by the fact that when the overlap is in the first positions the shared distractor phonemes would prime the target distractor phonemes in the phoneme system, since they share the same absolute position in the phonetic string. The second prediction is a consequence of the obtained results Simulation 2: only when the target are long we observed a nonword distractor length effect in the number of cycles the model required to name the picture. The third prediction results from the interplay between the semantic-lexical and the nonlexical routes in the phoneme system. As a matter of fact phonological unrelated pairs of stimuli would lead to a distractor length effect as in Simulation 1. Onset phonological related target-distractor pairs would lead to a phonological facilitation effect compared to the phonological unrelated pairs and the distractor length effect would be reliable even in the onset phonological related condition. Why? This is because the facilitation exerted by the initial phonological overlap would be dispersed across the length of the nonword distractor, since the nonword partway works serially assembling the nonword phonological string from the leftmost to the rightmost phoneme. This advantage, however, would not be dissipated completely since the semantic-lexical route would have enough activation to inhibit the phonemes activated by the nonlexical route in the phoneme system. The resolution of the lateral inhibition in the phoneme system would cause the picture label reaching the naming threshold. This might happen even before the assembly of the nonword distractor had the chance to be completed.

The aim of Experiment 2 is to investigate if a phonological facilitation effect exists in the picture naming latencies when the superimposed distractor is a nonword. Specifically, we manipulated the length of the nonword distractor and the picture-distractor phonological relatedness, considering the first two phonemes of the experimental pair of stimuli.

Experiment 2

Method

Participants

Eighteen students of the Università degli Studi di Padova participated in the study as volunteers. They all had normal or corrected-to-normal vision. Participants were all native speakers of Italian.

Design

A within-subject design was employed with two factors orthogonally manipulated, both with two levels: length of pronounceable nonword distractors (short distractors: 4-5 phonemes *vs.* long distractors: 7-8 phonemes) and picture-distractor phonological relatedness (first two phonemes shared *vs.* no phonemes shared).

Materials

Thirty-one pictures were selected as target stimuli from the database of Dell'acqua et al. (2000). Their average number of phonemes was 6.2 (ranging from 4 to 8), counting geminate consonants as in GONNA as two phonemes. These pictures had a high name agreement value. The mean frequency of the target pictures was 1.86 (range: 0.69 – 2.94), from the Dell'acqua et al. (2000) database.

One hundred and twenty four nonword distractors were constructed; sixty-two were long distractors (7-8 phonemes) and the other sixty-two were short distractors (4-5 phonemes). Half of the long and half of the short distractors (thirty-one distractors each) shared the first two phonemes with the picture they were paired with, while the other half did not share with the picture name any phonemes in any positions of the string. Context-sensitive graphemes and multi-letter graphemes were avoided, so that the number of phonemes in each distractor stimulus was also the number of its letters. The four groups of distractors did not differ significantly in number or summed frequency of orthographic neighbors. Each target picture was presented four times: 1) with a long and phonologically related superimposed distractor, 2) with a long and phonologically unrelated superimposed distractor, 3) with a short and phonologically related superimposed distractor and 4) with a short and phonologically unrelated superimposed distractor. Eighteen experimental lists were created in which stimuli were presented in a different order for each list with the restriction that one particular target could not be followed by itself in the next 3 items. Furthermore, each list

began with three practice trials, as in Experiment 1. Appendix 4 reports the experimental stimuli used in Experiment 2.

Apparatus and Procedure were the same as in Experiment 1.

Results

Naming errors and apparatus failures (3.63%) were removed prior to analysis. Correct RTs were submitted to Van Selst & Jolicoeur (1994) outlier removal procedure, resulting in the elimination of 1.9% trials. Both the factor of length of nonword distractors (long distractor: 7-8 letters vs. short: 4-5 letters) and the factor of picture-distractor phonological relatedness (first two phonemes shared vs. none phoneme shared) were treated as a within-subject factors in both the by subject (F1) and the by items (F2) analyses. The same analysis was conducted both on RTs and on the Accuracy. Table 4 reports the means RTs for each experimental condition and their difference values.

	Distractor Length				Difference (RTs)
	Long (7 ph.)		Short (4 ph.)		
Onset Ph. Relatedness	RTs	%E	RTs	%E	
Related	730	2,5	732	1,6	-2,11
Unrelated	779	3,0	752	2.0	26,56
Difference	49	0.5	20	0.4	

Table 4. Means of the picture naming latencies [ms] and of naming Errors [%] of Exp 2 as a function of distractor length and picture-distractor phonological relatedness factors (first two phonemes shared vs. none phoneme shared). Length is considered in terms of the number of the constituent phonemes.

RTs.

Analysis revealed a main effect of onset phonological relatedness $F_1(1, 17) = 17.79$, $p < .05$, $F_2(1, 31) = 9.69$, $p < .05$ – i.e. when the pairs of stimuli shared the first two phonemes picture naming latencies were faster than when the pairs of stimuli did not share any phonemes. There was no main effect of distractor length, $F_1(1, 17) = 2.9$, $p > .05$, $F_2(1, 31) = 1.774$, $p > .05$. Analysis by subjects revealed a statistically significant interaction between the two main factors, i.e. target-distractor onset phonological relationship and distractor length, $F_1(1, 17) = 5.71$, $p < .05$, an interaction not found in the analysis by items $F_2(1, 31) = 2.035$, $p > .05$. When the picture-distractor pairs were phonologically related (they shared the first two phonemes) then there was no distractor length effect and in these conditions the picture naming latencies were the fastest ones. When the picture –distractors pairs did not share any

phoneme then the distractor length effect was evident: longer picture naming latencies when pictures were paired with long nonword distractors than when the same pictures were paired with short nonword distractors. Finally the paired t-test between the phonologically unrelated pairs of stimuli revealed an effect of nonword distractor length $t_{\text{subjects}}(1,17) = 3.012, p < .025, t_{\text{items}}(1,30) = 2.184, p = .037$, an effect not found when the pairs of stimuli were phonologically related, $|t| < 1$.

Accuracy.

The mean accuracy values and the differences between the mean accuracy values of all the experimental conditions are reported in Table 4.

Analyses revealed that neither the main effect of distractor length effect nor the main effect of end phonological relatedness were significant, and there was no interaction between distractor length and phonological relatedness (all p values $> .05$).

Discussion

The analysis showed an onset-relatedness effect: picture naming was faster when pictures were paired with nonword distractors that shared the first two phonemes compared than when the same pictures were paired with distractors that did not share any phonemes with the picture name.

We could propose an explanation in the context of the dual route theory of reading (Coltheart et al., 2001). The reading system is recruited for the phonological assembly of the pronounceable nonword distractor. Thus, the first phonemes to be activated are those belonging to the distractor, further they are activated sequentially by the nonlexical route, starting from the left most phoneme of the string. Since the left most distractor phonemes are available in the phoneme system before the target response, and in the case the target-distractor pair shared those two first phonemes, as happens in the phonological related condition of Experiment 2, there would be some activation flowing from the nonword distractor phonemes in the phoneme system to the target phonological representation in the phonological output lexicon. Since the target phonological representation is activated in parallel in the phonological output lexicon and its constituent phonemes are activated in parallel in the phoneme system, any extra activation received for any specific phoneme in the phoneme system would increase the total amount of activation of the target picture phonological representation and consequently the activation level of the picture phonemes. In the case of initial shared phonemes, the target phonological representation, receiving an extra amount of activation from the distractor phonemes would be subject to an exponential rise on activation in the phonological output lexicon and this would cause the target phonemes to

rapidly reach the required level of activation in the phoneme system to be named as the correct response to the task. The naming of the target picture, in the case of the phonological related condition, would happen before the nonlexical route has the chance to complete the phonological assembly of the nonword distractor. As a consequence, the time needed to name the target picture would be independent on the actual phonemic length of the nonword distractor since its assembly will not be completed by that time.

In the phonological unrelated condition instead the nonword distractor length effect emerges, and the size of the nonword distractor length effect we obtained in Experiment 2 is comparable to the size of the distractor length effect found in Experiment 1 (27ms compared to 26ms respectively).

When the target-distractor pairs are phonologically related, i.e. they share the first two phonemes, the distractor length effect completely disappears. The interaction clearly suggests that the onset phonological relatedness effect is due to the first two phonemes shared by the written nonword distractor and the target picture to be named. Specifically two different sources, i.e. the semantic-lexical route and the nonlexical route, send activation to a unique destination represented by the first two phonemes that occupy the first two slots in the phoneme system. If the onset was shared, it might receive the double amount of activation, reaching the critical threshold for those phonemes faster than in the scenario where the onset is not shared. At the same time this joint activation would raise the overall target phonological representation in the phonological output lexicon so that the phonemes belonging to the target pictures would become strong competitors in the phoneme system against the phonemes activated by the nonlexical route. The absence of the length effect might suggest that the target pronunciation reach the naming threshold before the nonword distractor pronunciation has been completely assembled.

A brief digression, Experiment 1, Experiment 2 and the REH

One account that seems able to explain our Experiment 1 is the response exclusion hypothesis, REH (proposed by Finkbeiner & Caramazza, 2006; and Mahon et al, 2007). This account posits that the phoneme system can only hold one representation at a time and that a decision mechanism works on the entire well phonologically formed response. This mechanism, once the nonword distractor phonological assembly is completed, deletes/excludes the distractor representation from the phoneme system if source information indicates that the representation in the phoneme system comes from the printed stimulus. Consequently the admission of the picture name to the phoneme system must wait until the distractor representation is fully formed in the phoneme system and then excluded. It will take longer for a representation of a long nonword distractor to be fully formed in the phoneme

system than a representation of a short nonword distractor to be fully formed in the phoneme system. So a picture will have to wait longer for admission to the phoneme system when the distractor is long compared to when it is short. That is a way of explaining the distractor length effect.

How might we explain the absence of a target length effect? We suggest that this is because the target representation is admitted to the phoneme system as a whole so the time to execute such admission is independent on the target length. It is in fact retrieved from the semantic-lexical route that retrieves the picture representation as a whole, in parallel. And it cannot enter into the phoneme system since the phonological distractor representation has been purged out of it. In other words the target admission to the phoneme system occurs after the distractor has been purged from the phoneme system and no interaction of target length with distractor length is expected.

However, although the REH is capable of explaining the results of Experiment 1, it has been challenged as a general explanation of distractor effects (Mulatti & Coltheart, 2012; Starreveld, La Heij & Verdonschot, 2013) and it failed to account for our Experiment 2 results. As a matter of fact we obtained a facilitatory phonological relatedness effect between the picture and the nonword distractor when they shared the first two phonemes.

The REH does not predict any effect of phonological relatedness between the target picture and the nonword distractor. This is because the REH states that the phonological response buffer can hold only one response at a time and that the picture response enters in the buffer only after the distractor one has been totally purged from the buffer. Thus, by the time the target picture response enters into the phonological response buffer the phonological representation belonging to the nonword distractor has been totally eliminated from that buffer. Since the phonological relatedness effect occurs because at the phonological level of the word production system there are some overlaps between the phonemes belonging to two different sources (the phonemes belonging to the nonword distractor and the phonemes belonging to the picture name), the REH is not able to offer any explanations of these effects.

This behavioural evidence, in the context of the REH, suggests that two of its principles are incorrect: 1) the phonological response buffer is not purged of the nonword phoneme string by the time the picture phonological representation enter in this store, 2) this buffer can hold two phonological representations at the same time.

We carried out Experiment 3 and Experiment 4 with the aim of further exploring the picture-distractor phonological relatedness specifically how this variable interacts with the distractor length variable a) when phonological relatedness interests the final two phonemes (Experiment 3) and b) when the position of the phonological relatedness between the picture

name and the nonword distractor changes across the target-distractor phonemic string (Experiment 4). We thus might have sufficient material to advance an alternative account to the REH and to the DRC-SEM theory, neither of which can explain all of the results of Experiments 1 and 2.

Experiment 3

Method

Participants

Twenty-seven students of the Università degli Studi di Padova participated in the study as volunteers. They all had normal or corrected-to-normal vision. Participants were all native speakers of Italian.

Design

A within-subject design was employed with two factors orthogonally manipulated, both with two levels: the length of pronounceable nonword distractors (short distractors: 4-5 phonemes *vs.* long distractors: 7-8 phonemes) and the picture-distractor phonological relatedness (last two phonemes shared *vs.* no phonemes shared).

Material

Thirty-two pictures were selected as target stimuli from the database of Dell'acqua et al. (2000). Their average number of phonemes was 6.1 (ranging from 4 to 8), counting geminate consonants as in GONNA as two phonemes. These pictures had a high name agreement value. The mean frequency of the target pictures was 1.23 (range: 0.70-2.94), from the Dell'acqua et al. (2000) database.

One hundred and twenty eight nonword distractors are constructed; sixty-four were long distractors (7-8 phonemes) and the other sixty-four were short distractors (4-5 phonemes). Half of the long and half of the short distractors (thirty-two distractors each) shared the last two phonemes with the picture they were paired with, while the other half did not share any phonemes with the picture name in any positions of the string. Context-sensitive graphemes and multi-letter graphemes were avoided, so that the number of phonemes in each distractor stimulus was also the number of its letters. The four groups of distractors did not differ significantly in number or summed frequency of orthographic neighbors. Each target picture was presented four times: 1) with a long and phonologically related superimposed distractor, 2) with a long and phonologically unrelated superimposed distractor, 3) with a

short and phonologically related superimposed distractor and 4) with a short and phonologically unrelated superimposed distractor. Twenty-three experimental lists were created in which stimuli were presented in a different order for each list with the restriction that one particular target could not be followed by itself in the next 3 items. Furthermore, each list began with three practice trials, as in Experiment 1. Appendix 5 reports the experimental stimuli used in Experiment 3.

Apparatus and Procedure were the same as in Experiment 1.

Results

Naming errors and apparatus failures (6.01%) were removed prior to analysis. Correct RTs were submitted to the Van Selst & Jolicoeur (1994) outlier removal procedure, resulting in the elimination of 1.7% trials. Both the factor of length of nonword distractors (long distractor: 7-8 letters vs. short: 4-5 letters) and the factor of picture-distractor phonological relatedness (last two phonemes shared vs. none phoneme shared) were treated as a within-subject factors in both the by subject (F1) and the by item (F2) analyses. The same analysis was conducted both on the RT and on the accuracy values.

Table 5 reports the means reaction times for each experimental condition and their difference values with the means accuracy by subjects.

	Distractor Length				Difference (RTs)
	Long (7 ph.)		Short (4 ph.)		
End Ph. Relatedness	RTs	%E	RTs	%E	
Related	726	2,4	709	2,4	17
Unrelated	752	2,4	735	2,4	17
Difference	26	0,0	26	0,0	

Table 5. Means of picture naming latencies [ms] and of naming errors [%] of Experiment 3 as a function of distractor length and picture-distractor phonological relatedness factors (last two phonemes shared vs. none phoneme shared). Length is considered in terms of the number of the constituent phonemes.

RTs

There was both a main effect of nonword distractor length, $F(1, 26) = 4.23, p < .05$, $F(1, 31) = 5.47, p < .05$, and a main effect of picture-distractor phonological relatedness, $F(1, 26) = 22.32, p < .001$, $F(1, 31) = 7.95, p < .001$. The interaction between these two factors was not significant, $F(1, 26) = 0.011, p > .05$, $F(1, 31) = 0.003, p > .05$.

Accuracy

The means accuracy values by subjects are reported in Table 5.

The analysis reveals no interaction between the distractor length and the phonological relatedness effects, neither the main effect of distractor length effect nor the main effect of end phonological relatedness were significant, all p values $> .05$. In each condition the mean value of picture naming errors considering the data by subjects was 2.4%, and considering the data by items 2%.

Discussion

The analysis reveals a main effect of end-phonological relatedness. Picture naming latencies are faster when the picture-distractor pairs share the last two phonemes compared to the condition in which the picture-distractor pairs did not share any phonemes. The finding of a phonological relatedness effect here is inconsistent with the REH, for the reason given in the discussion of Experiment 2.

Because there were target-distractor pairs in which target and distractor differed in number of phonemes, when target and distractor shared end phonemes these shared phonemes often occupied different absolute positions, and yet there was still end-related facilitation. This is evidence against any model in which phoneme positions are coded in terms of absolute position. This point is commented on further in the Discussion of Simulation 4.

The end-phonological relatedness between the nonword distractor and the picture is suggesting that the phonological store is not entirely purged by the nonword distractor phonemes at the time the phonemes of the picture have been activated for the pronunciation. As a matter of fact what happens is that those nonword distractor phonemes that are shared with the picture are able to prime those picture phonemes even if they are occupying different absolute position in the nonword string or another possibility is that they only feed-activation back to the phonological representation of the target, without priming the target's phonemes.

The analysis revealed a nonword distractor length effect as well and an additive pattern between the end phonological relatedness variable and the nonword distractor length variable.

Within the DRC-SEM theory and explanation could be found postulating that the rightmost phonemes of the distractor send the same amount of activation back to the target representation in the phonological output lexicon, regardless on how 'right' they are, i.e. regardless of the nonword distractor length.

One thing which Experiments 2 and 3 cannot tell us directly is whether the shared-phoneme facilitation effect is the same size when the shared phonemes are at the beginning of the picture name as when they are at the end. Experiment 4 had both an onset-related condition and an end-related condition (as well as an unrelated condition) so that whether

there is any effect of the position of the shared phonemes could be determined.

Experiment 4

Method

Participants

Twenty-five students of the Università degli Studi di Padova participated in the study as volunteers. They all had normal or corrected-to-normal vision. Participants were all native speakers of Italian.

Design

A within-subject design was employed with a main factor of the position of the picture-distractor phonological relatedness. The pairs of stimuli could share the initial two phonemes, the final two phonemes or could have none shared phonemes.

Materials

Thirty pictures were selected as target stimuli from the database of Dell'acqua et al. (2000). Their average number of phonemes was 6.3 (ranging from 4 to 8), counting geminate consonants as in GONNA as two phonemes. These pictures had a high name agreement value. The mean frequency of the target pictures was 1.23 (range: 0.70 – 2.94), from the Dell'acqua et al. (2000) database.

Ninety nonword distractors are constructed as an experimental nonword distractors, all of them had 7 constituent phonemes. One third of the total experimental nonword distractors (thirty distractors each) shared the last two phonemes with the picture they were paired with, a second third shared the final two phonemes while the other thirty did not share with the picture name any phonemes in any positions of the string. Context-sensitive graphemes and multi-letter graphemes were avoided, so that the number of phonemes in each distractor stimulus was also the number of its letters. The three groups of distractors did not differ significantly in number or summed frequency of orthographic neighbors. Each target picture was presented three times: 1) with an initial phonologically related superimposed distractor, 2) with a final phonologically related superimposed distractor, 3) with a phonologically unrelated superimposed distractor. Ninety experimental item pairs and other sixty pairs of stimuli that constituted the filler items for a total of one hundred and fifty trials for each list

composed each experimental list. Twenty experimental lists were created in which stimuli were presented in a different order for each list with the restriction that one particular target could not be followed by itself in the next 3 items. Furthermore, each list began with four practice trials. Appendix 6 reports the experimental stimuli used in Experiment 4.

Apparatus and Procedure were the same as in Experiment 1.

Results

Naming errors and apparatus failures (6.31%) were removed prior to analysis. Correct RTs were submitted to Selst & Jolicoeur (1994) outlier removal procedure, resulting in the elimination of 1.42% trials. The main factor of phonological overlap (initial two phonemes shared vs. final two phonemes shared vs. none phoneme shared) is treated as a within subject factor in both the by subject (F1) and the by item (F2) analyses. The same analysis was conducted both on the reaction times (RT) and on the naming errors (Accuracy).

Table 6 reports the means of RT and accuracy for the three experimental conditions examined in Experiment 4.

Ph. Relatedness Pos.	RTs	%E	Difference (RTs)
Onset	760	0,09	None-onset 50
End	786	0,1	None-end 24
None	810	0,08	

Table 6. Means of the picture naming latencies [ms] and of naming Errors [%] of Experiment 4 as a function of the position of the target-distractor phonological relatedness (Onset = first two phonemes; End = last two phonemes; none = control condition).

RTs

The analysis reveals a main effect of phonological relatedness both in the analysis by subjects and in the analysis by items, F1 (1,24) = 11.5, $p < .001$, F2 (2, 89) = 3.74, $p < .05$. Moreover, paired t tests revealed statistical significance for all the comparisons, in both the analysis by subjects and the analysis by items. What the comparisons found, were 1) a greater advantage for the initial phonological relatedness overlap between the picture distractor pairs: picture naming latencies in this condition were faster than a) the phonological unrelated control condition $t_{\text{subjects}} = -4.1$, $p < .05$, $t_{\text{items}} = -4.6$, $p < .05$ and b) the final phonological overlap condition $t_{\text{subjects}} = -2.8$, $p < .05$, $t_{\text{items}} = -2.4$, $p < .05$, and 2) an advantage on the picture naming latencies when the phonological relatedness involved the two final phonemes

compared to the phonological unrelated condition $t_{\text{subjects}} = -2.4$, $p < .025$, $t_{\text{items}} = -2.1$, $p < .025$, the latter was the slowest condition.

Accuracy

The analysis failed to find the main effect of target-distractor phonological relatedness according to the position of the phonological overlap, all F values < 1 . The paired t -test comparisons failed to reach any statistical significance $|t_s| < 1$.

Discussion

The analysis reveals a phonological facilitation effect due to the initial picture-distractor phonological overlap as shown in Experiment 2. Further, the analysis reveals a phonological facilitation effect due to the final picture-distractor phonological overlap as shown in Experiment 3. The final target-distractor phonological relatedness effect shown in Experiment 3 was smaller in size compared to the onset target-distractor phonological relatedness effect shown in Experiment 2 (26ms and 35ms on average respectively). This pattern, reported in two previous different experiments, is consistent with the results obtained in Experiment 4: a significant final picture-distractor phonological relatedness effect was found that however was significantly smaller to the onset picture-distractor phonological relatedness. In our Experiment 4 the nonword distractors were all of the same phonemic length that was comparable to the phonemic length of the target phonemic length on average, 6,3 the phonemic length of the target pictures and 7 the phonemic length of all the nonword distractors.

Why is the phonological relatedness effect smaller when the overlapping phonemes are at the end of target and distractor than when they are at the beginning? This is because of the serial functioning of the nonlexical route. As we propose to explain the onset phonological effect obtained in Experiment 2 and the final phonological relatedness effect obtained in Experiment 3, this is due to the serial functioning of the nonlexical route. Indeed, the nonlexical route is recruited to compute the phonological assembly of the nonword distractor and it proceeds assigning a phoneme to each grapheme, from the leftmost one to the rightmost one. When the overlap occurs very early in the nonword string then the amount of the activation the shared phonemes send to the target phonemic representation is maximal compared to all the other positions in the string. In this case the target phonemic string activated in the phoneme system would reach the naming threshold before the nonlexical route is able to complete the nonword distractor phonological assembly in the phoneme

system. The distractor length effect is thus absorbed by the onset phonological facilitation effect.

When instead the phonological overlap occurs later in the nonword string, then the amount of activation the target phonemes spread to the target phonemic representation is smaller than in the former case; and this is because the reading system would know the shared phonemes only later in time. As a consequence the nonword distractor length effect in this condition is totally expressed on the picture naming latencies. This however would predict an interaction between the distractor length and the phonological relatedness when the overlap is at the end, but we previously shown an additive pattern between these two variables (Experiment 3).

We ran three simulations on the explored distractor phonemic length, onset picture-distractor phonological relatedness and final picture-distractor phonological relatedness effects in order 1) to test the DRC-SEM and 2) to understand the observed phenomena through the use of the model. Each simulation corresponds to one of the Experiments reported above. The aim of this simulation work is also to test the phoneme position-coding scheme implemented on the phonemic system of the DRC-SEM. In Experiments 3 and 4 there was end-related facilitation even though in this condition overlapping phonemes did not always occupy the same absolute positions in distractor and target; DRC-SEM uses an absolute position coding scheme in the phoneme system, and so would not be expected to show end-related facilitation if target and distractor are of different phoneme lengths.

Simulation 3

Properties of the stimuli (for the complete list of stimuli see Appendix 7)

As in Experiment 2, there were two independent variables here: distractor length (short vs. long) and target-distractor phonological relatedness (pictures and nonword distractors shared their first two phonemes or they did not share any phonemes).

Twenty targets were selected from the CELEX database (Baayen et al., 1993), they had a medium value of spoken word frequency and they consisted of six phonemes. Each target was paired with four types of distractors 1) short, with the onset phonologically related to the picture name, 2) short, completely phonologically unrelated to the picture name, 3) long, with the onset phonologically related to the picture name, 4) long, completely phonologically unrelated to the picture name. A total of eighty distractors were created: half of them were long distractors (6 phonemes) and half short (3 or 4 phonemes). Long nonword distractors were forty, of these distractors half were constructed in order to share with the target picture the first two phonemes, and the other half were constructed with none phoneme

shared with the picture name.

Results

Table 7 shows the averages of the number of cycles the model required to name the pictures as a function of distractor length and onset-phonological relatedness.

Onset Ph. Relatedness	Distractor Length		Difference (cycles)
	Long (6 ph.) n.Cycles	Short (3/4 ph.) n.Cycles	
Related	159,26	150,37	8,89
Unrelated	223,00	221,00	2,00
Difference	63,74	70,63	

Table 7. Means of the number of DRC-SEM cycles of Simulation 3 as a function of distractor length and the onset-phonological relatedness between pictures and distractor pairs (they shared the first two phonemes or none phoneme). Length is considered in terms of the number of the constituent phonemes.

We calculated for each target picture the effect of distractor length effect both for the phonological unrelated condition and the distractor length effect for the onset-phonological related condition. We then subtracted the former obtained values from the obtained latter values, obtaining in this way a measure of interaction for each target picture. Then we tested whether these interactions were significantly different from zero. The analysis reveals a significant interaction, $t(18) = 4$, $p < .001$. Further, analyses conducted by means of the McNemar's tests revealed a) a significant main effect of distractor length both for the phonological related and for the phonological unrelated conditions (p values $< .001$) and b) a main effect of onset-phonological relatedness (p values $< .001$) for both the long and short nonword distractor conditions.

Discussion

As in Simulation 3, in Experiment 2 we investigated the nonword distractor phonemic length and the target-distractor onset phonological relationship between the target picture and the nonword distractor. A facilitatory effect of picture-distractor onset phonological relatedness was shown both in Experiment 2 and in Simulation 3. In Experiment 2 we also found a significant interaction: a nonword distractor length effect occurred in the phonologically unrelated target distractor pairs but not in the phonologically onset related target distractor pairs. In Simulation 3, there was also an interaction between these two factors but of a completely different pattern from Experiment 2: the size of the nonword distractor

length effect was greater for the onset-phonologically related pairs of stimuli than for the phonologically unrelated pairs of stimuli.

What causes this inverse pattern of the interaction found in Simulation 3 versus Experiment 2? Comparing human and simulated data the first incongruence to mention concerns the different pattern of result in the onset-phonological condition where the distractor length effect emerges in the number of cycles the model requires to name the target picture but completely disappears in the picture naming latencies. Specifically the model – in contrast to the human data – brings the advantage of the first positions phonological overlap along all the string of the nonword distractors. Indeed this is the condition where the distractor length effect is maximally expressed. Thus, the nonlexical route spends more time on the phonological assembly of nonword distractors when nonwords are long than when they are short. Moreover, the reason why the difference between long and short distractor conditions is greater for phonologically related pairs of stimuli is twofold:

- 1) Given the fact that for short distractors the first two phonemes are shared, the nonlexical route has only to convert at maximum two other phonemes to complete the assembly, but then the target phonemes are already approaching the naming threshold keeping the advantage of the double activation level sent to its onset phonemes.
- 2) The long nonword distractors requiring a greater number of cycles to be phonologically computed, they prolong the lateral inhibition going on in the phoneme slots of the phoneme system, specifically those slots who are different phonemes competing for one position. The facilitation due to the shared initial phonemes dissipates during the time required to assembly the nonword phonemic string. However, there is still facilitation for the related pairs when the distractors are long.

Simulation 4

Properties of the stimuli, for the complete list of stimuli see Appendix 8

As in Experiment 3, there were two independent variables here: distractor length (short vs. long) and target-distractor phonological relatedness (pictures and nonword distractors shared their last two phonemes or they did not share any phonemes).

Twenty-one targets were selected from the CELEX database (Baayen et al., 1993), they had a medium value of spoken word frequency and they consisted of six phonemes. Each

target was paired with four types of distractor. A total of eighty-four distractors were created: half of them were long distractors (6 phonemes) and half short (3 or 4 phonemes). There were 42 nonword distractors; of these, half shared with the target picture the last two phonemes, and the other half shared no phonemes with the picture name.

Results

Table 8 shows the averages of the number of cycles the model required to name the picture as a function of distractor length and end-phonological relatedness.

End Ph. Relatedness	Distractor Length		Difference (cycles)
	Long (6 ph.)	Short (3/4 ph.)	
Related	n.Cycles 216,71	n.Cycles 221,95	-5,24
Unrelated	n.Cycles 223,00	n.Cycles 222,00	1,00
Difference	6,29	0,05	

Table 8. Means of the number of DRC-SEM cycles of Simulation 4 as a function of distractor length and the end-phonological relatedness between pictures and distractor pairs (they shared the last two phonemes or none phoneme). Length is considered in terms of the number of the constituent phonemes.

We calculated for each target the value of the distractor length effect in the phonological unrelated condition and the distractor length effect for each target in the end-phonological related condition. Then we subtracted from the former obtained values the latter obtained ones, which gave us a measure of the interaction for each target. We then tested if the set of obtained differences values were significantly different from zero by a one-sample *t* test. This analysis reveals the interaction between the distractor length – in terms of number of the constituent phonemes – and the picture-distractor phonological relatedness variable, $t(20) = -15$, $p < 0.01$. Analyses using McNemar's tests revealed that when distractors are short, the phonological relatedness effect was not statistically significant ($p > .05$), whereas when distractors are long, pictures paired with long phonologically end-related distractors are named significantly faster than when paired with long distractors that did not share any phonemes ($p < .001$). Further, when the picture – distractor pairs are phonologically related by the phonemes in the last two positions, then the model's RTs are significantly greater with short distractors than long distractors ($p < .001$), whereas when instead the picture-distractor pairs are phonologically unrelated the McNemar's test reveals that picture paired with short distractors are responded to faster than those paired with long distractors ($p < .001$). There was one cycle of difference on average between these two conditions.

Discussion

In Experiment 3, human readers showed additive effects of end-relatedness and distractor length; but DRC shows an interaction – there is a relatedness effect only in the long distractor condition. This happens because according to the model, if a phoneme of the distractor occupies a different ordinal position in the string compared to the same identical phoneme but in the target string, it is not recognized as the same phoneme. To be recognised as the same, a phoneme has to share the same ordinal position in the picture name phoneme string and the nonword distractor phoneme string. Consequently, the shared last two phonemes of the short distractors are treated by the model as two phonemes to be inhibited because they occupy different absolute positions in picture name and distractor.

When the nonword distractors are long instead, the last two phonemes of the target share the same absolute position of the nonword distractors phoneme and so the model is responsive to whether the last two phonemes of the distractor are or are not shared by the picture name. As a consequence the nonword distractor phonemes after a certain amount of cycles are subject to the decay activation but the last two phonemes, in the case of end-phonological relatedness between the two stimuli, maintain and raise their level of activation due to the feedback and feed forward connections between the phoneme system and the phonological output lexicon, where the target picture phonological representation is held. Long nonword distractors bring to the picture naming task a different amount of interference due to the final phonemic overlap. When the stimuli shared the final two phonemes, the model could relieve the commonality and keep the activation level of these phonemes, firstly activated by the nonlexical route.

This simulation results highlight a special feature of the human reading system that is not conserved in the DRC-SEM model, that is the capability of the system to keep track of the shared phonemes between the picture and the nonword distractors even when they occupy different absolute positions in the strings they belong to. The human reading system seems thus not to use a phoneme position coding scheme that is based on absolute position.

Simulation 5

Properties of the stimuli (for the complete list of stimuli see Appendix 9).

As in Experiment 4, there was one independent variable, the position of the phonological overlap between the target picture and the nonword distractors, with three

levels: picture-distractor pairs could share the first two phoneme (onset), the last two phonemes (end) or none phoneme at all (control condition).

Nineteen targets were selected from the CELEX database (Baayen et al., 1993), they had a medium value of spoken word frequency and they consisted of six phonemes. Each target was paired with three types of distractors, differing from each other only for the position of the phonemes shared with the picture they were paired with: 1) onset-phonologically related, 2) end-phonologically related, 3) phonologically unrelated. All distractors however had six phonemes, as did the target pictures. A total of fifty-seven distractors were created.

Results

Table 9 shows the averages of the number of cycles the model required to name the pictures as a function of target-distractor position of phonological relatedness (onset vs. end vs. controls).

Ph. Relatedness Pos.	N.Cycles	Difference (Cycles)
Onset	159,11	None-onset 63,89
End	216,16	None-end 6,84
None	223,00	

Table 9. Means of the number of DRC-SEM cycles of Simulation 5 as a function of the position of the target-distractor phonological relatedness (Onset = first two phonemes; End = last two phonemes; none = control condition).

McNemar's tests revealed statistically significant differences between the three conditions. When the pictures were onset-phonologically related to the nonword distractors fewer cycles were needed to produce the picture name than in the other two conditions (p values both $< .001$). Respectively, the value of difference was of 57 cycles between the onset related target-distractor pairs and end related target-distractor pairs and 64 cycles between the onset related and the unrelated pairs of stimuli. When the same pictures were paired with end-phonologically related distractors, the model still needed significantly fewer cycles to produce the picture name compared to the unrelated condition ($p < .001$).

Discussion

The analysis reveals a perfect congruency with the pattern of human results obtained in the corresponding Experiment 4: a position dependent phonological relatedness effect occurs in both the model and human readers.

This is the only one of the three simulations in which the simulation and the behavioural data showed complete congruence. This is because the phonological overlap between the picture name and the nonword distractors always involved the phonemes that occupy the same absolute position in both the string of the stimuli. Thus the model is able to simulate the phonological relatedness effect only when the shared phonemes occupy the same ordinal position, i.e., when they both compete for the same slot in the phoneme system. That there is greater advantage when the phonological overlap is at the onset of the pairs of stimuli than when the overlap involved the last two phonemes is due to the serial functioning of the nonlexical route as explained in the discussion section of Experiment 4.

Experiment 5

In several of the experiments just reported, we explored effects of target length and distractor length. We always measured these in terms of number of phonemes. But the number of phonemes in a stimulus will be highly correlated with the number of syllables, and so we cannot tell whether any length effects we have obtained are due to the number of phonemes in the stimuli or the number of syllables. We need to decide which of these is the relevant variable.

Overall we obtained a distractor length effect, simulated congruently with the DRC-SEM model (see Simulation 1). Since the DRC-SEM model does not represent syllables in the phoneme system, any length effects the model shows must be due to the number of the phonemes in the written nonword distractors,

Hence, we carried out a fifth PNWI experiment where the nonword distractor length was orthogonally manipulated according to the two main factors: number of constituent phonemes or number of constituent syllables. The aim was to decide whether it is phoneme length or syllable length that is responsible for the distractor length effect in the PNWI effect.

Method

Participants.

Twenty-seven participants from the Università degli Studi di Padova participated in the study as volunteers. They had normal or corrected-to-normal vision. Participants were all native speakers of Italian.

Design

A within-subject design was employed with the number of the constituent syllables (three levels, two *vs.* three *vs.* four syllables) and the number of the constituent phonemes (three levels, six *vs.* seven *vs.* eight phonemes) treated as within-factors.

Materials

Thirty-six target pictures were selected from the database of Dell'acqua et al. (2000). All picture labels had eight phonemes and on average 3.3 syllables (25 target pictures had three syllables and 11 had four syllables), a high name agreement value (87% on average, range [45 - 100]) and a medium range of spoken frequency value (1.7, range [0.6 - 2.72]). Five groups of pronounceable nonword distractors were constructed. The following five distractor conditions were created: 1) 2 syllables and 7 phonemes, 2) 3 syllables and 6 phonemes, 3) 3 syllables and 7 phonemes, 4) 3 syllables and 8 phonemes, 5) 4 syllables and 7 phonemes. No phonemes were shared between target - distractor pairs. As in Experiment 1, context-sensitive graphemes and multi-letter graphemes were avoided, so that the number of the phonemes in each distractor stimulus was also the number of its letters as in Experiment 1. None of the distractors had any orthographic neighbors.

Each target picture was presented five times, according to the experimental condition they belong to (i.e. the five condition above cited). Twenty experimental lists were randomly created, one list for each subject in which each target was presented five times and the serial order of the experimental stimuli presentation was randomly created for each experimental list. The experimental stimuli used in Experiment 5 are reported in Appendix 10 & Appendix 11.

Apparatus and procedure

The Apparatus and the Procedure of Experiment 5 was comparable to that of Experiment 1 except that the practice session included eighteen stimuli.

Results

Naming errors and apparatus failures (8.4%) were removed prior to analysis. Correct RTs were submitted to (Selst & Jolicoeur, 1994) outlier removal procedure, resulting in the elimination of 2.25% trials. The entire set of data was divided in two portions. In the first analysis, we explore the role of the syllable keeping all the experimental data concerning the nonword distractors of 7 phonemes but varying for the number of syllables (three, four or five syllables) and in the second analysis we explore the role of the phonemes keeping all the experimental data concerning nonword distractors of 3 syllables but varying the number of phonemes (six, seven or eight phoneme). In each of these two cases a two-way ANOVA considering both the length of the distractors in terms of number of constituent syllables (3 *vs.*

4 vs. 5) – in Analysis 1 – and in terms of number of constituent phonemes (6 vs. 7 vs. 8) – in Analysis 2 – combined with the factor of target length as number of constituent syllables (3 vs. 4 syllables) as within factors in both the analysis of subjects (F1) and the analysis by items (F2). Table 10 A & B reports the means RTs according to the experimental condition considered.

A)	Target picture				Difference (RTs)
	3 syllables		4 syllables		
Distractors (7 Ph.)	RTs	E%	RTs	E%	
2 syllables	760	4	809	6	49
3 syllables	775	4	819	4	44
4 syllables	789	4	828	4	39
Diff. 4 syll-3syll	14		9		
Diff. 4 syll-2syll	29		19		

B)	Target picture				Difference (RTs)
	3 syllables		4 syllables		
Distractors (3 Syll.)	RTs	E%	RTs	E%	
6 Phonemes	770	4	814	3	44
7 Phonemes	775	4	819	4	44
8 Phonemes	791	4	804	4	13
Diff. 8ph-7ph	16		-15		
Diff. 8ph-6ph	21		10		

Table 10. A) Means of the picture naming latencies [ms] and of the picture naming errors [%] of the experimental conditions considered in Analysis 1; B) Means of the picture naming latencies [ms] and of the picture naming errors [%] of the experimental conditions considered in Analysis 2. RTs. Analysis A.

The analysis failed to show any effect due to the length in terms of the number of the constituent syllables of the nonword distractors, $F_1(1, 2) = .624, p > .05$, $F_2(1, 2) = .477, p > .05$. However, it showed a main effect of number of syllables in the target picture name, $F_1(1, 2) = 6.24, p < .05$, $F_2(1, 2) = 8.46, p < .05$. There was no interaction between the two factors, $F_1(1, 2) = 0.31, p > .05$, $F_2(1, 2) = .008, p > .05$.

RTs. Analysis B.

The analysis failed to show any effect due to the number of the phonemes constituting the nonword distractors, $F_1(1, 2) = .046, p > .05$, $F_2(1, 2) = 0.70, p > .05$. A main effect of the number of the syllables in the target picture name was found in the analysis by subjects, $F_1(1, 2) = 4.833, p < .05$, but not in the analysis by items, $F_2(1, 2) = 3.57, p > .05$. There was no interaction between the two factors, $F_1(1, 2) = .467, p > .05$, $F_2(1, 2) = .282, p > .05$.

Accuracy: Analysis 1 & Analysis 2.

Table 10 A & B reports the means of the picture naming errors according to the experimental conditions considered.

Both analyses revealed no interaction between the distractor length and the syllables target length effects, both considering the length of the distractors as number of constituent phonemes and as number of constituent syllables. Neither the main effect of distractor length effect (both considering number of phonemes and of syllables as predictors) nor the main effect of syllable target length were significant, all p values $> .05$.

Discussion

The analysis conducted failed to find any modulation of the written nonword distractor length on the picture naming latencies in the PNWI task. Experiment 5 investigated the length of the nonword distractors both in terms of number of phonemes and in terms of number of syllables. Neither of these properties of the distractor showed effects on reaction times, which was in contrast to what was found in Experiment 1, namely, a distractor length effect. Thus we have not achieved the aim of disambiguating the distractor length effect found in Experiment 1, since there was no distractor length effect at all in Experiment 5⁷.

Furthermore the analysis showed a picture name length effect: picture names composed by three syllables are named faster than picture names composed by four syllables, this main effect was found regardless of to what experimental condition the written distractor belonged to.

Where does the distractor length effect found in Experiment 1 come from? It might be possible that other factors such as articulation, coarticulation, the complexity of the syllables influences the picture naming latencies. From our Experiment 2, 3 and 4 we demonstrate a clear role of the nonlexical route affecting the naming latencies. Specifically, the serial phonological assembly of the nonlexical route – that proceeds from the leftmost grapheme, assigning the appropriate phoneme, to the rightmost one of the written distractor – it seems to be a crucial aspect for all the effects found in the behavioral data.

One of the conclusions that might be drawn from this experiment however is that despite the absence of any distractor length effect, the phonological assembly of the nonword distractor phonology has occurred and probably the interplay with the activation of the picture

⁷ This was not the result of lack of power in Experiment 5 since that experiment used more subjects and more stimuli per cell than Experiment 1.

name phonology (showed instead in the other previous experiments) might be hidden by other contextual aspects of the task and by the properties belonging to the nonword distractors.

Although from our data we can claim that the syllables of the written nonword distractors did not play a modulation in the picture naming latencies, it remains unclear 1) if there is a syllabification process of the nonword distractor, 2) how it works and 3) if there is a common syllabification mechanism shared by the two routes (lexical-semantic and nonlexical routes). Furthermore, we claim that the constituent syllables of the picture name affected the reaction times. Although the picture name is not available into the visual field of the participants, it has instead to be retrieved from the semantic lexical route. This is the first study in the picture naming literature reporting a syllable length effect in PNWI. In order to give strength to this finding we could further investigate in future this effect in a simple picture naming task.

Finally, what Experiment 5 suggests is to always consider the syllable length as a possible candidate in the modulation of the picture naming latencies. Models of word production and reading aloud should account for this effect, implementing a syllabification process, overall for languages as Italian, which is composed for the most part by multisyllabic words. Concluding, since this is a salient factor in the picture naming task, increasing interest and research has to be carried out to explore and investigate how the syllables are computed in a pronounceable nonword distractor and if there is a shared syllabification process between word, pictures, nonwords and how it works according to the experimental task required. The final, most important aim is, however, increasing our knowledge about the human reading and word production systems in the human environmental context.

General Discussion

In this paper we have used the PNWI effect in experimental and computational-modelling work to shed some light on the nature of the systems used for picture naming and reading aloud.

This work represents an attempt to establish a proper experimental paradigm, the PNWI one. In comparison to previous reported work (Rosinski et al., 1975; Posnansky & Rayner, 1977; Rosinski, 1977; Guttentag & Haith, 1978; Rayner & Posnansky, 1978; Lupker, 1979; Briggs & Underwood, 1982; Lupker, 1982; Rayner & Springer, 1986) we have improved the paradigm regarding the experimental procedure and the method, in the way that researchers are able to implement a solid PNWI experiment and to properly compare the obtained results and replicate those reported from now on.

A total of five PNWI experiments were reported, DRC-SEM model was tested in four of them. Table 11 shows the congruence or incongruence between human data and simulations.

	<i>Effects</i>	<i>Human data</i>	<i>Simulation</i>
<i>Exp. 1 - Sim. 1</i>	Distractor Length	✓	✓
<i>Exp. 1 - Sim. 2</i>	Distractor Length	✓	✗
	Target Length	✗	✗
	Interaction	✗	✓
<i>Exp. 2 - Sim. 3</i>	Onset Relatedness Effect	✓	✓
	Distractor Length	✗	✓
	Interaction	✓	✓
<i>Exp. 3 - Sim. 4</i>	End Relatedness Effect	✓	✓
	Distractor Length	✓	✓
	Interaction	✗	✓
<i>Exp. 4 - Sim. 5</i>	None - Onset (first two ph.)	✓	✓
	None - End (last two ph.)	✓	✓
	onset -end	✓	✓

Table 11. Congruence or Incongruence between the patterns of human data and simulations results reported in this paper.

In Experiment 1 we found a distractor length effect: long nonword distractors led to slower picture naming latencies than short distractors did. Simulation 1 was congruent with this human data pattern: in DRC-SEM, a greater number of cycles was required by the model to name pictures when these were paired with long nonword distractors than when the same pictures were paired with short distractors. This amount of interference could be ascribed to the phoneme system: the more phonemes activated by the nonlexical route there are, the more the picture's representation in the phonological output lexicon is inhibited by the phoneme system, and consequently its phonemes will require more time to get activated to the naming level threshold in the phoneme system.

We explored the results of Experiment 1 further by splitting the data of this experiment to see whether the length of the names of the target pictures influenced picture naming latencies when the distractor length effect is manipulated as well. In this analysis human data showed a distractor length effect but no target length effect, and there was no interaction between these two factors.

The corresponding simulation showed an interactive pattern of results: long pictures

paired with long distractors led to the greatest number of cycles needed by the model to produce the picture name in comparison to all the other experimental condition. The reported interaction in the simulation number 2 shown how the model is sensitive to the effective number of phonemic slots involved in lateral competition in the phoneme system. In the model there is a competition to be solved before the picture name could be pronounced. This competition is the one occurring between different phonemes activated by the nonlexical route and the semantic lexical route for the same phonemic slot (the same ordinal position in the string).

Concerning the short target pictures condition, the distractor length is not able to affect the number of processing cycles required to name the picture because in the case of short target name the picture phonological representation is reaching its naming threshold before the nonlexical route completes its full job on the nonword string. Behavioural data are suggesting instead that the only variable able to affect picture naming latencies is the phonemic length of the nonword distractor, regardless of the length of the name of the picture. We explained this pattern of results proposing the REH account, but with the following behavioural data we have falsified this account.

The additivity shown in the human data is evidence against DRC-SEM, and any theory of how the human reading (and picture naming) system works will have to explain this additivity.

Our experimental investigation proceeded with a second experiment where we independently varied the length of the nonword distractors and the onset-phonological relatedness between the written nonword distractor and the picture name. Human data showed an onset phonological relatedness effect and an interaction: when the picture distractor pairs of stimuli were phonologically related (they shared the first two phonemes) there was no trace of distractor length effect, whereas when the pairs were phonologically unrelated the distractor length effect was significant. On the whole phonologically related pairs led to shorter picture naming latencies than phonologically unrelated ones.

The corresponding simulation showed the opposite pattern to the interaction found in human data (as well as two main effects). The nonword distractor length effect was greater for onset-phonologically related pairs of stimuli than for unrelated ones. The model on the whole, needed a smaller number of cycles to produce the picture names when they were paired with distractors sharing the first two phonemes. How might this incongruence between human data (Experiment 2) and Simulation 3 be explained?

Essentially, we need to claim that the model keeps track of the phonemic advantage brought by the first two phonemes along all the computational assembly of the phonology

corresponding to the nonword distractors. Furthermore, considering the phonologically related pairs of stimuli the greater the number of the phonemes in the nonword distractor, the lesser the advantage would be. This is because the advantage would be dissipated during the time needed for the nonlexical route to complete the nonword distractor phonological assembly. This pattern is totally absent in human data. When pairs of stimuli shared the first two phonemes, picture naming latencies were the same across the different levels of nonword distractor length. This might be due to the strong activation that the phonological representation of the target picture receives via feedback from the phonemes activated in the phoneme system. The picture's representation in the phonological output lexicon in turn would send activation to its phonemes that would rapidly resolve the lateral inhibition, both in the case of short and long nonword distractors. In the case of unrelated pairs, instead, human data shown the distractor length effect, as reported in Experiment 1.

In Experiment 3, we investigated the effect of sharing the last two phonemes between the to be named pictures and the visually presented nonword distractors, orthogonally with the manipulation of nonword distractor length. Note that the orthographic representations of the target pictures were not visually available to the participants. This is a relevant aspect because whatever the effects we found could not be due to visually available information about the target picture name.

Human data showed an additive pattern: specifically, long nonword distractors led to slower picture naming latencies compared to short nonword distractors. This is the main effect of nonword distractor length. Regardless of the nonword length, human data showed a main effect of the end phonological relatedness: pictures paired with nonwords that shared with the target name the last two phonemes were named faster than when the same pictures were paired with nonword distractors that did not share any phonemes at all.

In the corresponding simulation we found a different pattern of results, an interactive one: no end-phonological relatedness effect was present when targets and distractor pairs differ in length (which was the case with short nonword distractors) but there was an end-phonological relatedness effect when target-distractor pairs had the same length (i.e. when they both had six phonemes, which was the case with long nonword distractors).

One explanation of this effect is that the model is able to keep track that the last two phonemes of the picture-nonword pairs are shared only when they occupy exactly the same absolute ordinal position in the string, i.e. as in the picture FRUMPS and the long paired nonword distractor SKREPS, the 5th and the 6th phonemes are, in both stimuli, the phonemes /p/ and /s/. The absence of interference in the last two slots of the phoneme system led to a lesser number of cycles being required for naming the picture. Indeed both the last two

phonemes belonging to the phonological representation of the picture and those belonging to the nonword phonemes – activated serially by the nonlexical route – are activating the same phonemic representations, unique for each of the considered slot. Thus, the same unique unit for each of the considered slots receives activation from two different sources. When instead the last two phonemes of the distractor occurs earlier, not in the 5th and 6th positions as in the picture name but for instance in the 2nd and 3rd one, then the model is unable to recognize that these phonemes are still equivalent, i.e. as in the picture FRUMPS and the short paired nonword distractor IPS. Moreover, the length effect reported in Simulation 4 for end-related pairs is opposite to the one obtained for phonologically unrelated pairs (also found in Experiment 1 and Simulation 1). We found that long related distractors led to the model to respond in a shorter number of cycles than short related distractor did. This effect finds its explanation above, in the importance of sharing the last two phonemes in the exactly the same absolute slot position.

Finally Experiment 4 and the corresponding Simulation 5 explored the position of the phonological relatedness in the picture-distractor pairs, keeping constant the length of the nonword distractors, which were built having the same length in terms of the number of phonemes of the picture names. Human data and the simulation showed the same pattern: advantage for onset-phonologically related pairs in comparison with end-related pairs and an advantage for the end-related pairs compared to the control condition.

This pattern of congruency supports our proposal that the model is able to appropriately simulate the human data only when the phonological relatedness involved phonemes in target and distractor that are in the same absolute position in the phoneme system. So changes in how the model represents phoneme position are necessary if the DRC-SEM model is to be able to simulate the human data we have reported.

The experimental evidence we have reported here indicates that the operation of the reading system of adult skilled readers cannot be completely suppressed even when the instructions of the task explicitly ask the subject to ignore written stimuli. This occurs even when these written stimuli are unfamiliar (i.e. are nonwords).

In addition, we have shown how in the PNWI paradigm specific features of the nonword distractors modulate the picture naming latencies:

- 1) Long distractors interfere more than short ones;
- 2) Onset or end phonologically related distractors interfere less than phonologically unrelated distractors;
- 3) Onset-phonological relatedness interacts with distractor length;

- 4) End-phonological relatedness does not interact with distractor length;
- 5) When the length of the nonword distractors is kept constant, onset overlap produce the greatest facilitation, the completed unrelated distractors the greatest interference, and the end related distractors represent the intermediary condition between the above mentioned.

We tested the DRC-SEM model running the corresponding simulations of the reported behavioural investigations (see Table 14).

Overall, we reported three patterns of incongruence, plus one of congruence strengthen our idea (Simulation 2, 3, 4 and 5) that overall indicate the changes needed in the DRC-SEM model to improve its adequacy as an account of the human word-production (picture naming) and reading systems.

1. The semantic lexical route should be more independent of the number of phonemic slots involved in the lateral competition.
2. The phonemic coding position implemented in the current version of DRC-SEM is too anchored to the absolute position and this is also the reason why the current version of the model failed on Simulation 3 and Simulation 4. More dialogue has to be implemented between the activated phonemes by the two procedures, regardless to the ordinal position they occupy in the string. The reported human data (Experiment 3) suggest indeed a relative (ends-related) phonemic position coding.

What controls the nonword distractor length effect in the picture naming latencies, the number of syllables or the constituent phonemes?

In order to explore the nature of the distractor length reported in Experiment 1, we further investigate that effect, disambiguating the source of interference skimming from the different number of the constituent phonemes of the nonword distractor or the different number of its constituent syllables. The target length in terms of number of syllables was orthogonally varied. What the results showed is a target length effect and an absence of any effect of distractor length considered both in term of syllables and phonemes. Picture naming latencies were longer when the pictures had four syllables than when they had three syllables.

From this experiment we could conclude that we failed to show any effect of syllable length belonging to the nonword written distractor. This is partially in contrast to the evidence reported by Jared & Seidenberg (1990); Ferrand (2000) and more recently by Ferrand & New

(2003), where they reported that naming latencies were affected by the syllabic length of nonword and by very low-frequency words, in a reading aloud task. They failed to show such an effect in a lexical decision task both for nonword and for high frequency word. According to them their data are compatible with a computational architecture (the multiple trace memory model for polysyllabic word naming - Ans, Carbonnel & Valdois (1998) - that depends on the activity of two procedures, 1) a global procedures that operates in parallel across a letter string and 2) an analytic procedure that operates serially across a letter string, that would be responsible for the syllabic length effect they reported or of any nonword distractor length effect in reading aloud.

Our Experiment 5 failed to show the nonword distractor length effect we reported in Experiment 1. So it remains unclear what role the number of the nonword constituent phonemes plays in the PNWI paradigm. Further, other aspects as phonetic planning or articulatory planning of the nonword string might have played a role in hiding the phonemic length effect.

However, previous experimental investigations reported in this paper (Experiment 1, the reanalysis of Experiment 1 considering the target phonemic length and Experiment 4) showed the phonemic distractor length effect. Although we cannot claim that the phonemic length of the nonword distractor affects the picture naming latencies, we suggest this. We indeed demonstrated and discussed the crucial recruitment of the nonlexical route in the PNWI task and how this serial procedure interplays with the semantic lexical route which in turn tries to overcome the information available from the written stimulus to the reading system, retrieving the name of the line drawing visually presented.

Despite a lack of interference (or of absence of facilitation) coming from the written nonword distractors, we reported a syllabic effect due to the picture name. We thus underline the importance of a syllabification process to be inserted in any model of picture naming although in the picture naming task literature some of the studies reported a picture syllabic length effect (Santiago, MacKay, Palma & Rho, 2000; Santiago, MacKay & Palma, 2002) and some did not (Bachoud-Levi, Dupoux, Cohen & Mehler, 1998; Meyer, Roelofs & Levelt, 2003). In all these works however there was not a concomitant control for the phonemic length of the picture label.

Conclusions

Every model of speech production uses some scheme for representing phoneme position, but none of these schemes can explain our PNWI findings. So, new theoretical work

needs to be done on how phoneme position is represented in the speech production system.

This semantic version of the DRC model has been used just twice in the literature in order to perform human data of different tasks than the reading aloud one. We therefore encourage research efforts to develop a more complex semantic system (similar to the human one) in order to be able to simulate even more experimental evidence from several task types and many of the semantic effects that have been shown in the literature even in color naming and in the PWI tasks.

Finally, our data suggest the need to implement a syllabification process in any model of word production (or picture naming). Still, it remains unclear if this syllabification process would be shared by the semantic-lexical and nonlexical route or if it is a specific component. It is quite essential to develop other research work on this issue, overall in a language as Italian that is composed prevalently of polysyllabic words. This predominant feature presumably affects the nonlexical procedure in pronouncing new words or inexistent polysyllabic nonwords.

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Appendix 1

Experimental pairs of picture-nonword distractor stimuli used in Experiment 1.

Picture name (target)	Written nonword distractor	
	Long	Short
aquila	SEPOFENO	POFDE
banana	PRIGOLE	ILSVO
bilancia	TRUFESMO	DOFRE
camicia	DROFUTO	PLEVO
candela	TRUBITIO	ITISO
canguro	FISPELTI	SILFE
cannone	FRIPULI	LUFRI
cappello	SIVRUNTI	NIRBI
caramella	BOFISTO	NOSBI
carciofo	GEMUSTE	USZE
carota	FEDUSIME	IBEDI
casco	RINEVEBI	NIBU
cavallo	BRESUNI	SIDRE
chitarra	DEMOVESO	ZUFE
ciliegia	STODUMO	NUFMO
cintura	BOSEMEPO	SBEPO
fionda	PESULBRE	PURME
foglia	VRESEMBE	MEVRE
forchetta	MUPILSVI	SIMZI
fragola	VUDINTE	SIVNE
freccia	SOLVUNTO	DUSNO
giraffa	VOSUNTO	UZMO
gonna	CESIRTE	IFBE
grattugia	SLENOMPO	NOSPE
guanto	PEDRIME	SFEBI
lampada	PROSUNE	NIRSO
leone	ZARTUVI	BITSA
maglione	STRUBUTU	SUCU
maiale	BROSUVO	UVGO
martello	FISVUNGI	NUSGI
ombrello	NUSPIZIA	VIPSA
pera	MUSTIMBO	NOFDI
pesca	LORTUNI	UZGO
pinguino	BRELTAVE	ATAFE
pistola	MEGUNDRE	GUDNE
poltrona	BEFUZIBE	SBIBE
scarpa	VILDEMBI	DILNI
sciarpa	GOLTENFO	UNZLO
sedia	POTRUVO	ORVU
stivale	ROGUNFO	OBUGO
sveglia	MURTODRO	NOFRO
tamburo	SIDELPIE	CEPSE
tigre	BOLSUMA	PUDCA
topo	RIMELDA	FNIVI
trattore	FLIZULVI	FLUZI
treno	BALFISMA	SIBFA
tromba	GEDUSVI	ISFNE
zaino	DEPULTRE	DERFE
zattera	MINGULIO	NILGO
zucca	DRINOLPO	DRIPO

Appendix 2

Pairs of picture-nonword distractor stimuli used in Simulation 1.

Picture name (target)	Written nonword distractor	
	Long	Short
binds	skampts	dryg
blasts	squomps	jemp
blonds	strysps	culp
boosts	scampts	culp
browns	squompt	holb
brig	sprulks	dryf
clamps	skrulks	dryf
clap	squalks	culf
clinks	skronks	deld
crafts	sprencs	drys
cranks	stronds	pyvs
crisps	strints	sugs
crusts	sprumtz	holv
faints	swempts	holk
frosts	splolps	sugs
glimpsed	slonstz	jemp
gluts	splilgz	vuld
mikes	spralvs	dryd
plaints	slepst	zemp
plunks	skryses	culc
prompts	strysts	dryg
quests	skwulvs	delp
scans	blympts	dryz
snaps	flonktz	fect
spills	quankts	zemf
tempts	squolvs	culm
twelfths	sprivzd	hulb
twelves	skrosps	culb
wides	skrults	dryt
wolds	skamptz	ofts

Appendix 3

Pairs of picture-nonword distractor stimuli used in Simulation 2.

Picture name (target)		Written nonword distractor	
Long	Short	Long	Short
quests	hag	dryd	spralvs
blasts	dud	jemp	squomps
clamps	dun	pyvs	stronds
crafts	hep	sugs	splolps
cranks	guv	holk	swempts
crisps	hun	jemp	slonstz
crusts	mod	vuld	splilgz
frosts	ref	culf	squalks
twelves	tec	culb	skrosps
blonds	deb	culp	strysps
clinks	cad	holv	sprumtz
plaints	elf	cule	skryscs
plunks	biz	dryg	strysts
prompts	con	delp	skwulvs
glimpsed	cam	deld	skronks
twelfths	cog	hulb	sprivzd

Appendix 4

Experimental pairs of picture-nonword distractor stimuli used in Experiment 2.

The target-distractor phonological relatedness concerns the first two phonemes.

Picture name (target)	Written nonword distractor			
	Long		Short	
	Phonologically Related	Unrelated	Phonologically Related	Unrelated
banana	BARORMI	PRIGOLE	BAZVO	ILSVO
bilancia	BIMURSTE	TRUFESMO	BIDFO	DOFRE
camicia	CASUVLO	DROFUTO	CAVUO	PLEVO
candela	CABROSTI	TRUBITIO	CABSU	ITISO
carciofo	CATELDE	GEMUSTE	CAMU	USZE
carota	CAFILUBI	FEDUSIME	CADSU	IBEDI
cavallo	CAMIPRE	BRESUNI	CAPZU	SIDRE
ciliegia	CISIRTI	STODUMO	CIRFU	NUFMO
fionda	FISIBULE	PESULBRE	FIDLU	PURME
forchetta	FOSGUMPI	MUPLSVI	FOVBI	SIMPO
fragola	FRISIDE	GUDINTE	FRUPI	SIVNE
freccia	FRONPLO	SOLVUNTO	FRUSO	DUSNO
giraffa	GIBESMO	VOSINTO	GIFU	UZMO
gonna	GODRIBE	CESIRTE	GOPU	IFBE
grattugia	GROMESPO	SLENOMPO	GRUFU	NOSPE
guanto	GUFIRPE	PEDRIME	GUVRI	SFEBI
leone	LESPRAGI	ZARTUVI	LEBZI	BITSA
maiale	MASCOBO	BROSUVO	MABU	UVGO
martello	MAVUSGRI	FISVUNGI	MAZPU	NUSGI
pera	PETLOSVI	MUSTIMBO	PEDBI	NOFDI
pesca	PEFLIVO	LORTUNI	PEIU	UZGO
pistola	PINGURME	MEGUNDRE	PIRFE	GUDNE
stivale	STUMOPO	ROGUNFO	STODO	OBUGO
sveglia	SVOMUBRO	MURTOURO	SVORO	NOFRO
tamburo	TADLISVE	SIDELPIE	TAFLU	CEPSE
tigre	TIBOSVA	BOLSUMA	TIVSO	PUDCA
topo	TOGRIMA	RIMELDA	TODVI	FNIVI
treno	TRIBALVI	BALFISMA	TRIFU	SIBFA
tromba	TRUSFLA	GEDUSVI	TRUZO	ISFNE
zaino	ZAVEPUDE	DEPULTRE	ZAFDE	DERFE
zattera	ZAGUILFO	MINGULIO	ZAFLI	NILGO

Appendix 5

Experimental pairs of picture-nonword distractor stimuli used in Experiment 3.

The target-distractor phonological relatedness concerns the last two phonemes.

Picture name (target)	Written nonword distractor			
	Long		Short	
	Phonologically Related	Unrelated	Phonologically Related	Unrelated
banana	MIRORNA	PRIGOLE	USNA	IPDO
bilancia	SEMURTIA	TRUFESMO	DUFIA	DOFRE
camicia	LUSOVIA	DROFUTO	ZUDIA	PLEVO
candela	TRUSTOLA	TRUBITIO	OVLA	ITSO
carciofo	TEDELFO	GEMUSTE	USFO	USZE
carota	LIFUBITA	FEDUSIME	IDUTA	IBEDI
cavallo	DEPROLO	BRESUNI	ZIPLO	SIDRE
chitarra	MONFEGRA	GEVODESO	UBRA	USBO
ciliegia	TOSURIA	STODUMO	UFRIA	NUFMO
fionda	LUSEBUDA	PESULBRE	VULDA	PURME
forchetta	PISGUNTA	MUPLSVI	DUZTA	SIMPO
fragola	STIDELA	GUDINTE	EPCLA	SIVNE
freccia	MOPOLNIA	SOLVUNTO	SDUIA	DUSNO
giraffa	MOBESFA	VOSINTO	ZUFA	UZMO
gonna	DRIBENA	CESIRTE	OFNA	EFBO
grattugia	FOVIMPIA	SLENOMPO	EPDIA	NOSPE
guanto	PEFIRTO	PEDRIME	DIVTO	SFEBI
leone	GISPRANE	ZARTUVI	SIBNE	TISBA
maiale	BOSOCLE	BROSUVO	UVLE	UVGO
martello	GRISNULO	FISVUNGI	NISLO	NUSGI
pera	GILTOVRA	MUSTIMBO	NIDRA	NOFDI
pesca	FLIVOCA	LORTUNI	UZCA	UZGO
pistola	GURMEFLA	MEGUNDRE	DRULA	GUDNE
stivale	POMURLE	ROGUNFO	OGLE	OBGO
sveglia	BROMUNIA	MURTODRO	OFRIA	NOFRO
tamburo	SEVILDRO	SIDELPIE	DEPRO	CEPSE
tigre	DOSUVRE	BOLSUMA	OVRE	UDCA
topo	GRAMIPO	RIMELDA	ILPO	IFLI
treno	SIVIBANO	BALFISMA	LIFNO	SIBFA
tromba	LEFISBA	GEDUSVI	IVBA	ISFE
zaino	PUVEDENO	DEPULTRE	GEPNO	DERFE
zattera	GUILOFRA	MINGULIO	ILFRA	NILGO

Appendix 6

Experimental pairs of picture-nonword distractor stimuli used in Experiment 4.

Picture name (target)	Written nonword distractor		
	Position of the Phonological Relatedness		
	Initial	Final	Control Condition
banana	BASOLTE	MIRORNA	PRIGOLE
bilancia	BIMERSO	SEMOTIA	FRUSOMO
camicia	CADOPRE	LUSOVIA	DROFUTO
candela	CAFRIPO	TRUTOLA	TRUTIBO
carota	CASPIVE	LIFISTA	MEDISFE
casco	CARTUME	VUTRICO	NIRLETI
cavallo	CAFISTE	DEPROLO	BRESUNI
ciliegia	CIFROMO	MUSCRIA	STODUMO
coniglio	COVARTE	STREFIO	MABERFA
cravatta	CRIDELO	BOSUNTA	POSULBE
fragola	FREBIVE	STIDELA	GUDINTE
giraffa	GIVUSTO	MOBESFA	VOSINTO
gonna	GOMELDI	DRIBENA	CESIRTE
guanto	GUIRECI	PEFIRTO	PEDRIME
leone	LEBARTA	GAPRINE	ZARTUVI
limone	LIDRACI	PRADANE	FRATUCA
maiale	MATRUFO	BESOCLE	BROSUVO
martello	MABILSI	GRINILO	FIVULNI
ombrello	OMITTIA	ISTACLO	DIPISCA
pecora	PEFLIBI	SILUTRA	FRINUGI
pera	PEFLOSI	GILOVRA	MOSTIBO
pesca	PETRIBO	FLIVOCA	LORTUNI
pigiama	PINELTO	VRESUMA	FENOSTE
pistola	PICUDRE	GUMEFLA	MERIGNE
scarpa	SCOMISO	FREBIPA	BENOLTE
scopa	SCULTRI	MELVIPA	GEBRULI
sedia	SERTUGO	GRUNFIA	VUDOFRI
stivale	STORUMO	POMURLE	ROGUNFO
tigre	TIFUNTA	DOSUVRE	BOLSUMA
topo	TOMILSA	GRAMIPO	RIMELDA

Appendix 7

Pairs of picture-nonword distractor stimuli used in Simulation 3.

The target-distractor phonological relatedness concerns the first two phonemes.

Picture name (target)	Written nonword distractor			
	Long		Short	
	Phonologically Related	Unrelated	Phonologically Related	Unrelated
blimps	blolns	dwonds	blut	zon
clanks	clylbs	brumpt	kliz	bup
clunks	klylns	brampt	klaz	tad
crimps	krulbs	gwelds	creb	gli
flunks	flilvs	grampt	flef	zit
franks	frolns	twilms	fruv	yug
frumps	frelds	kwylds	frav	jic
plunks	plilbs	trynds	pla	ids
primps	prunds	quolvs	pru	vun
scamps	skrelv	grelvs	squ	dyt
scants	scwump	drylbs	scu	ilp
scrags	sculps	plompt	sko	fot
scrips	scwund	dwolms	sco	dal
sculpt	skwylm	dwands	sku	meg
skimps	scwift	blelds	skac	druz
slinks	slalbs	grompt	sla	wom
stomps	strunt	kwelbs	stu	jik
strops	stilds	kwalms	stov	gwak
swanks	swempt	trylms	swe	jop

Appendix 8

Pairs of picture-nonword distractor stimuli used in Simulation 4.

The target-distractor phonological relatedness concerns the last two phonemes.

Picture name (target)	Written nonword distractor			
	Long		Short	
	Phonologically Related	Unrelated	Phonologically Related	Unrelated
blimps	CRUSPS	DWANDS	EPS	VON
clanks	SNISCS	DRYNDS	ICS	NOM
clunks	SNYSKS	GWYMPT	UKS	YOD
crimps	TWESPS	GWELDS	IPS	BUB
flunks	KRYSKS	TWOMPT	UCS	MEG
franks	GLOSKS	BLULNS	IKS	HIB
frumps	SKREPS	CWALNS	OSPS	KILK
mulcts	CLYFTS	DWYNDS	UTS	GYF
plunks	KROLKS	TRINDS	YUCS	TEMF
primps	SLESPS	KLOLNS	YOPS	CLAV
prinks	QUELKS	DWELBS	JEKS	ZALM
scamps	GRYSPS	TROLVS	FAPS	BRUT
scants	VYMPTS	PRILDS	OTS	GOZ
scrag	PLELGS	BLEMPT	UGS	LUB
scrips	KLYMPS	BLELVS	ZOPS	BEMS
sculpt	QUYMPT	GWYNDS	OPT	VEB
skimps	BRULPS	TWULNS	WUPS	DROT
slinks	TRALKS	PRAMPT	HUCS	YUND
stomps	FRASPS	QUYNDS	ZUPS	DWYK
strops	DREMPS	CWULBS	LUPS	NYNC
swanks	GLILCS	GLULNS	FAKS	BLOL

Appendix 9

Pairs of picture-nonword distractor stimuli used in Simulation 5.

Picture name (target)	Written nonword distractor		
	Position of the Phonological Relatedness		
	Initial	Final	Control Condition
blimps	bloivs	kwusps	kwonds
clanks	klulds	spusks	gwympt
clunks	klalms	swyscs	dwempt
crimps	cralns	flosps	glolns
flunks	flinds	skwaks	drympt
franks	frulns	spylks	plends
frumps	frelns	klesps	quilvs
plunks	plelns	gwyscs	twinds
primps	profft	swosps	cwolvvs
prinks	prends	twulks	blalds
scamps	scryvs	gwilps	drolbs
scants	scrylm	glofts	grulms
scrags	skwimp	plelgs	blympt
scrips	squalk	flopls	twunds
sculpt	squosc	trympt	gwinds
skimps	scwugs	twolps	trolvs
stomps	strans	crelps	kwalns
strops	stulds	clulps	kwelms
swanks	swunds	kwonds	grilbs

Appendix 10

Experimental pairs of picture-nonword distractor stimuli used in Experiment 5.

Target picture with 3 syllables.

Picture name (target)	Written nonword distractor					
	7 Phonemes			3 Syllables		
	2 Syllables	3 Syllables	4 Syllables	6 Phonemes	7 Phonemes	8 Phonemes
cammello	STRIDRI	ZIRTUVI	USIBUNI	GUBUTI	ZIRTUVI	BRITUSVI
cancello	STRIMPI	PRIVUFI	IMIRIZI	DIMUVI	PRIVUFI	RISTUSVI
cappello	BRINFRI	SIRINTI	UBIDUFI	SIVUTI	SIRINTI	TRIVUNTI
carretto	SLISPLI	DULUNDI	ULINUZI	ZUMIFI	DULUNDI	DILVUNSI
carriola	STEMPSE	SDUNESE	EDUSEVE	TEMUFE	SDUNESE	DESTEMPE
carrozza	PLESBLE	PESULME	EDILIBE	VILUDE	PESULME	FULSEVI
cassetto	FRULPRI	MIVILBI	UFIDUNI	DIFUBI	MIVILBI	VILURPRI
castello	BRILBRI	VIMUNZE	INUPUDI	PIRIFA	VIMUNZE	PINVIRBI
cerniera	STOMBLO	GOMULDO	OSULUFO	FUPODO	GOMULDO	GLUMOFLO
coltello	STIRNUI	RAVISMA	ASANIPI	VACUSA	RAVISMA	PRASINDI
cravatta	SLOMBLI	MIVILBI	INEPULO	MESOPE	MIVILBI	MOLPISBO
martello	SFUNDUI	SBIVUSI	UPINUSI	DICUNI	SBIVUSI	TINVISNI
ombrello	SPINSPA	ANFUSVI	IDAPUNI	SINAGA	ANFUSVI	CASCUNIA
pennello	GRISCRI	BRAMIGA	UDAMIGA	MABIDA	BRAMIGA	TARZURVI
pinguino	FRASTRE	MASARVE	ESAFELA	FAVADE	MASARVE	MARSELFÈ
poltrona	SFIRSVE	SEMISVE	DIBEFEI	MUDISE	SEMISVE	DISFESME
sgabello	FRISTRI	FRITUMI	ISUNUVI	PIZUFI	FRITUMI	TIPUNFRI
trattore	SVINFLI	IPLUMPI	IBIMUDI	FIMUPI	IPLUMPI	NULVUMPI
tricielo	SPANFUE	PASEMBE	ASENAFE	ZADUME	PASEMBE	SANDUNGA
bicchiere	STLOSPO	GLAZUVO	ALODUMA	DAMOGO	GLAZUVO	SLUBANZA
coperchio	FLULBLA	GLAMASA	USUTAMA	FUNULA	GLAMASA	BLAVUNTA
cucchiaio	STREMPE	SETERDE	EGUMUDE	DEZEFE	SETERDE	RELPELPE
forchetta	BLINDLI	PISLUVI	IZIPULI	PISUMI	PISLUVI	PILSULPE
grattugia	VLOMPLE	ZEFUNDE	OFEDOMO	COPESE	ZEFUNDE	MOSUMPLO

Appendix 11

Experimental pairs of picture-nonword distractor stimuli used in Experiment 5.

Target picture with 4 syllables.

Picture name (target)	Written nonword distractor					
	7 Phonemes			3 Syllables		
	2 Syllables	3 Syllables	4 Syllables	6 Phonemes	7 Phonemes	8 Phonemes
asparago	GLENCLI	BELINVE	ETIMUBI	MIDIBE	BELINVE	NELVINFI
binocolo	STRUMPE	RASDEGA	AMUSUVE	RUDAFa	RASDEGA	RASTUFRA
elefante	GROSPRI	PRODIBO	OSIVUBO	ZOMIPO	PRODIBO	CAMBOSPI
libreria	SFUNSTO	DUSOMPO	ODUMUFO	DUCUSO	DUSOMPO	CUNSUNGO
papavero	SFUNBLI	FUSTIBI	USINULI	BILUFI	FUSTIBI	LUSMINFI
peperone	FLASTLI	GALTIVA	ATASIMA	TASUMI	GALTIVA	MALSILTA
piramide	SFONTLO	VOLFUBO	ONUGOLO	FOGUBO	VOLFUBO	FLOSULSO
pomodoro	FLUSCLA	NALGATI	ABIGALI	SILUVE	NALGATI	GLASILVE
tulipano	GREMBRE	BREDEME	EFEVESE	REMEVE	BREDEME	SEBRECRE
damigiana	PRUSTRO	FESULTE	OSUPUVE	FULUBO	FESULTE	ZERVOLZE
orecchini	FLAMSTA	CALPAFA	UMAPUDA	GUBULA	CALPAFA	VASDABLA
batteria	FLUSPLO	FULMOCO	ONUVOPO	PUVUCO	FULMOCO	FLOZULPO

**PAPER 2: Further understanding on the phonological
relatedness effects from PWI/PNWI tasks and DRC-SEM data**

Lisa Ceccherini, Max Coltheart, Claudio Mulatti & Steven Saunders

Abstract

In this paper we investigate some issues concerning the speech production and the reading systems. We particularly probed the interplay of activation/inhibition between units belonging to two sources, a written distractor stimulus (a word or a nonword) and a target stimulus (a picture to be named aloud). Understanding the target-distractor phonological relatedness effects is one of the main aims of this paper. We did this carrying out two experiments by means of the Picture Nonword Interference (PNWI) and the Picture Word Interference (PWI) paradigms. In the first study we reported an additive pattern of results between nonword distractor length (long *vs.* short), target frequency (high *vs.* low) and end phonological relatedness (last two phonemes shared *vs.* no phonological overlap). When written words were used as distractor instead we reported an interactive pattern of results between target frequency (high *vs.* low) and onset phonological relatedness (first two phonemes shared *vs.* unrelated onset). Simulations carried out with a Semantic version of the DRC model (Coltheart et al., 2001) partially failed to simulate human data. Further evidence in favour of a relative position-coding scheme for phonemes was obtained. Any theory or computational model of reading and speech production needs to consider this feature of the phonemic system.

Keywords

Word production (picture naming)

Picture-nonword interference paradigm

Picture-word interference paradigm

Phonological relatedness effect

Target frequency effect

Nonword distractor length effect

Computational modelling

DRC-SEM

Introduction

The Picture-Word Interference paradigm (PWI) is an experimental paradigm used in psycholinguistic research to investigate the mechanisms involved in phonological lexical access and, more generally, in word production (picture naming), (Glaser & Dungenhoff, 1984). Participants are visually presented with a picture of an object simultaneously with an over-printed distractor word. They are asked to name aloud the picture (target) ignoring the written stimulus (distractor). A closely-related paradigm is the Picture-Nonword Interference paradigm (PNWI), (Rosinski et al., 1975; Rosinski, Pellegrino & Siegel, 1977). The only difference between these two paradigms is that in the PNWI task pictures are paired with printed distractors that are nonwords instead of words. These paradigms can be used to investigate the properties of the human reading system and the word production system, and in particular how the target picture name can be finally produced despite the fact that the pronunciation of the printed distractor is activated and interferes with the relevant task to produce the correct response (see Paper 1 for a review of studies demonstrating such interference effects in the PNWI paradigm).

We took as a landmark model the dual route theory of reading aloud and the corresponding computational model of visual word recognition and reading aloud, the Dual Route Cascaded Model (Coltheart et al., 2001). We adapted this theory to the picture naming task by adding to the DRC model a semantic component – i.e. a system of semantic units each representing the semantic concept of a word present in the DRC model's orthographic lexicon. This DRC-SEM model was used in work reported in Paper 1 of this thesis. It is available for download at <http://www.cogsci.mq.edu.au/~ssaunder/DRC/drc-sem/>, and is depicted in Figure 10.

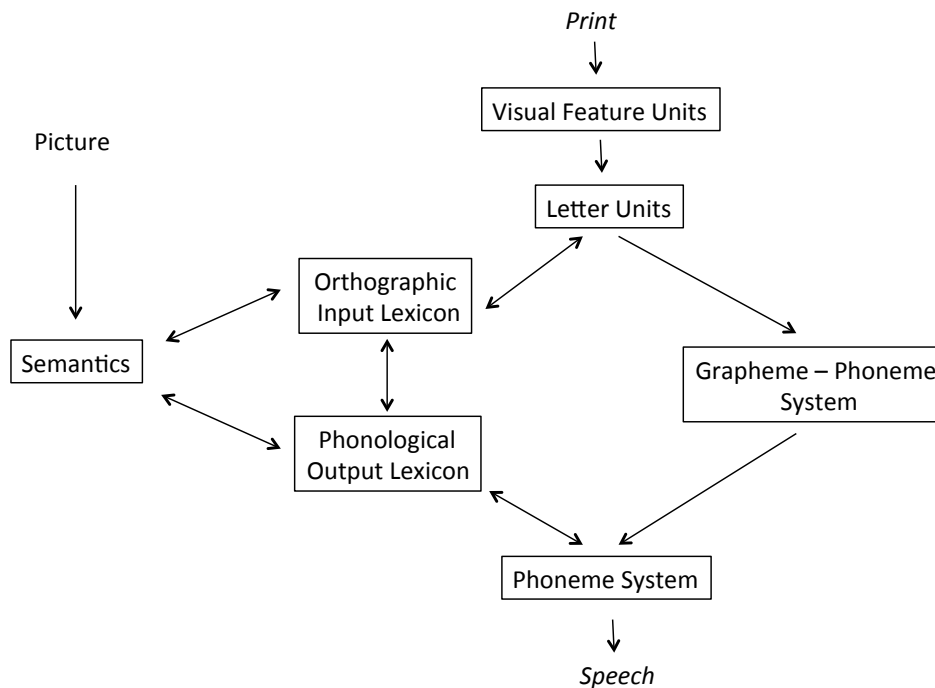


Figure 10. Semantic version of the DRC model (Coltheart et al., 2001) with the inclusion of a picture recognition pathway (on the left).

According to the dual-route theory of reading, the human reading system simultaneously reads written stimuli by means of two different pathways, the lexical route and the nonlexical route. Essentially, the lexical route activates the orthographic representation of the word - held in the orthographic input lexicon - and then its phonological representation - held in the phonological output lexicon. The activation is passed on from the lexical phonological representation to the constituent phonemes of the written stimulus, held in the phoneme system. The lexical route works in parallel across the input string. It reads correctly all words (regular and irregular) but cannot read new words or nonwords, because these do not possess orthographic or phonological lexical representations.

The other route simultaneously recruited at the presentation of a visual written stimulus is the nonlexical route: it is essential for the phonological recoding of nonwords, and it works on the word\ nonword string realising its phonological assembly serially, proceeding from the leftmost grapheme to the rightmost one (for a detailed account of the model and the specific features of each route see Coltheart et al., 2001). This route can read correctly all regular words, new words or nonwords but it cannot read irregular words correctly.

DRC-SEM has an added route, to permit picture naming. Picture naming is simulated by the model switching on the unit in the semantic system that represents that picture. That will result in activation of the picture name in the phonological output lexicon and then activation of the corresponding phonemes in the phoneme system. Since the phoneme system of DRC is also activated by a simultaneously-presented written stimulus (word or nonword),

when DRC-SEM's task is to name a picture in the presence of a written distractor stimulus competition between the picture-name's phonemes and the phonemes of the printed distractor can occur at the phoneme system, and that is how DRC-SEM seeks to simulate the PWI and PWNI effects.

With the PWI and PWNI paradigms, experiments in which properties of the target picture names and properties of the printed distractors (either words or nonwords) are manipulated can allow us to make inferences about characteristics of the word production (picture naming) system and characteristics of the reading system. Previous studies that address questions about what is happening between and within the speech production system (involved in picture naming) and the reading system (recruited for reading the written distractor) in a PNWI task were reviewed in Paper 1 of this thesis. In that paper we also reported the results of four PNWI experiments and their corresponding simulations using the DRC-SEM model. The investigated variables were 1) the length of the nonword distractors and 2) the phonological relatedness between the picture name and the nonword distractor. Our findings with the PNWI paradigm were, in sum:

(a) there is a nonword distractor length effect: people show slower picture naming latencies when pictures are paired with long nonword distractors (7/8 phonemes) than when the same pictures are paired with shorter nonword distractors (4/5 phonemes). The DRC-SEM model succeeded in simulating this distractor length effect.

(b) distractor length and target length do not interact: the distractor length effect is the same for targets with few phonemes and targets with many phonemes. DRC-SEM could not simulate this additivity: for the model, there was a distractor length effect when targets were long but no effect when targets were short.

(c) when distractor nonword and target picture share their first two phonemes, there is facilitation of picture-naming, compared to an unrelated condition. There is, as in (a) and (b) a distractor length effect, but this occurs only when target and distractor are phonologically unrelated: when they share their initial two phonemes there is no distractor length effect. DRC-SEM simulations showed a different pattern of results: there was an interaction between relatedness and length, with the distractor length effect being larger in the related than the unrelated condition.

(d) when distractor nonword and target picture share their *last* two phonemes, there is facilitation of picture-naming, compared to an unrelated condition. However, the last-phonemes facilitation effect, though itself significant, was significantly smaller than the first-phonemes facilitation effect reported in (c) above. There was, as in (a) (b) and (c), a distractor length effect. There was additivity of the effects of phonological relatedness and nonword

distractor length. In the DRC-SEM simulations there were significant facilitatory effects of first-phonemes and last-phonemes phonological relatedness, and the effect was larger in the first-phonemes condition than in the last-phonemes condition, all of which was true of the human data also. However, DRC-SEM failed to simulate the additivity of last-phonemes relatedness and distractor length: for the model, when target and distractor were phonologically unrelated, RTs were longer with longer distractors than with shorter distractors, as in the human data, but this was not so when target and distractor were phonologically related; on the contrary, here RTs were significantly *shorter* when distractors were long than when they were short, the opposite of the human result.

(e) in the experiments of Paper 1 that involved end-phonemes facilitation, targets and distractors were not always the same length. When they were not, the phonemes that were common to target and distractor did not have the same absolute phonemic positions. Post-hoc analyses showed that this made no difference to the size of the ends-phoneme facilitation effect. DRC-SEM could not simulate this finding: the model shows an end-phonemes facilitation effect only when the shared final phonemes are in the same absolute positions in target name and distractor.

The results reviewed above offer answers to some questions about the nature of the picture naming and reading systems, whilst also raising others (which we mention below).

One question to which the results of Paper 1 offers the beginnings of an answer concerns how phoneme position is coded for picture naming and reading aloud. DRC-SEM was able to simulate a number of effects seen in the human data, but failed to simulate others, and all of the failures of DRC-SEM simulations are due to the model's using an absolute-position coding scheme in the phoneme system. Findings (b) and (e) above offer particularly strong evidence against an absolute phoneme-position coding scheme. What these results suggest instead is some kind of relative-position coding such as ends-relative coding. So if DRC is to be successfully extended to the simulation of picture naming, a different phoneme-position coding scheme will be needed, and since no one believes that picture naming and reading aloud use different phoneme systems this would have serious implications for DRC modelling of reading.

A second question to which Paper 1 offers an answer concerns the left-to-right seriality of the nonlexical route. The finding that the effect of phonemic relatedness between picture name and nonword distractor is greater when initial phonemes overlap than when final phonemes overlap is evidence for this conception of how the nonlexical route operates (and so, not surprisingly, DRC-SEM can simulate this effect).

A question that remains to be answered is: How is the distractor length effect to be

explained? DRC-SEM was able to simulate this effect (see finding (a) above), but the DRC-SEM explanation of the effect cannot be correct because the model fails to simulate the additivity of nonword distractor length and target length seen in the human data. Perhaps the nonword distractor length effect occurs because the activation of the picture name's phonemes cannot begin until the nonlexical route has finished working on the printed distractor, and then discarded its phonological representation (as postulated by the Response Exclusion Hypothesis: (Mahon et al., 2007)? No, because if that were the case there would be no effects of target-distractor phonological relatedness (and see Mulatti and Coltheart (2012), for other reasons for rejecting the Response Exclusion Hypothesis.).

In general, more investigations are needed to understand what is going on in the PNWI task; many questions about this remain unanswered, specifically those concerning the stage at which the two stimuli (print and picture) interfere with each other, competing to be produced by the speech production system, e.g.:

- How is the semantic lexical route activating the phonology of the picture name concurrently with the activation of the phonology of the nonword distractor?
- What is the stage of this process that is involved in the competition or interference with the phonological nonword distractor assembly?
- Where is the locus of the facilitation due to picture-distractor phonological overlap?

In order to throw some light on such issues, we investigate in Experiment 1 of this paper how the frequency of the picture name interacts with nonword distractor length and with target-distractor phonological relatedness (last two phonemes shared *vs.* no phonological overlap). The target frequency effect in the picture naming task refers to the finding that picture naming is faster when the spoken frequency value of the picture name is high than when it is low (Miozzo & Caramazza, 2003; Costa et al., 2005; Mahon et al., 2007).

If the computation of the nonword distractor's phonology interferes with the resolution of the picture-naming task in the phoneme system, then we should observe an interaction between target-distractor phonological relatedness and target frequency, in contrast, if these two variables exert their effects in different loci, we should expect additivity of these two factors (Sternberg, 1969). Since in Experiment 3 of Paper 1 we obtained an additive pattern between end-phonological relatedness and nonword distractor length, we could hypothesize that the two variables exert their effect at different stages of the picture naming system. The target frequency effect in picture naming is thought to arise at stages earlier than the phonemic stage: for example, Barry, Morrison & Ellis (1997) explained this effect as arising because the link from a word's lemma (syntactic) representation to its lexeme (phonological-lexicon) representation is stronger when frequency is high than when it is low. So an

experiment in which the variables of target frequency, nonword distractor length and target-distractor phonological relatedness are orthogonally varied should throw light on the nature of the speech production and reading systems.

In order to explore the initial phonological relatedness effect further, we carried out the second experiment reported in this paper. It investigated the first-phonemes relatedness effect using *words* as distractors i.e. using the PWI paradigm. When distractors are words this implies the predominant recruitment of the lexical reading route, so to better understand where the initial phonological relatedness variable exerts its effect within the speech production system we manipulated the frequency of the target picture names. When distractors are words, the interplay between the distractor word representation and the picture name representation could arise at several stages of the speech production system, e.g. at the level of activation of semantic information, activation of syntactic information⁸, activation of lexical phonological information, or finally in the phonemic system.

As previously mentioned the picture frequency effect in the picture naming task has been postulated to affect the connections between the lemma and the lexeme representations (Barry et al., 1997). In the context of PWI an onset phonological relatedness has been previously found: faster picture naming latencies when pictures were paired with onset related distractor words (first two phonemes shared) than when the same pictures were paired with phonologically unrelated distractor words (Starreveld & La Heij, 1996a; Damian & Martin, 1999). This effect has been postulated to arise at the stage of phoneme retrieval (Meyer & Schriefers, 1991). By means of our second experiment we could try to answer questions about the nature of the onset-phonological relatedness and the locus of the interplay between this variable and the target frequency variable, specifically looking at the direct-lexical and semantic-lexical routes, mainly recruited in the PWI paradigm as opposed to the PNWI paradigm.

And to further explore the capabilities and inabilities of the DRC-SEM model, we applied it to the simulation of both of the experiments reported in this paper. The simulations are reported after each experiment.

⁸ Not in the DRC-SEM model, of course, since it does not represent syntactic information

Experiment 1

Method

Participants

Twenty-eight students of the Università degli Studi di Padova participated in the study as volunteers. They all had normal or corrected-to-normal vision. Participants were all native speakers of Italian.

Design

A within-subject design was employed with the frequency of the picture name (high frequency pictures *vs.* low frequency pictures), the length of pronounceable nonword distractors (short distractors: 4-5 phonemes *vs.* long distractors: 7-8 phonemes) and the target-nonword distractor phonological relatedness (the target-distractors pairs could share the last two phonemes or could be phonologically totally unrelated) manipulated.

Materials

Sixty pictures were selected as target stimuli from the database of Dell'acqua et al. (2000). Thirty had a low frequency value, 3.5, (range: 0.3 - 9) and the other thirty pictures had a high frequency value, 39.3, (range: 9.4 - 167); frequencies were taken from the database of Dell'acqua et al. (2000). Their average number of phonemes was 5.8 in both the groups of targets (ranging from 2 to 9), counting geminate consonants as in GONNA as two phonemes. All the pictures had a high name agreement value.

Two hundred and forty nonword distractors were constructed; 120 were long distractors (7-8 phonemes) and the other 120 were short distractors (4-5 phonemes). Context-sensitive graphemes and multi-letter graphemes were avoided, so that the number of the phonemes in each distractor stimulus was also the number of its letters. None of the distractors had any orthographic neighbors. Half of the long distractors were end-phonologically related with the target picture name – they shared the last two phonemes – and half were phonologically unrelated. Each target belonging to each of the target frequency groups (high frequency *vs.* low frequency) was presented four times, 1) with a long and end-phonologically related superimposed nonword distractor 2) with a long and phonologically unrelated superimposed nonword distractor 3) with a short and end-phonologically related superimposed distractor and finally 4) with a short and phonologically unrelated superimposed nonword distractor. All other phonological overlap between the name of the

target and the phonology of the distractor was avoided.

Twenty-eight experimental lists were created in which stimuli were presented in a different order for each list with the restriction that one particular target could not be followed by itself in the next 3 items. Furthermore, each list began with three practice trials. Appendix 1 reports the stimuli used in Experiment 1.

Apparatus

The experiment took place in a sound-attenuated and dimly lit room. The stimuli were displayed on a 17" cathode-ray tube monitor controlled by a 686 IBM-clone and E-prime software. The onset of vocal responses was detected using a high-impedance microphone to which a voice-key was connected.

Procedure

Participants were tested individually. They were instructed to name the target picture aloud as quickly and accurately as possible while disregarding the superimposed distractor nonword. On each trial, a fixation point (+) appeared in the center of the screen for 500ms. Following the fixation point's offset, a blank screen was displayed for 100ms, followed by the presentation of a picture-nonword pair, which remained visible until a vocal response was detected or 3s elapsed. The ITI was fixed at 1000ms. When projected on the screen, pictures occupied an ideal square of about 6 × 6 cm. The nonword distractors were shown in capital letters in Geneva font, bold, 20-point. Pictures were centered at fixation, and word position varied randomly in the region around fixation to prevent participants from systematically fixating the portion of the picture not containing the distractor – (as was done by e.g. La Heij et al. (1985); Glaser & Glaser (1989)). The viewing distance was 60cm. Target/distractor pairs were presented in a different random order for each participant. The experimenter recorded each response as correct or incorrect. The experimental session was preceded by a practice session of 8 trials and a familiarization session in which subjects saw all the pictures of the experiment (practice, trial and experimental pictures) for a total of seventy-one pictures, with their corresponding names presented beside them.

Results

Naming errors and apparatus failures (4.8%) were removed prior to analysis. Correct RTs were submitted to the Van Selst & Jolicoeur (1994) outlier removal procedure, resulting in the elimination of 1.7 % trials. The factors a) frequency of the target picture (high

frequency vs. low frequency), b) length of nonword distractors (long distractor: 7-8 letters vs. short: 4-5 letters), c) target-distractor phonological relatedness (last two phonemes shared vs. no phonemes shared), were all treated as within-subject factors in the analysis by-subjects (F1). The factor target frequency in the analysis by-items (F2) was treated as between-subjects.

The subject means per condition are shown in Table 12 for the high frequency target condition and in Table 13 for the low frequency target condition.

Target-distractor Phonological Rel.	Distractor Length				Difference (RTs)
	Long (7-8 ph.)		Short (4-5 ph.)		
	RTs	E %	RTs	E%	
Unrelated	729	1	722	3	7
End related	719	2	696	2	23
Difference	10		26		

Table 12. Means of RTs and Accuracy (percentages of errors) for High Frequency Targets.

Target-distractor Phonological Rel.	Distractor Length				Difference (RTs)
	Long (7-8 ph.)		Short (4-5 ph.)		
	RTs	E%	RTs	E%	
Unrelated	763	2	753	3	10
End related	733	4	727	2	6
Difference	30		26		

Table 13. Means of RTs and Accuracy (percentages of errors) for low frequency targets. RTs (Analysis 1).

Three-factor ANOVAs were carried out with the subject data (F1) and the item data (F2), the factors being target name frequency, distractor length and phonological relatedness. In neither analysis did any interaction effect approach significance, so we will discuss only main effects.

Mean reaction times for high frequency targets were significantly faster than for low frequency targets (by 28ms in the subject data, by 30ms in the item data). This effect was significant in the analysis by subjects $F_1(1, 27) = 43.4, p < .001$, but not in the analysis by items $F_2(1, 58) = 2.9, p = .092$.

Mean picture-naming latencies were faster with short nonword distractors than with long nonword distractors (12ms in the subject data, by 17ms in the item data). This effect was significant both by subjects ($F_1(1,27) = 7.8, p < .001$) and by items ($F_2(1, 58) = 13.8, p <$

Mean picture naming latencies were faster with phonologically-related distractors than with phonologically unrelated distractors (by 23ms in the subject data, by 21ms in the item data). This effect was significant both by subjects $F_1(1, 27) = 19.9, p < .001$ and by items ($F_2(1, 58) = 22.5, p < .001$).

Accuracy.

F1 and F2 analyses of the accuracy data yielded only one significant effect: the interaction between the length of the nonword distractor factor and the target frequency factor was not significant in the analysis by subjects ($F_1(1, 27) = 3.4, p > .05$) but was significant in the analysis by items ($F_2(1, 58) = 6.89, p < .001$).

A further look on the phonological relatedness effect according to the position of the picture-distractor shared phonemes (Analysis 2).

We further explored the phonological relatedness effect for high vs. low frequency targets and long vs. short nonword pronounceable distractors. In analysis 2 we considered a new factor, the position of the two shared final phonemes of the nonword in respect to the position of the two shared final phonemes of the picture name. Because picture name and distractor were not always of the same phonemic length, these phoneme pairs could occupy the same absolute position in distractor and target (same condition), they could occur earlier in the distractor than in the target (earlier condition) or they could occur later in the distractor than in the target (later condition).

We carried out 2 ANOVAs for both the analysis by subjects (F1) and the analysis by items (F2). One ANOVA was carried out on the end-phonological relatedness effect considering the short distractor condition, where we considered the three levels of shared phoneme position and target frequency (high vs. low) as within factor in analysis by subjects; in the analysis by items instead, the both target frequency and position were considered as between factors. Correspondingly this happened to the second ANOVA, carried out on the phonological effect belonging to the long distractor condition. However, since in the long distractor and low frequency target conditions there were no items in the earlier condition, we could only compare same vs. later conditions both for high and low frequency target pictures paired with long distractors. Table 14 and Table 15 report the end phonological relatedness means (resulting from the subtraction of the end related condition from the phonological unrelated one) as a function of target frequency and position of the shared phonemes, when pictures are paired with short nonword distractors (Table 14) and when they are paired with long nonword distractors (Table 15).

Position of the two final shared phonemes	Target Frequency		Differences (RTs)
	Low	High	
Earlier	18	53	- 35
Same	27	61	- 34
Later	8	52	- 44

Table 14. Short distractors: means of the End Phonological Relatedness effect as a function of the position of the two shared phonemes and of the target frequency.

Position of the two final shared phonemes	Target Frequency		Differences (RTs)
	Low	High	
Same	26	35	9
Later	8	30	22

Table 15. Long distractors: means of the End Phonological Relatedness effect as a function of the position of the two shared phonemes and of the target frequency.

RTs (Analysis 2).

None of the conducted Analysis revealed any statistically significant effects. For the short nonword distractor conditions we obtained no main effect of position $F_1(2, 54) = 0.35$, $p > .5$, $F_2(2, 54) = 0.05$, $p > .05$, no main effect of target frequency, $F_1(1, 27) = 2.35$, $p > .5$, $F_2(1, 54) = 0.168$, $p > .5$, and finally no statistically significant interaction, $F_1(2, 54) = 0.047$, $p > .5$, $F_2(2, 54) = 0.121$, $p > .5$, for both the analysis by subjects and the analysis by items.

Again, for the long nonword distractor condition we obtained no main effect of position $F_1(1, 27) = 0.46$, $p > .5$, $F_2(1, 54) = 0.37$, $p > .05$, no main effect of target frequency, $F_1(1, 27) = 1.157$, $p > .5$, $F_2(1, 54) = 0.478$, $p > .5$, and finally no statistically significant interaction, $F_1(1, 27) = 0.177$, $p > .5$, $F_2(1, 54) = 1.41$, $p > .5$, for both the analysis by subjects and the analysis by items.

Discussion

Analysis 1 revealed significant main effects of target frequency, nonword distractor length and picture-distractor phonological relatedness and no significant interactions between these factors. The target frequency effect in PWI and PNWI is described by slower picture naming latencies for pictures with a low frequency value. The nonword distractor length effect is described by longer picture naming latencies for pictures paired with long nonword distractors. Finally, the end-phonological relatedness effect between pictures and distractors (when they share the last two phonemes) is described by faster picture naming latencies for pictures paired with end-related nonword pronounceable distractors.

How might these three main effects and their additive pattern be explained?

The source of the target frequency effect might be located at the lexeme level (Jescheniak and Levelt, 1994). In reading aloud the word frequency effect has been proposed to affect the strength of the connections between different representations, i.e. those connecting the lemma to the lexeme. Barry et al. (1997) proposed that the frequency effect in picture naming could affect how a word's phonological representation is activated for its production in speech, at the level of phonological word-form encoding. Interestingly we found the target frequency effect did not interact with any other of the variables we used, and this has some implications in localizing the source of the main effects we found.

The phonological effect we obtained in this experiment was previously reported in Experiment 3 of Paper 1 of this thesis. In that Experiment 3 we obtained an additive pattern between the end-relatedness effect and the nonword distractor length effect as we have obtained here. Since the phonological relatedness effect could reasonably be proposed to occur at the level at which the activation coming from the picture name's entry in the phonological output lexicon activates the picture name's phonemes and sums with the activation that the shared distractor phonemes have already received from the nonlexical route, then the target frequency effect must occur earlier than this level in the human system, given that considering the additive pattern of frequency and relatedness. In the DRC-SEM model the target frequency effect occurs within the orthographic input lexicon, the SEM system and the phonological output lexicon (i.e. the higher a word frequency is the easier it is to excite its entries in these three systems). Indeed the target frequency effect could occur in the human reading system because the units representing the high frequency pictures are featured by a higher level of resting activation.

This pictured pattern of different resting levels should result in the following sketch: comparing the phonemic string of a high frequency picture to one belonging to a low frequency picture in a certain time X, then the phonemes belonging to a high frequency

picture will be more activated. This outline could be considered as a consequence of a higher level of activation that distinguishes the orthographic and phonological units of high frequency target pictures. However the human reading system might benefit of another source of facilitation for high frequency representations, namely an extra speed in spreading activation for those excitatory connections linking the orthographic input lexicon to the phonological output lexicon, the semantic system to the orthographic input lexicon and the semantic system to the phonological output lexicon. The human reading system thus could be sensitive to two different sources of the frequency effect (i.e. different resting levels and different speeds in spreading activation for high vs. low frequency unit representations).

The nonword distractor length effect is attributed to the serial functioning of the nonlexical route. The more phonemes a nonword distractor has, the more time the nonlexical route will need to complete the assembly of all the distractor's phonemes. In Paper 1 of this thesis we reported that the DRC-SEM model successfully simulates this effect and that the source of this effect in the model is on the inhibitory feedback connections that link the distractor phonemes to the target phonological representation held in the phonological output lexicon. The greater the number of nonword phonemes that are activated in the phoneme system, the greater will be the amount of inhibition sent back from the phoneme system to the target picture's representation in the phonological output lexicon, which will delay the full activation of the picture name's phonemes.

It is more difficult to give a satisfactory explanation of the additive pattern between the nonword distractor length and the end-phonological relatedness effect. Indeed these two effects seem to have the same locus, but if so, we would have obtained an interactive pattern. Nevertheless this logic would be true if and only if the human reading and speech production systems were stage systems (*stage* as defined by Sternberg (1969)).

According to the DRC model, the communication between the phoneme system and the phonological output lexicon is not staged but is instead cascaded/interactive (i.e. via continuously operating feedback and feed-forward excitatory and inhibitory connections). However when the communication between two levels is cascaded this does not mean that there is a complete operation overlap (for a different view see Sternberg (1998a)). Indeed the output of one level needs a certain amount of time before activating the following level. During this time only the first level is operating, not the second level. It follows that variables affecting the first level start to modulate its operation earlier than variables affecting the second level. These two groups of variables could mutually modulate the duration of the other level through the communicating connections. This is the source of an interaction effect when two variables affect two different levels in cascaded communication. But this is not our case

either. The nonword distractor length affects mostly the inhibitory feedback connections from the phoneme system to the phonological output lexicon: the effect is expressed by a longer duration in activating 1) the target phonological output lexicon representation and 2) the target phonemes in the phoneme system. According to this account, the target-distractor ends-phonological relatedness effect should be influenced by the nonword distractor length effect, since it involves the duration of both phonological output lexicon and phoneme system operation levels, determinant levels for any phonological effects in PNWI task. Human data fail to show the expected interaction. So, can two variables, supposed to affect the same level or the same connections, exert additive pattern of results? Our results speak in favor of this. However looking at the DRC-SEM functional architecture we already know that the source of the nonword distractor length effect is in the inhibitory connections from the phoneme system to the phonological output lexicon; we might argue that the source of the end relatedness effect is instead in the excitatory connections from the phoneme system to the phonological output lexicon. But this still again doesn't help to explain the observed additivity.

One way to explain this additivity is to assume that the effect of the phonological relatedness variable on the nonword distractor length is modulated by the position the shared phonemes occupy in the string (onset overlap *vs.* end overlap). Indeed human data reported in Paper 1 of this thesis showed an interactive pattern between nonword distractor length and onset-phonological overlap (first two phonemes) but additivity when the overlap involved the picture-nonword end (last two phonemes). However the reason why this happens still remains obscure. We could suppose it is due to the nonlexical route computation on the distractor stimuli; if that is the only route that works serially, any position-dependent effects must reflect its computations.

Another issue that remains unsolved is the nature of these effects:

- 1) Is the nonword distractor length effect a facilitation for short nonword distractors or an interference for long nonword distractors?
- 2) Is the phonological facilitation effect expressed by a facilitation of the end related pairs or an interference expressed by the phonological unrelated pairs?
- 3) Is the target frequency effect an expression of a facilitation in naming the pictures with an high frequency value or an interference in naming those with low frequency values?

At this point we may claim that the nonword length effect is the result of the inhibition accumulated across the nonword phonemic string sent to the picture phonological

representation; the more phonemes, the more inhibition. DRC-SEM Simulation 1 reported in Paper 1 of this thesis supports this view. Similarly in that paper we obtained some evidence supporting the view that the phonological relatedness effect is a facilitation due to onset or end phonologically related pairs (i.e. the facilitation obtained for the phonologically related pairs was not a lack of interference but it was properly expressing facilitation), see DRC-SEM Simulations 3 or 4 of Paper 1.

We are not able at this point to define the nature of the target picture frequency effect although we know how the DRC-SEM framework simulates this effect in a picture naming task. It is by having a scaled frequency value that is added to the net-input for each orthographic input lexicon and phonological output lexicon unit on each cycle. High frequency words and high frequency pictures have a higher scaled frequency value.

Analysis 2 of Experiment 1 showed that the facilitation due to phonological end-overlap is not modulated by the absolute position the phonemes actually occupy in both the phonemic picture and nonword strings, and the fact that this is so both when the nonword distractor string is long and when it is short supports the view that in the human phonemic system the absolute position of the shared phonemes does not matter. This suggests that the phonemic system is characterized by a relative position coding scheme, in contrast to the DRC-SEM model where the position-coding scheme of phonemes is absolute.

We now report the DRC-SEM simulation of Experiment 1, which could help in understanding the nature of the behavioral phenomena observed.

DRC-SEM Simulations of Experiment 1

Table 16 shows the parameter set adopted for simulation 1.

<i>Parameters</i>	<i>Values</i>
SemanticsOnset	60
SemanticsOrthlexExcitation	0.25
SemanticsPhonlexExcitation	0.25
SemanticsExternalExcitation	0.5
Letter Decay (at cycle 120)	1.0
PhonemeUnsupportedDecay	0.05

Table 16. parameter set adopted for simulation 1.

Since DRC-SEM is a model of the reading of English, the simulation stimuli were English words chosen so as to have the same properties as the Italian words used in the experiment with human subjects. Thus, as in Experiment 1, there were three independent variables here: target frequency (high *vs.* low values of target frequency), nonword distractor length (short *vs.* long) and target-distractor phonological relatedness (pictures and nonword distractors shared their last two phonemes or they did not share any phonemes).

Twenty four targets were selected from the CELEX database (Baayen et al., 1993), half of them of high frequency value⁹ (mean 54, range 20-192) and the other half of the targets of low frequency value (mean 0,03, range 0-1). Targets had 5 phonemes on average (range 4 – 6) and 6 letters on average (range 4-7). Since we are attempting to simulate Italian data where all the picture names are GPC-regular, all the DRC-SEM picture names are GPC-regular.

Each target was paired with four types of distractor: 1) long and end-phonologically related distractors; 2) long and completely phonologically unrelated distractors; 3) short and end-phonologically related distractors; 4) short and completely phonologically unrelated distractors. For each of the four distractor conditions thirty stimuli were created.

A total of ninety-six distractors were created: half of them were long distractors (6 phonemes) and half short (3 or 4 phonemes). In turn, half of the long distractors shared the last two phonemes with the target pictures and the other half of long distractors had no phonemic overlap at all with the target. The same treatment was applied for the short distractor conditions.

Results

Table 17 show the mean number of cycles the model required to name the pictures as a function of distractor length and end-phonological relatedness, for high frequency target pictures and Table 18 for low frequency target pictures.

⁹ We report here the written frequency value of the target picture. However spoken and written frequency values are highly correlated.

Target-distractor Phonological Rel.	Distractor Length		Difference
	Long (7-8 ph.)	Short (4-5 ph.)	
Unrelated	No. Cycles 222	No. Cycles 189	33
End related	218	190	28
Difference	4	-1	

Table 17. High frequency target pictures. Means of the number of DRC-SEM cycles of Simulation 1 as a function of distractor length and the End-Phonological Relatedness between pictures and distractor pairs (they shared the last two phonemes or none phoneme). Length is considered in terms of the number of the constituent phonemes.

Target-distractor Phonological Rel.	Distractor Length		Difference
	Long (7-8 ph.)	Short (4-5 ph.)	
Unrelated	No. Cycles 223	No. Cycles 212	11
End related	224	212	12
Difference	1	0	

Table 18. Low frequency target pictures. Means of the number of DRC-SEM cycles of Simulation 2 as a function of distractor length and the End-Phonological Relatedness between pictures and distractor pairs (they shared the last two phonemes or none phoneme). Length is considered in terms of the number of the constituent phonemes.

For analysis, firstly we split the data into two parts according to target frequency (high vs. low). Within each level of target frequency we calculated for each of the twenty-four targets 1) the difference between long and short distractors both in the end-phonological related condition and in the phonological unrelated condition and 2) the difference between the phonological unrelated pairs and the end-phonological related pairs both in the long nonword distractor condition and in the short nonword distractor condition. A McNemar's test was carried out on the resulting data to test the main effects and the interaction in each level of picture frequency. The tests showed a main effect of nonword length both for high and low frequency targets, p values $< .001$, no effect of end-phonological relatedness for either high or low frequency targets was found, p values $> .05$, and no the interaction between distractor length and end-phonological relatedness for either level of target frequency, p values $> .05$.

Secondly, we tested the 3-way interaction collapsing the data over the phonological-relatedness factor, to obtain four conditions: 1) short distractors paired with high frequency targets, 2) short distractors paired with low frequency targets, 3) long distractors paired with high frequency targets, 4) long distractors paired with low frequency targets.

Table 19 shows the DRC-SEM naming latencies according these new four conditions.

Target Frequency	Distractor Length		Difference
	Long (7-8 ph.)	Short (4-5 ph.)	
	No. Cycles	No. Cycles	
Low Frequency	224	212	12
High Frequency	220	189	31
Difference	4	23	

Table 19. Collapsing the data for phonological relatedness. Means of DRC-SEM cycles of the interaction.

Two randomisation tests were carried out within each level of nonword distractor length to test the significance of the target frequency effect, for short distractors $t(1, 46) = 6.26, p < .0001, p_{\text{resampling}}^{10} = 0$ and for long distractors $t(1, 46) = 3.55, p < .0001, p_{\text{resampling}} = 0$. The test revealed a main effect of target frequency for both short (low – high = 22.5 cycles) and long (low – high = 3.5 cycles) nonword distractors.

A second pair of randomisation tests were carried out within each level of target frequency to test the significance of the nonword distractor length effect, for high frequency targets $t(1, 46) = 12, p < .0001, p_{\text{resampling}} = 0$ and for low frequency targets $t(1, 46) = 4.2, p < .0001, p_{\text{resampling}} = 0$. The test revealed the main effect of nonword distractor length for both high (long – short = 31 cycles) and low (long – short = 12 cycles) frequency target pictures.

In order to test the interaction a randomisation test was carried out on the data representing the differences resulting from the subtraction of the short nonword distractor condition to the long nonword distractor condition within each level of target frequency. The test reveals a significant interaction, $t(1, 46) = -5.3, p < .0001, p_{\text{resampling}} = 0$. The target frequency effect is greater in size when the distractors are short than when the distractors are long. Further, the size of the distractor length effect is greater for high frequency targets than for low frequency targets.

Discussion:

Some of the human effects were captured by the simulation: in both human data and simulation, high frequency pictures were named faster than low frequency pictures, and short distractors produced faster responses than long distractors.

¹⁰ This value of probability represents the proportion of resampled $\mathbf{M}_a - \mathbf{M}_b$ values whose distance from zero is as great as or greater than the observed value of $\mathbf{M}_a - \mathbf{M}_b$, where \mathbf{M}_a and \mathbf{M}_b are the means of the SEM-DRC cycles belonging to the experimental conditions considered. Following the link used for this calculation: <http://vassarstats.net/resamp1.html>

However, there were also two effects which were present in the human data but not in the simulation. These were:

(a) Humans produced faster picture naming latencies when the pictures were paired with nonword distractors that shared the last two phonemes, compared to controls, whereas DRC-SEM showed no effect of last-phonemes phonological relationship.

As discussed in relation to Experiment 4 of Paper 1, because in DRC phoneme position coding is in terms of absolute position, DRC can only show a facilitatory effect of target and distractor sharing their last two phonemes if these shared phonemes are in the same absolute positions in target and distractor. In this experiment this was the case with only 25% of target distractor pairs, so no effect for DRC-SEM could emerge here. Unlike DRC, human readers are unaffected by whether phonemes shared by target and distractor do or do not occupy common absolute positions (Analysis 2 demonstrated that). So this experiment supports the conclusion from Experiment 3 of Paper 1 that DRC's absolute phoneme position scheme is not an accurate representation of how phoneme position is coded in the human speech production system.

(b) Human RTs showed additivity of the factors of nonword distractor length and target word frequency, whereas DRC-SEM showed an interaction (smaller target frequency effect for pictures paired with long nonword distractors than when the same pictures are paired with short nonwords, i.e. smaller distractor length effect for low frequency targets than high frequency targets). Why do these two factors interact in the DRC-SEM model?

The frequency effect arises in the model because a scaled frequency value is added to the net-input for each orthographic input lexicon and phonological output lexicon unit on each cycle. In the DRC-SEM model the orthographic input lexicon and phonological output lexicon's units (corresponding to the picture name) are activated indirectly by the picture semantic unit held in the semantic system. High frequency words and high frequency pictures have a higher scaled frequency value.

The nonword distractor length effect arises in the model because long nonword distractors, having a greater number of phonemes, send back to the phonological output lexicon picture's representations more inhibition – via feedback from the phoneme system – than short distractors do. Considering the pattern of the interaction according to which we shown smaller distractor length effect for low frequency targets than high frequency targets, it could be the case that:

1) Long nonword distractors affect phonological output lexicon picture's representation more than short nonword distractors because of stronger inhibitory feedback connections from the phoneme system, and;

2) The lower the frequency value of the picture name the more slowly its activation level rises in in the phonological output lexicon, so that the distractor length would affect high frequency picture name representation in the phonological output lexicon more than those of low frequency. This is because the inhibition sent by long nonword distractor phonemes would affect a phonological picture representation whose unit's activation value is higher and so more susceptible to inhibition compared to picture representations for which the level of activation in the phonological output lexicon is low because the rate at which activation rises is slow. This proposal, however, turns out not to be true because when one looks at the phonological output lexicon activation values for each semantic unit in the last cycle (the cycle on which DRC makes its naming response), it is possible to see that when distractors are long the modulation of the phonological output lexicon activation is the same both for high and low frequency target pictures – see Table 20.

Target Frequency	Distractor Length		Difference
	Long (7-8 ph.)	Short (4-5 ph.)	
	POL	POL	
Low Frequency	.98	.95	.03
High Frequency	.98	.97	.01
Difference	.00	-.02	

Table 20. Values of Phonological Output Lexicon [POL] activation at the last No. Of DRC-SEM cycle. Collapsing the data for phonological relatedness.

However this observation is made at different number of cycles for each semantic unit, since they belong to four different experimental conditions that led to different model picture naming latencies. Thus Table 21 shows instead the phonological output lexicon activation value at the same number of cycles both for short and long distractors, i.e. at the last cycle of short distractors. In this case the comparison would happen at the same amount of time elapsed from the presentation of the picture-short and picture-long nonword distractor.

Target Frequency	Distractor Length		Difference
	Long (7-8 ph.)	Short (4-5 ph.)	
Low Frequency	.90	.95	-.05
High Frequency	.46	.97	-.51
Difference	.54	-.02	

Table 21. Values of Phonological Output Lexicon [POL] activation at the last No. Of DRC – SEM cycle of the short distractors, collapsing across the factor of phonological relatedness.

The data reported in this table show that the activation values of the phonological representation of the target when the distractor is long are lower when the target is of high frequency than when the target is of low frequency, on the last naming cycle of short distractors. This pattern of values however would intuitively predict a different pattern of model latencies: indeed when the target has a high frequency value and is paired with long nonword distractor the target phonological representation has the lowest value of activation, both in comparison to when the same high frequency pictures are paired with short nonword distractor (.97 value of difference) and when instead long nonword distractors are paired with low frequency pictures (.51 activation value of difference). However this is the pattern that could be detected at one time in modelling the task, namely the time when the model name high or low frequency pictures paired with short distractors. Although this analysis is not helpful in understanding the phenomena, it is valuable to appreciate that on average the model is able to invert the pattern of activation in the subsequent 22 cycles (that is the value from the difference between picture naming latencies of pictures paired with long minus short distractors, collapsing for the frequency value of the pictures).

The nonword distractor length effect is expressed by a greater number of DRC cycles needed by the model to be able to name the picture name when nonword distractors are long compared to when they are short; DRC-SEM has to counteract the inhibition sent to the phonological output lexicon picture representation from the distractor phonemes activated in the phoneme system, and that inhibition will be greater for long than for short distractors. The greater the number of cycles is the greater is the inhibition that the distractor's phonemes can send back to the picture phonological output lexicon representation. Since this process occurs over time, the size of the target picture frequency effect could be reduced because of the inhibition sent from the long nonword distractors phonemes from the phoneme system to the picture's phonological output lexicon representation. Indeed the inhibition increases with the

number of cycles since the phonemes belonging to the picture's name in phoneme system became stronger competitors, and this seems to occur approximately at the same time for both high and low frequency picture name.

This interaction between nonword distractor length and picture frequency is an example of how for two variables that affect two different levels of the model – the nonword distractor length effects the inhibitory connection from phoneme system to phonological output lexicon whereas the target frequency affects the resting levels of the representations held in orthographic input lexicon, phonological output lexicon and SEM system – each variable can bias the effect of the other because in the DRC model the phonological output lexicon and the phoneme system are levels characterized by inhibitory and excitatory bidirectional communications which allow this mutual bias.

In order to more deeply explore the nature of the target frequency effect and how this variable interacts with the phonological activation of distractor words, we carried out a second experiment manipulating two factors: target frequency and the onset phonological relatedness between target pictures and distractor words. We did this using a PWI task.

Experiment 2

In experiment 2 we investigated the effect of initial phonological relatedness between the target picture names and distractor words, when the pairs of stimuli shared the first two phonemes, and how this effect is modulated by the frequency of the target pictures.

Method

Participants

Twenty students of the Università degli Studi di Padova participated in the study as volunteers. They all had normal or corrected-to-normal vision. Participants were all native speakers of Italian.

Design

A within-subject design was employed with the factor frequency of the target picture (high frequency *vs.* low frequency picture name) and the factor target-distractor phonological relatedness (initial two phonemes shared *vs.* no phonemes shared) orthogonally manipulated.

Materials

Sixty pictures were selected as target stimuli from the database of Dell'acqua et al.

(2000). Thirty of these were of high frequency value, mean frequency value of 42.5, ranging from 192.08 to 2.1. The other half of the pictures were of low frequency value, mean frequency value of 6.4, ranging from 15 to 0.3, frequencies were taken from the database of Dell'acqua et al. (2000).

Their average number of phonemes was 6 in both the target groups (ranging from 2 to 9 in the high frequency target group and from 4 to 10 in the low frequency target group, counting geminate consonants as in GONNA as two phonemes). All the pictures had a high name agreement value and each target picture was presented twice, once with an initial phonologically related superimposed distractor word and once with a phonological unrelated superimposed distractor word.

Table 22 shows the properties of the experimental target picture names and the four groups of the distractor words.

One hundred and twenty pronounceable word distractors were selected from Colfis database (Laudanna, Thornton, Brown, Burani & Marconi, 1995). Sixty were initial-phonological related distractors; 30 of them shared with high frequency target pictures the first two phonemes and the other 30 related distractor words shared the first two phonemes with the low frequency target pictures. The other 60 distractor words were completely phonologically unrelated to the picture names and were paired with the respective two groups of target pictures of high and low frequency values.

Twenty experimental lists were created in which stimuli were presented in a different order for each list with the restriction that one particular target could not be followed by itself in the next 3 items. Furthermore, each list began with three practice trials. Appendix 3 reports the stimuli used in Experiment 2.

	PH. NO.	LETT. NO.	SYL. NO	N	FREQ.
<i>HIGH FREQUENCY TARGETS (30)</i>	5.87	6.13	2.53	3.16	42.50
<i>LOW FREQUENCY TARGETS (30)</i>	6.10	6.37	2.77	5.06	6.40
<i>PH. RELATED DIST. WORDS (60)</i>	6.73	7.03	2.77	3.17	9.27
<i>UNRELATED DIST. WORDS (60)</i>	6.87	7.07	2.98	3.13	12.06

Table 22. Properties of the experimental target picture names and the four groups of the distractor words.

Apparatus

The Apparatus was the same as with Experiment 1.

The procedure was identical to the procedure of Experiment 1 except that the experimental session was preceded by a practice session of 14 trials and a familiarization session in which subjects saw all the pictures of the experiment (practice, trial and experimental pictures) for a total of seventy-seven pictures, with their corresponding names presented beside them.

Results

Naming errors and apparatus failures (9%) were removed prior to analysis. Correct RTs were submitted to the Van Selst & Jolicoeur (1994) outlier removal procedure, resulting in the elimination of 0.75% trials. The factors of target-distractor phonological relatedness (initial related *vs.* phonological unrelated) and target frequency (high *vs.* low) were treated as a within-subject factor in the analysis by-subject (F1). The target frequency factor was treated as a between-subjects factor in the analysis by-items (F2). Table 23 reports the means of RTs and accuracy corresponding to the experimental conditions.

	Target Picture Frequency				Difference (RTs)
	Low Frequency		High Frequency		
Target – Distractor Ph. Relatedness	RTs	E%	RTs	E%	
Unrelated	876	2	827	2	49
Onset Related	730	1	727	1	3
Difference	146		100		

Table 23. Means of Reaction Times [ms] and naming errors [%] of the considered experimental conditions.

RTs

Two-factor ANOVAs were carried out with the subject data (F1) and the item data (F2), the factors being target name frequency, distractor length begin- phonological relatedness. Interaction effect approaches significance as well as the two main effects.

Mean reaction times for high frequency targets were significantly faster than for low frequency targets (by 46ms in the subject data, by 28ms in the item data). This effect was significant both in the analysis by subjects and in the analysis by items, $F_1(1,19) = 5.27, p < .05$, $F_2(1,58) = 2.39, p < .05$.

Mean picture-naming latencies were faster with phonologically-related distractors than with phonologically unrelated distractors (by 47ms in the subject data, by 131ms in the item data). This effect was significant both by subjects and by items, $F_1(1,19) = 29.13, p < .05$, $F_2(1,58) = 214, p < .05$.

A significant interaction between the two factors was found both in the analysis by subject and in the analysis by items, $F_1(1,19) = 4.9, p < .05, F_2(1,58) = 7.41, p < .05$. The target frequency effect vanishes for the onset related picture-distractor words pairs but was significant for the phonologically unrelated pairs of stimuli, $t_{\text{subjects}}(1,19) = |2.4|, p < .05$.

Accuracy

F1 and F2 analyses of the accuracy data shown no main effects of target frequency $F_1(1,19) = 0.5, p > .05, F_2(1,58) = 0.96, p > .05$ or of onset-phonological picture-distractor relatedness $F_1(1,19) = 3.2, p > .05, F_2(1,58) = 1.8, p > .05$ and no interaction between the two factors, $F_1(1,19) = 0.001, p > .05, F_2(1,58) = 0.11, p > .05$.

Discussion

When picture names and their word distractors shared their first two phonemes there was no target frequency effect. In contrast, when picture-distractor pairs were completely phonologically unrelated, the target distractor frequency was significant: high frequency pictures were named faster than low frequency target pictures. Why this pattern of interaction?

The target frequency effect might occur at the stage of lexical retrieval, specifically when the lexeme and the phonological word-form have been activated.

It might occur because 1) the phonological representations of high frequency pictures are activated faster than low frequency pictures 2) the timing with which the phonology of the picture name is actually activated in the phonological output lexicon may vary as a function of frequency, occurring earlier for pictures having a high frequency value compared to pictures having a low frequency value.

Here we might point out two phenomena:

1) Since in the picture-word interference paradigm the distractor word activates its phonology before the target picture does¹¹, it could be that by the time the picture name's phonology stored in the phonological output lexicon gets activation and consequently sends activation to its own phonemes in the phoneme system, the distractor word phonology has already sent activation to its own phonemes in the phoneme system, facilitating the picture naming task whenever targets and distractors share the same onset (first two phonemes).

¹¹ This might happen for several reasons: written stimulus presented in foveal area, word and pictures follow different pathways, words are processed faster than pictures.

2) As mentioned above, when the picture name has a high frequency value, it can activate its phonological word-form earlier than a low frequency picture name would (indeed activation of both the picture's orthographic representation and its phonological representation, held respectively in orthographic input lexicon and phonological output lexicon, could be modulated by the picture's frequency value).

These two phenomena, taken together, have some implications:

1. When pictures are paired with completely phonological unrelated distractors the target frequency effect could emerge because of the different timing with which low and high frequency pictures activate the phonology of their corresponding names: this would happen earlier for high frequency pictures.

Suppose instead the timing of the phonological word-form activation of the picture name is the same for both the stimuli, the effect might occur because high frequency pictures possess a higher level of activation of the phonological unit of the picture name stored in the phonological output lexicon. Here units that receive activation from the phonological output lexicon would benefit from this stronger activation – namely, the target phonemes in the phoneme system.

2. When pictures are paired with initial phonological related distractors, the phonological relatedness effect emerges because by the time the picture name activates its phonemes in the phoneme system the distractor word has already sent activation to its own phonemes. Thus, if the picture and the distractor strings share the two initial phonemes, then these two phonemes - held in the phoneme system - would receive activation from two sources (the picture and distractor activated phonological representations). This benefit would theoretically add a further advantage to the naming latencies of high frequency pictures. We will discuss this point later.

What is still unclear is the nature of the phonological facilitation effect in the human reading and speech production systems. Is it a facilitation due to the joint activation coming to the first two phonemes from two different sources (the phonology of the picture and the phonology of the distractor word) or is it a lack of interference in the first two positions that would lead to faster naming latencies in the initial phonological related pairs? The evidence reported in Paper 1 of this thesis (Experiment 4, Simulation 5) suggests that the target distractor phonological relatedness is a facilitatory effect, at least in PNWI. However we are now discussing a PWI

experiment.

3. The obtained interaction shows that when the picture name shares with the word distractor the first two phonemes the target frequency effect is absent. This pattern might occur because by the time the target phonemes receive activation from the picture name's phonological representation, the first two phonemes are already activated by the distractor's phonological representation and accelerate the naming latencies. The initial phonological overlap hides the target frequency effect because, by means of feedback and feed-forward excitatory connections from the phoneme system to the phonological output lexicon the initial overlap spread the benefit of the extra activation on all the phonology of the target picture name that in turn send more activation back to its own phonemes. This benefit in terms of level of activation speeds up the growth of activation of the phonemes belonging to low frequency targets, compared to the condition in which these targets are paired with phonologically unrelated distractors and furthermore compared to the condition in which high frequency targets are paired with onset related distractor words.

DRC-SEM Simulations of Experiment 2

Experiment 2 differs from Experiment 1 in that it is a PWI experiment, not a PNWI experiment, i.e. the distractors are words rather than nonwords. Appreciation of this difference is necessary in order to understand why the DRC-SEM parameters used in the simulation of Experiment 2 differ from those used in the simulation of Experiment 1.

In DRC-SEM, when the distractor is a word, its representations at the level of the phoneme system are activated much faster than when the distractor is a nonword, because activation of phonemes via the lexical reading route occurs for words but not for nonwords. Thus in the PWI task the lexical route operates simultaneously on two different stimuli, a picture to be named and a printed distractor word to be ignored. We needed to find a parameter set that allowed the model to deal with two concomitant stimuli for which phonology is managed essentially by the same route. For this reason we decided:

- 1) to activate the target word's semantic representation 30 cycles earlier than in the previous simulations (where targets were pictures);
- 2) to start the full Letter Decay at cycle 40 instead of 120 and;
- 3) to set `SemanticOrthlexInhibition` and `SemanticPhonlexInhibition`, to .35 (these were both zero in the Experiment 1 simulations). These last two parameters send inhibition to all the

orthographic and phonological representations except the target one. The parameter set adopted for simulation 2 is shown in Table 24.

<i>Parameters</i>	<i>Values</i>
SemanticsOnset	30
SemanticsOrthlexInhibition	0.35
SemanticsPhonlexInhibition	0.35
SemanticsOrthlexExcitation	0.25
SemanticsPhonlexExcitation	0.25
SemanticsExternalExcitation	0.5
Letter Decay (at cycle 40)	1.0
PhonemeUnsupportedDecay	0.05

Table 24. Parameter set adopted for simulation 2.

Properties of the stimuli (for the complete list of stimuli see Appendix 4)

As in Experiment 2, there were two independent variables here: target frequency (high vs. low values of target frequency) and target-distractor onset phonological relatedness (pictures and nonword distractors shared their first two phonemes or they did not share any phonemes).

The same forty-eight targets (twenty-four high frequency and twenty-four low frequency targets) used in the previous simulation were used here. Ninety-six distractors were selected from the CELEX database (Baayen et al., 1993) so that each target of frequency level was paired with two types of distractors: 1) onset-phonologically related distractors (the phonological overlap involved the first two phonemes); 2) completely phonologically unrelated distractors.

All the distractors had 6 or 7 phonemes; the average for each group of distractor was 6 phonemes. The average of the both the group of target frequency was 5 phonemes (range 4 - 6). We run separately two simulations, one corresponding to the high frequency targets (Simulation 3) and one corresponding to low frequency targets (Simulation 4).

Results

We had to discard two pairs of stimuli for each of the target frequency set of stimuli because the model named the distractor rather than the target.

Table 25 shows the averages of the number of cycles the model required to name the pictures as a function of target frequency and end-phonological relatedness.

Target-distractor Phonological Rel.	Target Frequency		Difference
	Low	High	
Unrelated	No. Cycles 192	No. Cycles 136	56
Onset related	No. Cycles 174	No. Cycles 111	63
Difference	No. Cycles 18	No. Cycles 25	

Table 25. Means of the number of DRC-SEM cycles as a function of Target Frequency (High Frequency Targets, simulation 3 and Low Frequency Targets, Simulation 4) and the End-Phonological Relatedness between pictures and distractor pairs (they shared the last two phonemes or none phoneme). Length is considered in terms of the number of the constituent phonemes.

Within each level of target frequency we calculated for each of the twenty-two targets the difference between the number of cycles the model need to name the picture in the phonological unrelated condition and the end-phonological related condition, then within each level of target-distractor phonological relatedness we calculated the difference between the number of cycles the model need to name low frequency target pictures and high frequency target pictures. Three McNemar's tests were carried out on the resulting data to test the main effects and the interaction. The tests shown 1) a main effect of phonological relatedness for both the target frequency values – greater number of cycles for unrelated pairs, 2) and a main effect of target frequency in both the phonological related and unrelated target distractor conditions – greater number of cycles for low frequency targets, p values $< .05$. No effect of the interaction between target frequency and onset-phonological relatedness was found, p values $> .05$.

Discussion:

Some of the human effects were captured by the simulation: in both human data and simulation, high frequency pictures were named faster than low frequency pictures, and onset-related distractors produced faster responses than unrelated distractors.

However, the simulation and the human data differed in one way: for the human data, there was an interaction between frequency and relatedness such that there was no effect of frequency in the related condition, whereas these two factors were additive in the simulation

data i.e. the frequency effect was the same size in the related and unrelated conditions.

This incongruence underlies some difference between the DRC model and the reading and speech production human systems.

It might be that the additivity is artificially produced by the model because of our choice in implementing the PWI instruction. All the distractors were subjected to the maximum decay value at the letter level at cycle 40, which means that from cycle 41 all the distractor units activated at any level of the model could only decrease in term of their level of activation. The units belonging to the distractor that are activated till cycle 40 are essentially all the features constituting the distractor letter, all the letters of the distractor, its orthographic representation held in the orthographic input lexicon, its phonological representation held in the phonological output lexicon, and the first or the first two phonemes activated in the phoneme system.

All the semantic units representing the pictures receive activation initially at cycle 30 regardless of their own frequency value. As soon as the target phonological representation in the phonological output lexicon receives activation then activation flows in a cascaded way to the constituent phonemes in the phoneme system. Then two different outcomes might be expected: when the target-distractor stimuli are unrelated the activation passes from the phonological output lexicon to the phoneme system starting from the value 0 in all the target phonemes, whereas, when they have an onset overlap the first two phonemes of the target would have already been activated by the distractor phonological representation. In the latter case the entire phoneme string would reach the naming threshold faster than when targets do not share with distractors the onset phonemes.

Further when the picture and the distractors are not phonologically related the first phoneme of the target needs to compete with the first phoneme of the distractor, previously activated for the same position. This observed distractor activation is the result of the non-lexical route, working on the distractor string before and after the semantic unit has been activated in the semantic system.

Thus to the main effect of target frequency would be added the advantage of having two phonemes in the first two position of the target phonemic string already being activated because of the previous activation of the distractor phonology.

However what the present simulation suggests is that the two variables affect different stages of the model or, better, that each of them independently modulates a stage or a level of the system. The human data implies instead a more flexible system where the two variables generate an interaction between the target frequency and the target distractor onset relatedness

effects. Furthermore obeying the PWI task instructions may involve in human subjects many additional cognitive mechanisms such as attention, selective and spatial attention, cognitive control, monitoring and so on, rather than the mere setting of parameters and subsequent instructions to the reading and speech production systems as DRC-SEM model instead does.

General Discussion

In this work we have explored some properties of the human reading and speech production system through two empirical investigations and through the comparisons made between the human results and simulations using the DRC-SEM model. We observed three main discrepancies between the human data and the model results:

1. Experiment 1 (PNWI): humans show facilitation in the naming latencies of pictures paired with nonword distractors that shared with the target the phonological end (the last two phonemes) compared to when the same targets were paired with phonological unrelated pairs. DRC-SEM did not show this result.
2. Experiment 1 (PNWI): Analysis 2 of the human data revealed that the effect of end relatedness position did not vary as a function of the absolute positions the shared distractor phonemes occupy in relation to the shared target phonemes. DRC-SEM model fails to simulate this a result.
3. Experiment 1 (PNWI): Human RTs showed additivity between nonword distractor length and target word frequency, whereas DRC-SEM showed an interaction (smaller target frequency effect for pictures paired with long nonword distractors and smaller distractor length effect for low frequency targets).
4. Experiment 2 (PWI): Human data show an interaction between the target picture frequency effect and the picture-word onset phonological relatedness, the simulated data instead show an additive pattern between these two variables.

These differences in the obtained results allowed us to propose some properties of the reading and speech production systems:

1. The phoneme system is characterized by a phoneme position-coding scheme that codes the relative position of each phoneme in the target or distractor phonemic strings. This proposal has been strengthened by the Analysis 2 of Experiment 1, which showed how the end relatedness facilitation effect did not change across the string of target-distractor phonemes.
2. It seems that inhibition in the DRC-SEM model is sensitive to the level of activation of its units, for instance in the phoneme system, i.e. the more a phoneme is active, the more strongly it can be inhibited.
3. Many cognitive mechanisms are involved in the PWI or PNWI tasks i.e. selective attention, spatial attention, central attention, cognitive control on the task, monitoring response mechanism and so on. None of these are implemented in any current models of reading and speech production. Nevertheless, we demonstrated the DRC-SEM is partially able to simulate our data.

Conclusions

Although this paper offers a way to begin to answer some critical and relevant questions concerning the facilitation and/or interference that a written stimulus (a word or a nonword) exerts on a primary task – that is the naming of a picture stimulus presented simultaneously – many issues concerning the PWI and the PNWI paradigms remain unsolved. It seems that the human reading and speech production systems are much more flexible than they are in any implemented model and that explanation of effects in these kinds of experiments may need to appeal to the contributions of other cognitive mechanisms such as attention and monitoring.

However, one feature that seems to be quite established by the data provided in this paper is the relative phoneme position-coding scheme that maps the phonemes of the written distractor and target picture strings in the correct position. Every theory or model of reading and speech production (DRC-SEM included) should implement this property in the phonemic system.

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Appendix 1

The target-distractor phonological relatedness concerns the last two phonemes.

Picture Name (Target)	Written Nonword Distractor			
	Long Distractors		Short Distractors	
	Phonological Related	Phonological Unrelated	Phonological Related	Phonological Unrelated
albero	VUTISRO	FUTISVI	SUFRO	SIFTU
bottiglia	SUCUNDIA	CUSUNDRE	ZUDIA	DUSVE
cammello	SURGILO	GURSITI	NISLO	NIRZU
cane	BORISINE	DOBRISLI	PUBNE	DRIBO
cappello	DUBRILO	RUDRISI	ZISLO	RISDI
castello	RIGIPILO	IGRIBUPI	MUDLO	VUGRI
cavallo	SREBULO	BRESUNI	ZIPLO	SIDRE
chiesa	DUNURSA	VUNUDRO	NURSA	RUVPO
corona	PUFIBENA	FIBEPUMI	FUDNA	DUSFE
cravatta	ZELUSTA	LESUZOI	LUFTA	LUFDE
elefante	VIMISOTE	MIROSVI	GIMTE	SUVMI
fiore	CUDAZURE	PUZUDACA	UZRE	UPZA
foglia	TEBUZIA	BETUCRE	DUTIA	NURTE
gatto	FEUCRITO	EFULICRI	DIVTO	IZFE
gonna	DRIBENA	CESIRTE	IFNA	IFBE
leone	GISPRINE	ZARTUVI	SIBNE	BITSA
letto	CAPURTO	PACURBI	SUZTO	NIRBI
mela	TRIVIULA	UVICUTRI	OVLA	IZVI
montagna	CUPEGNA	PECUBLE	ZUGNA	BULPE
mosca	GUREBICA	BERIGUTI	DIFCA	NIVBE
orologio	VEATESIO	ATESUVE	SUPIO	CEPSE
pesce	ROMISCE	RIMOTADO	VUSCE	NILGO
ponte	BRIFUTE	FACUBRI	GIFTE	SIBFA
re	ZUMAGORE	GAZUMOTI	UMRE	IFLI
scarpa	BUFEDIPA	DEFIBUNI	DEFPA	DEBFI
scrivania	BLEFUJA	FEZUBLO	UBIA	ZEFBE
squalo	TIVIBELO	MIVIBETE	VIMLO	MIVBI
stivale	POMURLE	ROGUNFO	OGLE	OBUGO
tazza	VRIFUZA	LUVRIFO	IVZA	VRIU
tenda	SICUPODA	CIPUZISO	USDA	USBO

Picture Name (Target)	Written Nonword Distractor			
	Long Distractors		Short Distractors	
	Phonological Related	Phonological Unrelated	Phonological Related	Phonological Unrelated
altalena	DIBIRONA	BISIDIRO	ISBNA	SDIBO
anatra	GUMESIRA	FUGEMISO	VUGRA	GIFSO
aquilone	PUSTRUNE	FRUSUMPI	VUSNE	SURFI
asino	REPULNO	PERUSBE	FUPNO	SBUPE
banana	MIRORNA	PRIGOLE	USNA	ILSVO
calzino	MESUTENO	SURUMETE	UTFNO	PEVRE
carota	LIFUBITA	FEDUSIME	IDUTA	IBEDI
cerniera	SPUBLURA	GUSPOBLO	DUZRA	PUSGO
coniglio	TREBAIO	MABRETA	EDRIO	ZUVJA
dondolo	TRUZALO	ZUPETRI	IZILO	SRUPE
fiocco	VEBESACO	VABUSELE	UBCO	UBTE
fionda	LUSEBUDA	PESULBRE	VULDA	PURME
granchio	SEMUVEIO	DUMESUVE	UTIO	UZVE
guanto	PEFIRTO	PEDRIME	DIVTO	SFEBI
gufo	BRITAFO	TALIBRE	ZAFO	IDPI
lumaca	BESINECA	NISEBIVE	VOFCA	VIRBE
ombrello	TUVANALO	CAVINUTA	TISLO	NITCA
pagliaccio	TRUZEIO	ZEMURTE	UFRIO	ZURME
pera	GILTOVRA	MUSTIMBO	NIDRA	NOFDI
pettine	COBORNE	BORCUSO	VOSNE	SUCU
pipa	BUFOROPA	ROCUBEFE	DUGPA	GUDBO
pomodoro	TICUSERO	SICETUGI	UCRO	ICTE
rana	CIZODENA	DEPUZICO	UBRA	EPZI
razzo	BLESIZO	PIBLESE	PLEZO	PLEVI
sciarpia	BLEFOPA	FUCEBLO	MLEPA	BLEME
scivolo	DUMURLO	GARMEDE	GEDLO	ADZE
sega	DRABILGA	TUBALDRI	BINGA	NUPDO
tigre	DOSUVRE	BOLSUMA	OVRE	PUDCA
topo	GRAMIPO	RIMELDA	ILPO	FNIVI
volpe	RUNIZAPE	NUMIRAZA	NUMPE	RUZMI

Appendix 2

The target-distractor phonological relatedness concerns the last two phonemes.

Picture Name (Target)	Written Nonword Distractor			
	Long Distractors		Short Distractors	
	Phonological Related	Phonological Unrelated	Phonological Related	Phonological Unrelated
branch	skliems	klarftz	mauntch	ghares
claims	skreubz	sterspe	bermes	douge
clubs	skreubz	drymps	leybs	smerv
crimes	splims	ghlutst	zeymms	sphoot
drink	splyngk	stelts	kurnck	smermn
flats	siltse	krarnzd	duitce	dozz
flights	duncktz	ghredzd	tiertse	koormed
grand	sprond	styxtse	hond	suift
grant	sklawnt	flawpes	rheynt	whorved
grounds	sklords	quanckt	gnurdes	oarlse
planned	browlnd	shreext	voigned	wrombe
print	skrante	smerlbd	choignt	glooch
scots	flormtz	growldz	alts	gneaged
speaks	trysks	blerlgz	phirx	whuitt
sports	yoekstz	ghralvd	poitze	werne
starts	lirmptz	ghrelvd	ghetes	kneithe
states	drusts	droalds	ootse	voupp
streets	preakts	pliribz	rartze	kaunsh
tells	skroulz	myxtfce	rarlze	chauthe
tend	skarlnd	braspz	choynd	ghayse
test	thruخته	flylkz	ignste	nourn
trained	bleulnd	kouxths	juigned	voorlce
troops	klirmps	glignzd	gheaps	narlge
trust	blynced	koolnz	zoussed	jauled

Picture Name (Target)	Written Nonword Distractor			
	Long Distractors		Short Distractors	
	Phonological Related	Phonological Unrelated	Phonological Related	Phonological Unrelated
brags	smelgz	quengkt	ghuggs	loomte
brigs	splilgz	sklenks	kougz	ausnht
brims	skrarmz	peendes	zoams	yowchte
brunch	sckwontch	plarkts	wrunтч	klouf
clefs	spramfs	trarmpe	pofes	braws
clines	draulns	smeefts	jowns	yoetse
clops	draspce	grignvz	doupes	phidth
clunks	skrarsx	graidzd	fouckse	thermp
crapes	stermps	blamfed	sayps	murlne
cricks	sfersx	gleulzd	fuiakse	geardz
drams	spramms	gleskt	mewms	fordth
drubs	skraubz	quopste	phirbs	teerst
drupes	quamps	blymfed	boorpce	morthe
flogs	strurgs	skrikte	jeygz	worved
flouts	sonckts	drenged	aiftse	krurde
glebes	snarlbz	dumptz	yourbz	pharred
glens	krawlns	barngxt	kneinz	doefed
grots	synktz	blurnke	arptz	numth
mutts	stufce	klorndz	gairtz	neage
prats	snayptz	klirnkz	foitze	knurgd
preens	sforlnz	stulged	yoans	physe
primp	scklamp	sklyved	lernp	toaffs
quiffs	spumfce	ghrumpt	sharfs	toolt
scoots	shelpts	dreelds	neartce	jourged

Appendix 3

The target-distractor phonological relatedness concerns the first two phonemes.

Picture Name (Target)	Written Word Distractor	
	Phonological Related	Phonological Unrelated
mela	metallo	siringa
letto	lenticchia	frangia
stivale	starnuto	poltrona
bottiglia	bovino	granchio
ponte	posata	crema
cammello	canzone	fagioli
castello	caviglia	pancia
gatto	gasolio	bottono
chiesa	chitarra	triciclo
corona	cofano	trottola
tazza	taverna	mattono
scrivania	scultura	coperchio
cane	carriola	treccia
elefante	elastico	balcone
pesce	pensiero	fazzoletto
fiore	fischio	pigiama
mosca	mollica	tamburo
cappello	calamita	forbice
cavallo	calcolo	funghi
re	restauro	cemento
foglia	fontana	cotone
leone	lenzuolo	zattera
montagna	morso	trave
squalo	squotere	lucchetto
scarpa	scorza	moneta
gonna	gomito	trapano
tenda	tempesta	resina
cravatta	croce	dente
albero	altare	sasso
orologio	orma	bilancia

Picture Name (Target)	Written Word Distarctor	
	Phonological Related	Phonological Unrelated
altalena	alettone	tenaglia
anatra	anulare	conchiglia
aquilone	aquila	serratura
asino	asola	portico
banana	barca	farfalla
calzino	candela	racchetta
carota	capanna	nuvola
cerniera	cetriolo	arancia
coniglio	collisione	mansarda
dondolo	dollaro	edera
fiocco	arpa	bastone
fionda	fiamma	sapone
granchio	granita	nocciolo
guanto	guscio	bomba
gufo	gusto	loggia
lumaca	lubrificante	soffitto
ombrello	omelia	bicchiere
pagliaccio	pavone	grembiule
pera	pennello	strofa
pettine	penisola	coperta
pipa	pillola	sgabello
pomodoro	postino	raggio
rana	rasoio	petalo
razzo	raviolo	costata
sciarpa	sconti	maniglia
scivolo	scoppio	cresta
sega	sentimento	tranello
tigre	timone	stufa
topo	torrone	freno
volpe	vortice	parrucca

Appendix 4

The target-distractor phonological relatedness concerns the first two phonemes.

Picture Name (Target)	Written Word Distractor	
	Phonological Related	Phonological Unrelated
branch	brinks	glimpse
claims	clinks	grunts
clubs	clamps	prints
crimes	crests	splints
drink	draughts	twelves
flats	flasks	cringed
flights	flanked	bronzed
grand	grasped	squabs
grant	grasps	squids
grounds	grafts	stumped
planned	plonked	shrinks
print	prompts	scalds
scots	scrapped	fringed
speaks	splits	trenched
sports	splodged	fronds
starts	strapped	grands
states	strummed	blonds
streets	stanchd	glands
tells	texts	frisks
tend	tempts	scrums
test	texts	blinds
trained	trunks	squeals
troops	tramps	cleansed
trust	traipsed	blends

Picture Name (Target)	Written ord Distarctor	
	Phonological Related	Phonological Unrelated
brags	bronx	staunched
brigs	bracts	spliced
brims	brands	flaunts
brunch	breasts	squads
clefs	clasped	primped
clines	clanked	primps
clops	clenched	trends
clunks	clinched	prompt
crapes	cranked	twelfth
cricks	crafts	plumped
drams	drenched	squint
drubs	drinks	slants
drupes	drunks	flinched
flogs	flexed	trounced
flouts	flunks	grinds
glebes	glanced	scraps
glens	glimpsed	scrubbed
grots	grants	blends
mutts	mulcts	grounds
prats	prinks	blondes
preens	prinked	stilts
primp	pranced	squalls
quiffs	quenched	tramped
scoots	scratched	friends

**PAPER 3: Some effects of nonword and word distractors
on reading words aloud**

Lisa Ceccherini, Max Coltheart & Claudio Mulatti

Abstract

The aim of this paper is twofold: 1) to further investigate some issues concerning the nonword length effect obtained in previous picture-nonword interference studies; and 2) to test and further improve the model of visual attention to multiple words proposed by Mulatti, Ceccherini & Coltheart, (2014). For these purposes we report here two word-nonword interference experiments and a third word-word interference experiment. The first two studies suggest that the nonlexical computation of the phonology of nonword distractors affects the word reading task. The last study raises some questions about the dynamics of activations of the lexical representations of target and distractor words. Specifically, the onset phonological relatedness effect we obtained in Experiment 3 (faster target naming latencies when distractor words shared with the target the first two phonemes, compared to distractor words with phonologically unrelated onset) leaves open the possibility that articulatory mechanisms are responsible for the effect, rather than there being a more lexical-phonological and phonemic account.

Keywords

Visual Word Recognition

Word and Nonword Reading aloud

Word-Word Interference task

Phonological relatedness effect

Target frequency effect

Nonword distractor length effect

Nonword pronounceability effect

Introduction

This paper reports work that studies the visual word recognition, reading and word production systems by means of the word-word interference paradigm, used for the first time by La Heij et al. (1990). In this paradigm, participants are exposed first to a fixation point which is then followed by a blank screen, which in turn is followed by two simultaneously-presented letter-strings, one at fixation and the other randomly above or below fixation. Participants are then required to read aloud the letter-string that appears below or above the one in the center of the screen, and to ignore the centered word. Thus, the non-centred string is the target stimulus and the centred string is the distractor stimulus. In the experiments we report, the target stimulus was always a word. In some of these experiments, the distractor stimulus was a word and in others it was a nonword. When the written distractor was a word we will refer to this paradigm as the WWI (word-word interference) paradigm. When the written distractor was a nonword we will refer to the paradigm as the WNWI (word-nonword interference) paradigm.

In all the three experiments reported, we manipulated the frequency of the target words (high *vs.* low). The properties of the distractor changed between experiments. In Experiment 1 we studied the factors of target frequency and nonword distractor length. In Experiment 2 we studied the factors of target frequency and the pronounceability of the nonword distractor (pronounceable *vs.* unpronounceable nonword distractors). In experiment 3 we studied the factors of target frequency and target-distractor phonological relatedness. In this third study the distractors were words and they could be onset-phonologically related with the target word (sharing the first two phonemes) or unrelated.

The WWI paradigm has been used previously by La Heij et al. (1990) and by Mulatti et al. (2014) and it has been shown to be a sensitive paradigm for revealing properties of the picture naming system and the reading system. Furthermore, Mulatti et al. (2014) have proposed a model capable of explaining the WWI findings reported in their paper. That model applies also to the WNWI paradigm.

Why were we interested in studying these effects? Why using this specific paradigm? The answers to these questions will be found by considering previous work reported in paper 1 and paper 2 of this thesis.

Specifically, in paper 1 we explored the effect of nonword distractor length using the PNWI paradigm. In this work, the role of this variable was not clear and the source of this effect was not identified therefore we decided to change paradigms, using words as targets instead of pictures and manipulating target frequency. In this way the speech production

system is involved solely via the reading system, since the target is no longer a picture to be named but instead a printed word to be read aloud. Moreover, varying the frequency of the target word would assess the strength of recruitment of the lexical route of the reading aloud system.

We adopted as our theoretical framework the dual route theory of reading aloud and its corresponding computational model, the Dual Route Computational (DRC) model of visual word recognition and reading aloud (Coltheart et al., 2001). Briefly, according to this theory there are two routes simultaneously recruited when a written stimulus is presented to the reader and they are specifically important for words (lexical route) or for new words/nonwords (nonlexical route); see Coltheart et al., 2001 for further details on how both the routes work.

In Experiment 1 we aimed to better understand the source of the nonword length effect in the reading system (studied in papers 1 and 2 through the PNWI paradigm), manipulating the interaction between the nonlexical route and the lexical one by means of the target frequency manipulation.

In Experiment 2 we further explored the finding of no nonword distractor length effect in Experiment 1. The factors here were the frequency of the target picture and the pronounceability of the nonword distractor. Target picture names of low and high frequency values were paired respectively with pronounceable or unpronounceable nonword distractors. If the nonlexical route is recruited for the reading of the nonword distractor, we would expect at least a main effect of pronounceability of the distractors (i.e. greater target naming latencies when the distractor is pronounceable than when the distractor is unpronounceable). This is because when the distractor is pronounceable, its phonology is assembled by the nonlexical route that proceeds serially on the string letter in input.

Finally Experiment 3 aimed to investigate in more depth the relation between target frequency and target-distractor phonological relatedness (first two phonemes shared *vs.* no phonological overlap). In this study both targets and distractors were words; paper 2 of this thesis also manipulated onset-phonological overlap but with pictures rather than words as targets. We considered the findings of these three experiments in relation to a model of reading aloud that resembles the DRC model in its structure but can be applied to multiple word/nonword processing as in the case of WWI or WNWI paradigms adopted here.

Experiment 1

Method

Participants

32 students of the Università degli Studi di Padova participated in the study as volunteers. They all had normal or corrected-to-normal vision and all were native speakers of Italian.

Design

A 2x2 factorial design with target frequency (high *vs.* low frequency) and nonword distractor length (short: 4-5 phonemes *vs.* long: 7-8 phonemes) as within-subject factors was used.

Material

Eighty words were selected from the COLFIS database as target stimuli (Laudanna, Thornton, Brown, Burani & Marconi, 1995): half of them were of high frequency (mean: 413; range: 250-880) and half were of low frequency (mean: 0.7; range: 0.3-1.2). High- and low-frequency words were balanced in terms of number of letters (6.6 *vs.* 6.6, $t < 1$), number of syllables (2.7 *vs.* 2.8, $t < 1$) and orthographic neighborhood size (4.2 *vs.* 3.1, $t < 1$). For each target two pronounceable nonword distractors were built (one short and one long); any phonological overlap between targets and distractors was avoided. Overall, one hundred and sixty pronounceable nonwords were built as nonword distractors. Half of them were short (4-5 phonemes, 4.6 on average) and the other half long (7-8 phonemes, 7.6 on average). Context-sensitive graphemes and multi-letter graphemes were avoided, so that the number of the phonemes in each distractor stimulus was also the number of its letters. None of the distractors had any orthographic neighbours. Each target word was presented twice, once with a short distractor and once with a long distractor. All stimuli were shown in Courier New font, lowercase, bold, 18-point size, and printed in black on a white background.

See Appendix 1 for the complete list of stimuli.

Apparatus

The experiment took place in a sound-attenuated and dimly lit room. The stimuli were displayed on a 17" cathode-ray tube monitor controlled by a 686 IBM-clone and E-prime software. The onset of vocal responses was detected using a high-impedance microphone to

which a voice-key was connected.

Procedure

Participants were tested individually. They were instructed to read the target aloud as quickly and accurately as possible, disregarding the distractor. On each trial, a fixation point (+) appeared in the center of the screen and between two bars (the distractor always fitted within the position of the two bars; see La Heij et al. (1990)) and was presented for 500ms. Following the fixation offset, a blank screen was displayed for 100ms, followed by the simultaneous presentation of the two stimuli, which remained visible until a vocal response was detected or 3s elapsed. The inter-trials-interval (ITI) was fixed at 1000ms.

The distractor stimulus was always presented in the center of the screen, i.e. in the place of the fixation point. The position of the target words was controlled and counterbalanced across participants. Two lists were constructed: in the first list, half of the targets in each condition were presented above the distractor and the other half below; in the second list, the pairing between targets and positions was reversed. The presentation of the two lists was counterbalanced across participants (see Mulatti et al. 2014) and target/distractor pairs were presented in a different random order for each participant. At a viewing distance of 60cm, the distance between the nearest contours of the written stimuli was 0.26 degree of visual angle, and their length ranged from 0.80 to 1.86 degree of visual angle. The experimenter scored each response as correct or incorrect on a sheet. The experimental session was preceded by a practice session of 11 trials.

Results

Naming errors and apparatus failures (6.9%) were removed prior to analysis. Correct RTs were submitted to the Van Selst & Jolicoeur (1994) recursive outlier removal procedure, resulting in the elimination of 1.1% trials. Target frequency (high *vs.* low frequency) and nonword distractor length (short *vs.* long) were both treated as within-subject factors in the by participants ANOVA (F1), whereas in the items ANOVA (F2) target frequency was treated as a between-subjects factor and nonword distractor length as a within-subject factor.

Mean correct RTs and error rates are reported in Table 26.

Target Frequency	Distractor Length				Difference (RTs)
	Long (7-8 ph.)		Short (4-5 ph.)		
	RTs	E%	RTs	E%	
Low	718	3	719	3	-1
High	670	1	668	1	2
Difference (RTs)	48		51		

Table 26. Means RTs and Accuracy (percentage of errors) as a function of target frequency and nonword distractor length factors. Length is considered in terms of the number of the constituent phonemes.

RTs

The analysis revealed a significant main effect of target frequency, $F_1(1, 31) = 51.1$, $MSE = 1540.62$, $p < .001$, $F_2(1, 78) = 35.27$, $MSE = 3012.14$, $p = .001$. Reading aloud latencies were significantly faster when target words were high frequency words (669ms) than when target words were low frequency words (719ms).

There was no main effect of distractor length $F_1(1, 31) = .008$, $MSE = 913.992$, $p = .92$, $F_2(1, 78) = .024$, $MSE = 729.563$, $p > .05$. The interaction between the two factors was not significant, $F_1(1, 31) = .0168$, $MSE = 454.92$, $p > .05$, $F_2(1, 78) = .374$, $MSE = 273$, $p > .05$.

Accuracy

The Analysis revealed a main effect of target frequency, $F_1(1, 31) = 12.99$, $MSE = .001$, $p < .05$, $F_2(1, 78) = 8.6$, $MSE = .001$, $p < .05$. Neither the distractor length effect nor the interaction between the two factors were significant, $F < 1$. Subjects made fewer errors when targets were high frequency words (1%) than when were low frequency words (3%). Pairwise comparisons via t-test were conducted on the proportion of naming errors of the long and short distractors in each level of the factor target frequency. There were no significant differences, $t < 1$.

Discussion

The results show only a main effect of target frequency – slower reading latencies for low frequency target words (50ms slower than high frequency target words). There was no nonword distractor length effect and no interaction between this factor and target frequency. The absence of a nonword distractor length effect is quite surprising, because whenever we manipulated this variable in the PNWI experiments of this thesis we always obtained a nonword distractor length effect: slower picture naming latencies for pictures paired with

longer nonword distractors.

However, here the target-distractor pairs are both written stimuli: pictures are not involved. This fact led us to 1) reason about the interplay between the two routes, the lexical and the nonlexical one, involved in reading aloud and 2) seek to understand how participants actually perform the WNWI task (i.e. can read aloud the target while suppressing the distractor).

We discuss our results in terms of the model proposed by Mulatti et al. (2014), since that model nicely offers an explanation of their results obtained from four distinct WWI experiments. Briefly, that model combines the features of the MS² model of feature binding (Hayworth, 2009; Hayworth, Lescroart & Biederman, 2011) and the DRC model of reading aloud (Coltheart et al., 2001).

According to the MS² model, when the visual system is presented with two simultaneous written stimuli the features of each stimulus are segregated from the background, dynamically bound together and loaded in two distinct slots (or object files as in Kahneman, Treisman & Gibbs (1992)), one representing the distractor (the stimulus at fixation) and the other one the target (the stimulus that is randomly above or below fixation). All the properties belonging to each of the stimuli (colour, position, etc.) are held in units bound to each of the distinct stimulus slots. At an early stage of processing, the slots correspond to *proto-words*, bundles of the visual features of the written stimuli. Only after a proto-word has been linked to a token (a lexical representation of that word) the WWI task can be performed (see Bowman & Wyble (2007) for the distinction between types and tokens in this context).

Mulatti et al. (2014) proposed that only after a proto-word has been identified (i.e. has reached an identification threshold in the orthographic input lexicon) it can be tokenized; this allows only one lexical entry to be tokenized even though other such entries are simultaneously activated to some degree. Furthermore these authors proposed that when two stimuli are simultaneously presented and form two proto-words, then two distinct letter detector levels are built, each set of letter detectors working independently of the other. In contrast, when a distractor stimulus is not a proto-word (e.g. it is a string of symbols rather than a string of letters), it does not cause the construction of a letter detection set, so the reading system immediately engages with the processing of the target.

Mulatti et al. (2014) also made the following two assumptions:

(a) *Upon presentation of a stimulus under optimal viewing conditions, processing up to the point of identification is ballistic – that is, it cannot be interrupted before that point.*

(b) *Tokenization must follow identification. Once a token has been formed, the system*

knows whether or not a given stimulus is presented at fixation, and thus it knows whether a given stimulus is the distractor or the target.

We argue here that these two assumptions might be revisited, because we need a model that possibly accounts for not only WWI data but also WNWI data, since in our Experiment 1 distractors are nonwords.

At early visual processing stages, distractors will be processed more efficiently than targets and will enter the reading system earlier because they occupy the fixation point – the foveal area is more sensitive than areas peripheral to it.

What happens in the WNWI paradigm might be the following sequence of events:

- 1) Both the stimuli form proto-words;
- 2) Since the system detects two proto-words, it builds two distinct letter detector sets and two sets of letter units that are functionally independent and within which letter processing occurs in parallel across the letter string;
- 3) Because the distractor nonword is foveal, it is processed more efficiently than the target in the first stages of visual processing, so it would trigger the lexical and nonlexical routes before the target does. Since the nonword distractors have no orthographic neighbours, they will not activate entries in the orthographic input lexicon and so, according to the views of Mulatti et al. (2014), identification and tokenization will not happen. However the system needs to know the position of the written stimulus in order to be able to classify it as target stimulus or as distractor stimulus.
- 4) Although our nonword distractors can recruit the nonlexical reading route which would compute their phonology, they cannot be “identified”, because only words can be identified. However, information concerning the position of the letter-strings (i.e. the absolute distractor string position information “at fixation” or the relative target string position information “the lower or the upper string”) may be available before identification. Whether or not the nonlexical route is effectively recruited is an empirical question: the results show no effect of nonword distractor length, which is a pointer for the nonlexical route recruitment (see Experiment 1, Experiment 3, Experiment 4 of Paper 1 of this thesis for its characterization). Two separate possibilities might arise:

(a) The nonlexical route is not recruited because the information on the position is available to the system when the distractor is a proto-word, so it would disregard the nonword on the basis of its position (the stimulus at fixation needs to be

ignored);

(b) Or it might occur that the nonword distractor length effect is absorbed at some stage.

Both of these cases are quite improbable: the former because if information about letter-string position would be available at the stage of proto-words, the system would dispose of the distractor before any activation in the orthographic input lexicon, and yet we know the distractor affects the WWI task. The latter case is improbable because the distractors are always the first stimuli to access the reading system, since they occupy a critical spatial position in the visual field of the participants.

However, in the same experimental session all the distractors were nonwords, and all the nonwords appeared at fixation, so participants might have used a strategy: the first stimulus entering the reading system is the stimulus to be ignored. Thus, after some trials where the nonlexical route has been recruited, the phonology assembled and the stimulus classified as nonword (i.e. as lacking a lexical entry) then distractor stimuli come to be erased from the system on each trial before the phonological assembly is completed. This interruption of the distractor phonological assembly would happen at approximately the same time regardless of the length of the nonword distractors, thus quite early after the phonological assembly started.

The target frequency effect is explained, according to the DRC model, by high frequency words having a higher resting level of the units that represent them in the orthographic and phonological lexicons, compared to low frequency words; this will produce faster naming latencies for high frequency words than for low frequency words.

It is possible though that the model proposed by Mulatti et al. (2014) explains our data as follows: the target word can be identified and then tokenized before the distractor nonword's complete phonology has been computed, regardless of its phonemic length. Concerning the nonword distractors, we are proposing that the nonlexical route is recruited for their phonological assembly and it begins their phonemic computation. Nevertheless, the nonlexical phonological computation will not be completed, only the first or the first couple of leftmost phonemes of the distractor string will be activated in the phonemic system, again regardless of the length of the nonword distractor phoneme strings.

The reading system will tokenize the target word only, binding together its orthographical representation with the corresponding proto-word that holds (among other features information) the information concerning the target relative spatial position. During the identification and tokenization process until the activation of its own phonemes and articulation, the target would never encounter other lexical competitors, since the only activated lexical entry that will be identified belongs to itself. As mentioned above, in the

phoneme system there will be lateral inhibition between the first or first two leftmost phonemes of the nonword distractor activated by the nonlexical route and those instead activated from the lexical route, belonging to the target. The results suggest that long and short distractors would bring to the phoneme system the same amount of lateral inhibition; the distractor phonological assembly is thus blocked at the same time in the process for both the types of distractors, consequently quite early in the reading process.

Alternatively one might suppose that nonword distractors in the WNW paradigm are not computed via the nonlexical route and they are instead blocked by the human reading system before the letters could be subjected to the grapheme-phoneme conversion rules of the nonlexical route. As far as we know, no evidence in the literature supports this view.

In the masked onset priming effect (MOPE) literature the most accredited accounts are the dual route account and the speech planning account (Dimitropoulou, Duñabeitia & Carreiras, 2010). Briefly the MOPE effect refers to faster target naming latencies when the target is preceded by a masked prime that shares the initial phoneme, compared to the condition in which the prime is completely phonologically unrelated – i.e. *take-PEAR* vs. *pole-PEAR*, (Forster & Davis, 1991). Dimitropoulou et al. (2010) manipulated the pronounceability of the nonword primes in Experiment 3 and Experiment 4. Indeed they considered the pronounceability of the nonword primes a critical feature that could help in (a) discriminating between the above-mentioned accounts and in (b) testing each of them. The dual route account (Coltheart et al., 2001; Mousikou, Coltheart, Finkbeiner & Saunders, 2010a; Mousikou et al., 2010b; Mousikou, Coltheart, Saunders & Yen, 2010c) explains the MOPE effect attributing its source in the match/mismatch of the onset orthographic/phonological prime-target overlap, regardless of the pronounceability of the prime. The speech planning account instead ascribes the MOPE effect on the articulatory and motor preparation of the utterance - which is impossible in a case where the prime is a string of consonants, (Kinoshita, 2000; Kinoshita & Woollams, 2002; Kinoshita & Lupker, 2003; Malouf & Kinoshita, 2007). The speech planning account, contrary to the dual route account, predicts the absence of the MOPE effect when target stimuli are preceded by masked unpronounceable primes. Dimitropoulou et al. (2010) reported experimental evidences in support of the speech planning account, i.e. the MOPE effect was absent for consonant string primes but it was reliable for high frequency word primes (the interactive pattern was found, see Experiment 4). All in all, their results suggest that the origin of the MOPE effect is located in the speech preparation process, i.e. Malouf & Kinoshita (2007). According to this account the preparation of the utterance of a word can proceed only after the preparation of its initial phonemic segment. Moreover the critical phoneme segment seems to be the initial

syllabic onset – i.e. the consonant cluster preceding its first vowel.

Beside these aspects of the MOPE effect, we now want to explore and understand the absence of the nonword distractor length effect in the NWN paradigm obtained in our Experiment 1. We investigated in Experiment 2 whether and how the reading system blocks or deactivates the distractors as a function of their pronounceability. We varied the target frequency value (high *vs.* low) and the pronounceability of the nonword distractors (pronounceable *vs.* unpronounceable).

If we obtain an absence of the pronounceability effect when target words are paired with unpronounceable nonword distractors then the speech planning account will find more support, since it posits that when a nonword is unpronounceable the translation from orthography to phonology is rapidly abandoned.

Experiment 2

Method

Participants

33 students of the Università degli Studi di Padova participated in the study as volunteers. They all had normal or corrected-to-normal vision. Participants were all native speakers of Italian.

Design

A 2x2 factorial design with target frequency (high *vs.* low frequency) and nonword distractor pronounceability (pronounceable *vs.* unpronounceable) as within-subject factors was used.

Materials

The same target stimuli selected for Experiment 1 were used here. For each target two pronounceable nonword distractors were built (one pronounceable and one unpronounceable, i.e. a string of consonants). Any phonological overlap between targets and distractors was avoided. Overall, one hundred and sixty nonwords were built as distractors. Context-sensitive graphemes and multi-letter graphemes were avoided, so that the number of the phonemes in each distractor stimulus was also the number of its letters. None of the distractors had any orthographic neighbours. All of them had 7 phonemes. Each target word was presented twice, once with a pronounceable nonword distractor and once with a string of consonants

(unpronounceable nonword distractor). All stimuli were shown in Courier New font, lowercase, bold, 18-point size, and printed in black on a white background. See Appendix 2 for the complete list of stimuli.

Apparatus & Procedure

See Experiment 1.

Results

Naming errors and apparatus failures (7.8%) were removed prior to analysis. Correct RTs were submitted to the Van Selst and Jolicœur (1994) recursive outlier removal procedure, resulting in the elimination of 0.9% trials. Target frequency (high *vs.* low frequency) and nonword distractor pronounceability (pronounceable *vs.* unpronounceable) were both treated as within-subject factors in the by participants ANOVA (F1), whereas in the items ANOVA (F2) target frequency was treated as a between-subjects factor and nonword distractor pronounceability as a within-subject factor. Mean correct RTs and error rates are reported in Table 27.

Target Frequency	Pronounceability of the Nonword Distractor				Difference (RTs)
	Pronounceable		Unpronounceable		
	RTs	E%	RTs	E%	
Low	692	3.3	683	2.5	9
High	662	1.2	643	0.7	19
Difference (RTs)	27		40		

Table 27. Means of RTs and Accuracy (percentages of errors) as a function of Target Frequency and Nonword Distractor Pronounceability factors.

RTs

The analysis revealed a significant main effect of target frequency, $F_1(1, 32) = 48$, $MSE = 37673$, $p < .001$, $F_2(1, 78) = 25$, $MSE = 45900$, $p < .001$. A significant main effect of pronounceability of the nonword distractor was revealed in the analysis by participants $F_1(1, 32) = 6.1$, $MSE = 5734$, $p < .005$, but not in the analysis by items $F_2(1, 78) = .5$, $MSE = 1638$, $p < .05$. The interaction between the two factors was not significant, $F_s < 1$.

Accuracy

The analysis revealed a main effect of target frequency, $F_1(1, 32) = 17$, $MSE = .013$, $p < .001$, $F_2(1, 78) = 18$, $MSE = .016$, $p < .01$. A main effect of pronounceability of the nonword distractor was revealed in the analysis by participants, $F_1(1,$

32) = 5.3, MSE = .001, $p < .05$, but not in the analysis by items $F_2(1, 78) = 3.7$, MSE = .003, $p > .05$. The interaction between the two factors was not significant, $F < 1$. Participants were more accurate in reading aloud high frequency target words (1% errors on average) than low frequency target words (3% errors on average). Participants were also more accurate in reading target words when paired with unpronounceable nonword distractors (1.6% errors on average) than when paired with pronounceable nonword distractors (2.2% errors on average).

Discussion

Experiment 2 shows a main effect of target frequency as in Experiment 1 (significant both in the analysis by subjects and in analysis by items) and a main effect of pronounceability of the nonword distractors (significant in the analysis by subjects only): faster naming latencies and higher naming accuracy for target words when paired with unpronounceable nonword distractors than when the same target words were paired with pronounceable nonword distractors (on average 28ms RT difference and 0.6% accuracy difference between these two conditions). This effect of pronounceability suggests that the null effect of nonword distractor length effect found in Experiment 1 is not due to a rejection of the nonword distractor a priori (at the stage of proto-words or letter identification), since pronounceable nonword distractors do seem to recruit the nonlexical route (if they did not, why would there be any effect of pronounceability?). What we don't know is how much of a pronounceable nonword distractor is processed by the nonlexical route, but it seems quite reasonable it starts the computation of the phonological assembly. Since identification and tokenization only happen for written stimuli that are words, then the range of time in which a nonword can affect the target reading task is determined by the time the target orthographic representation reaches the threshold for identification in the orthographic input lexicon. Once the identification threshold is reached, the system recovers the information about the word position and starts the decay in the activated units belonging to the distractor.

Thus, the effect of pronounceability seems to be an effect of interference due to the recruitment of the nonlexical route on the pronounceable strings. However it could be facilitation. Indeed a string of consonants recruits neither the lexical nor the nonlexical route. This is because it could be classified by the reading system as a not likely readable stimulus since the first early stage of visual processing, when the proto-word is formed (the whole shape of a string of consonants is rare either).

Overall our data seem to strengthen the speech planning account (Malouf & Kinoshita, 2007). This account posits that an utterance, in order to be named, needs to be articulatory

planned. Unpronounceable nonwords cannot be effectively prepared to be pronounced, consequently the human reading system would block the orthographic-phonological recoding, i.e. the nonlexical computation is quickly abandoned.

The human reading system would never identify the nonwords, whatever the condition of the distractor is (pronounceable *vs.* unpronounceable), and the only position information it has concerns the target's relative position only once it has been identified. The target frequency effect is explained congruently as in Experiment 1.

In Experiment 3 we would like to address the issue of the relative dynamics of activation of the orthographic and phonological lexical representations belonging to target-distractor pairs in which both the stimuli are words. We thus manipulated the target frequency value (high *vs.* low) and the onset-phonological relatedness between the target and the distractor (they could share the first two phonemes or not).

Experiment 3

Method

Participants

41 students of the Università degli Studi di Padova participated in the study as volunteers. They all had normal or corrected-to-normal vision. Participants were all native speakers of Italian.

Design

A 2x2 factorial design with target frequency (high *vs.* low frequency) and target-distractor onset phonological relatedness (first two phonemes shared *vs.* no phonological overlap) as within-subject factors was used. As noted above, all targets and also all distractors were words.

Materials

The material we used here is the same used in Experiment 2 of Paper 2 of this thesis. The only difference consist of the fact that the names of the target pictures used in that experiment were used here as target words. See

Appendix 3 for the complete list of stimuli.

See Experiment 1.

Results

Naming errors and apparatus failures (2%) were removed prior to analysis. Correct RTs were submitted to the Van Selst and Jolicoeur (1994) recursive outlier removal procedure, resulting in the elimination of 0.8% trials. Target frequency (high *vs.* low frequency) and target-distractor onset phonological relatedness (first two phonemes shared *vs.* no phonological overlap) were both treated as within-subject factors in the by participants ANOVA (F1), whereas in the items ANOVA (F2) target frequency was treated as a between-subjects factor and target-distractor onset phonological relatedness as a within-subject factor.

Mean correct RTs and error rates are reported in Table 28.

Target Freq.	Target-distractor Phonological Rel.				Difference (RTs)
	Unrelated		Onset related		
	RTs	E%	RTs	E%	
Low	756	3	635	2	121
High	729	3	632	1	97
Difference	27		3		

Table 28. Mean RTs and Accuracy (percentage of errors) as a function of Target Frequency and Target-Distractor Onset Phonological Relatedness.

RTs

The analysis revealed, a main effect of target frequency, $F_1(1, 40) = 9$, $MSE = 9031$, $p < .01$, $F_2(1, 58) = 5$, $MSE = 8019$, $p < .05$, a main effect of onset phonological relatedness $F_1(1, 40) = 50$, $MSE = 483965$, $p < .001$, $F_2(1, 58) = 714$, $MSE = 429962$, $p < .001$, and a significant interaction between these two factors, $F_1(1, 40) = 4.9$, $MSE = 1132$, $p < .05$, $F_2(1, 58) = 6.9$, $MSE = 4189$, $p < .05$. Pairwise comparisons conducted by means of t-tests revealed that the target frequency effect was significant only when the target – distractor pairs were phonologically unrelated, $t_1(40) = -3.2$, $p < .05$, $t_2(58) = -2.9$, $p < .05$.

Accuracy

The only statistically significant effect the analysis revealed was the onset phonological relatedness effect, $F_1(1, 40) = 4.9$, $MSE = 1132$, $p < .05$, $F_2(1, 58) = 6.9$, $MSE = 4189$, $p < .05$. Participants made more errors in reading aloud the target words when they were paired with phonologically unrelated distractor words (accuracy decreased 0.15% on average). Neither the effect of target frequency nor the interaction were found, $F > .05$.

Discussion

The results of Experiment 3 show:

- (a) A main effect of target frequency, congruently with Experiment 1 and Experiment 2;
- (b) A main effect of onset phonological relatedness, faster naming latencies for target paired with onset related distractors (109ms on average faster than phonologically unrelated pairs);
- (c) Interaction: no effect of target frequency for onset related target-distractor pairs.

We will focus on the discussion of (b) and (c) since (a) is explained in the Discussion section of Experiment 1. The onset phonological relatedness effect shows that a distractor word's phonology affects the target-naming task. The presence of the interaction suggests that the target phonological representation gets in touch with the distractor phonology through the feedback and feed-forward connections from the phonological lexicon of output to the phoneme system. However, one might also consider the possibility that it is a suprasegmental effect, involving the implementation of the articulatory gestures that will effectively produce the phonemes belonging to the target.

Concerning the first proposal, and explaining the data with the model proposed by Mulatti et al. (2014), two functionally independent letter-unit layers are built, one for the target word and one for the distractor word. Letter activations unfold in parallel within each set. The distractor word is the first stimulus that activates its lexical entry in the orthographic input lexicon. Until it reaches the identification threshold in the orthographic input lexicon, the distractor word's orthographic representation prevents (through lateral inhibition between entries in the orthographic input lexicon) the rise of activation in all the other orthographic representations (target word included). Once the distractor word has been identified and tokenized, so that information of the position and its identity has been bound together, decay of the activation of its orthographic lexical entry is triggered.

The speed with which a distractor word is identified in the orthographic lexicon is not affected by the frequency of the target, or by whether or not the distractor shares with the target their first two phonemes. Activation of the target word's orthographic representation starts to rise, the word will be identified and tokenized and the activation will continue to feed all the target units, from the letter level to the phoneme system. Since the activation spreads in a cascaded fashion from the orthographic input lexicon to the phoneme system, it might be that the distractor's orthographic representation, having risen to the identification threshold,

has sent activation to its phonological representation in the phonological output lexicon and consequently its phonemes have received a certain amount of activation in the phoneme system. Given that, when the target is identified and tokenized by the reading system, its phonological representation would be facilitated from activation sent as feedback from the phoneme system when the distractor word is onset related to the target word.

The first phonemes of the distractor word, as the first one of the target, word receive activation from both the routes, from the phonological representation of the word activated by the lexical route and from the GPC rule system of the nonlexical route. Since the phonological overlap involves the first two phonemes and the nonlexical route works serially on the string of letters in input, it is likely it contributes to the activation of the phonemic onset of both target and distractor stimuli in both phonologically related or unrelated pairs.

The onset phonological relatedness effect would be explained as facilitation due to the activation the target phonological representation receives from the distractor phonemes already active in phoneme system – note that the distractor phonemes by that time are subjected to decay. However the main effect of phonological relatedness could even be seen as interference for those pairs of stimuli without initial phonological overlap. Indeed, the competition between the activated phonemes for the same position needs to be solved through lateral inhibition, which is absent in case the onset is the same.

The interaction may be explained by postulating that the amount of facilitation due to the target-distractor shared phonological onset overcomes the difference of activation that distinguishes the phonological representation units belonging to targets having a high vs. low frequency value. Or it could even be that since the high frequency target representations possess already a high level of activation, then the extra amount of activation sent from the distractor phonemes cannot significantly further increase the activation level of the target phonological representation. The extra amount of activation would be able to affect instead the phonological representation belonging to low frequency distractors, speeding up the rise of activation and consequently the rise of activation of its own phonemes held in the phoneme system.

It is possible though that the observed phonological-relatedness effect reflects a more peripheral mechanism that is articulatory in nature. Indeed, the articulatory implementation of the vocal gestures might occur very early in the WWI task. Since the distractor word is presented at the fovea, suppose the mouth assumes the configuration for the articulation of the first phoneme/s of the distractor before considering the target articulation. In this case the first two phonemes are identical and the articulatory gesture would be the same, consequently the pronunciation of the target word would occur faster than when the first articulatory gestures

differ from each other between the target distractor pairs. Whether this account could offer an explanation for the observed interaction is an empirical issue that would merit further investigations.

In order to test this account of the onset-relatedness effect it would be worthwhile carrying out a lexical decision experiment with the same variables manipulated here, including nonwords. The response to that task does not need any articulatory process. If one observes the same pattern of results obtained here, then the coarticulation account will be falsified in favour of a more bottom-up explanation.

As the last point of this section it is worth noticing that we replicated the same pattern of results obtained in Experiment 2 of Paper 2 of this thesis. The only difference between the two experiments consists of the paradigm used. In that experiment we used a PWI paradigm, in this Experiment the WWI one. Here the target stimuli are words, in Experiment 2 of Paper 2 they were pictures. Here the distractors could appear above or below the targets, in Experiment 2 of Paper 2 they were overwritten upon the pictures.

Could we offer the same account for both patterns of results?

Notably, picture naming requires access to the semantic system in order to activate the phonological representation of the picture. Reading a word aloud instead accesses phonology from orthography. However if the effects are due to the connections (feed-forward and feedback, excitatory and inhibitory) that link the phonological output lexicon to the phoneme system then, the explanation could be the same. Indeed we explained our PWI results adopting as landmark theory a Semantic version of the DRC model, which Semantic component could be nicely added to the model proposed by Mulatti et al. (2014). However the SEM-DRC model is not able to simulate the PWI human data (it performs an additive pattern *vs.* human interaction).

General Discussion

The aim of this paper is to shed some light on the nonword distractor length effect obtained in all the previous human studies reported in this thesis. We studied this effect through another paradigm (i.e. the WNWI paradigm). Two human studies have been carried out, one manipulating directly the phonemic length of the nonword distractors, the second one manipulating the lexicality (pronounceable *vs.* unpronounceable stimuli) of nonword distractors all equal in phonemic length. Further, the target frequency value was jointly manipulated in both the experiments in order to investigate how the reading system deals with two concomitant stimuli, which recruit mainly two different routes to be read aloud (words

mainly recruit the lexical route *vs.* nonword mainly recruit the nonlexical route). The obtained results allowed us to empirically test and to theoretically improve the implementation of the model proposed by Mulatti et al. (2014).

The third experiment is a WWI experiment and addresses the issue concerning the dynamics of activation of the orthographic and phonological representations corresponding to the target-distractor word pairs. Here we manipulated the target frequency value jointly with the onset phonological relatedness.

Following the most relevant issues this paper arise concerning the vicissitudes of the target-distractor dialog in the WNWI and WWI tasks:

In the WNWI task:

1. The nonlexical route is recruited for the computation of the phonology of pronounceable nonword distractors.
2. The letter-detector sets are built for both unpronounceable and pronounceable nonword distractors, but the nonlexical route is not recruited for the unpronounceable nonword distractors phonological assembly. Unpronounceable nonword distractors seem to be discarded as unlikely stimuli to be read at an early stage of visual stimulus analysis (i.e. after letter identification). Alternatively, as Dimitropoulou et al. (2010) suggested, when a nonword is being translated into articulatory form and the human reading system detects an illegal phoneme sequence (i.e. when the nonword is unpronounceable and constituted by a string of consonant letters) the translation from orthography to phonology is abandoned. This is the speech planning account and our data strengthen this proposal.
3. We argue that nonword distractors are never identified and instead the range of time they can affect the target processing is limited by the time taken to identify the target.
4. We raise the issue of *when* the information about the position of a whole written letter-string in the visual field becomes available to the system. If it is available when the stimulus is still a proto-word, then what is the advantage to further proceed on computing the phonology of the nonword distractor?

In the WWI task:

1. Our data find a possible explanation according to two distinct accounts. One uses the model proposed in Mulatti et al. (2014), and the other the speech planning account (Dimitropoulou et al., 2010). One might seek to adjudicate between the two accounts

by means of lexical decision experiments.

2. One should not lose sight of the possibility that more general cognitive mechanisms like spatial attention, selective attention and strategies might have a prominent role in the various interference tasks we have used.

Conclusions

Here we have taken some further steps towards understanding what mechanisms of the human reading system are involved in the performance of the WWI and WNWI task, and have raised some new questions about how the human reading system concurrently deals with two written stimuli that compete to be read aloud.

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Appendix 1

Target Words	Length of Distractor Words	
	Long (7-8 ph.)	Short (4-5 ph.)
passato	FUBRESI	SUFGI
vita	CUSUNDRE	DUSFE
anno	GERSITE	LURZE
secondo	DOBRISLI	NIVBE
mondo	RUDRISI	RISDI
giorno	IGRIBUPI	VUGRI
lavoro	BRISINTE	SIDRE
presidente	VUNUDRO	RUVPO
momento	FIBEPUMI	DUSVE
punto	LESUZAI	LUFDE
governo	MIROSUVI	UVM I
storia	PACURBI	CEPSE
donna	BETULCRE	NURTE
nessuno	EFULICRI	IZFE
esempio	CESIRTE	IFBE
persone	ZARTUVI	BITSA
padre	FEZUBLO	NIRBI
paese	UVICUTRI	IZVI
politica	CIPUZISO	BULPE
amore	BERIGUTI	USBO
legge	FACUBRI	NIRZU
famiglia	RIMOTADO	NILGO
miliardi	BROSELFE	SIBFA
notte	GAZUMOTI	IFLI
pubblico	DEFIBUNI	DEBFI
centro	SIVUBRA	MIVBI
gente	PORSUVIA	OBUGO
madre	ROGUNFO	ZEFBO
problema	LUVRIFO	VRIU
gruppo	LEVRANTE	VIRFI
strada	MIDELBO	ITVE
ministro	PECUBLE	VREBA
situazione	PUZUDACA	DRIBO
rispetto	BOLSUMA	UPZA
acqua	FEVRESTI	TISVE
successo	ITRASUVE	NAFRI
fronte	SVAMILA	DRUPA
numero	FIDILPIA	BLIPI
giovane	TIMUNTRO	UBNU
consiglio	MIVIBETE	TIMLE

Target Words	Length of Distractor Words	
Low Frequency	Long (7-8 ph.)	Short (4-5 ph.)
moka	BISIDIRO	SDIBO
cameo	LIFRASTI	ITFA
gnomo	FRUSUMPI	SURFI
mirto	PERUSBE	SBUPE
gelso	PRIGOLE	IPIUA
zanna	SURUMETE	PEVRE
acino	FEDUSIME	IBEDI
sesamo	ZIMURTE	IVRE
botola	MUSTIMBO	PUSGO
aratro	ZUPETRI	SRUPE
papaia	VABUSELE	UBTE
fachiro	PESULBRE	PURME
meringa	DUMESUVE	UZVE
sequoia	PEDRIME	IVTE
cappero	TALIBRE	IDPI
grondaia	NISEBIVE	VIRBE
estuario	CAVINUTA	NITCA
girasole	BRUSTOVA	SFEBI
tentacolo	LIPIVUDI	NOFDI
cornamusa	BORCUSO	SUCU
acquarello	RIFIBUFI	IFBI
gobba	SICETUGI	ICTE
tetano	MUGISBRI	EPZI
fiordo	PIBLESE	PLEVI
samurai	FUCEBLO	BLEME
grattugia	LOTROFIE	ADZE
damigiana	TUBALDRI	NUPDO
arpa	FUGEMISO	ILSVO
amido	RIMELDA	FNIVI
frutteto	NUMIRAZA	RUZMI
marionetta	BIROLUFE	GUDBO
tufo	SLABEVRE	LIVNI
cloro	MABRETA	ZUVUA
dazio	CLERUVE	ZURME
fobia	GUSPOBLO	MEBRE
cavia	BRONOFLE	GIFSO
liuto	GARMEDE	VREFA
spilla	DEPUZICO	UBLE
zaffiro	CLEMUSTE	PUDCA
sandalo	TIBISUNE	FRUVI

Appendix 2

Target Words	Pronounceability of Distractor Words	
High Frequency	Pronounceable	Unpronounceable
passato	FUBRESI	NCBZFDL
vita	CUSUDRE	NCFDZBP
anno	GERSITE	CFZPBDT
secondo	DOBRISI	BFZPTFR
mondo	RUDRISI	TPCZFBV
giorno	SEVUMPE	SZMTPVP
lavoro	SIMBITE	NVPTMZS
presidente	VUNUDRO	MLZVRBG
momento	FIBAPRA	RPZSVTS
punto	LESUZAI	MVSZRGF
governo	MIRUSVI	TSPDBFC
storia	PACURBI	QBPGDF
donna	BETICRE	FGVSPBR
nessuno	FALICRI	QDFPVBG
esempio	CESIRTE	GBVFDQL
persone	ZARTUVI	LTZVBDC
padre	FEZUBLO	BLNCZST
paese	UVICUTI	LTVDZBC
politica	VRENUSE	ZDBVMSR
amore	BIRGUTI	GQSVFCT
legge	FACUBRI	TCFVSQM
famiglia	RIMODEO	STCVQPB
miliardi	BOSELFE	GCSVTQF
notte	FADISTI	FQVMSCG
pubblico	DEFABRE	NDVZTLM
centro	SIVUBRA	SZPLDBG
gente	DIBROFA	BLPSDZR
madre	ROGUNFO	ZNSLPBF
problema	LUVRIFO	NSDQVCZ
gruppo	VRALETE	ZLDMSNB
strada	MIDELBO	MCNBGFP
ministro	PECUBLE	PVFCLDZ
situazione	PUZUCRA	MDRCVPL
rispetto	BOLSUMA	PDCNFMV
acqua	FEVRETI	TNSDRFP
successo	SAVRITA	MRTPFZL
fronte	SVAMILA	LQBDPSG
numero	FIDIPIA	SDPBTQL
giovane	TIMUTRO	TLDPQSR
consiglio	VEBRAME	RBPTQDM

Target Words	Pronounceability of Distractor Words	
	Pronounceable	Unpronounceable
moka	SIBEDRI	PBTSRQL
cameo	LIFASTI	RTPFSGB
gnomo	FRUSUPI	BVCPFDS
mirto	PERUSB	DFZBCPN
gelso	PRIGOLE	PDNTCMR
zanna	ZURTOME	RVTSMPD
acino	FEDUSME	QFBDPGS
sesamo	ZIMURTE	VPLBTDZ
botola	MITUMBE	GQVCFSM
aratro	ZUPETRI	CBZPDVL
papaia	VOBUSLE	LMDGBST
fachiro	PESUBRE	VDTSPZG
meringa	DOMULVO	CNDSTCV
sequoia	PEDRIME	MRTNPLF
cappero	TALIBRE	FGTLDV
grondaia	NISEBLE	QPFMPTS
estuario	CAVINUA	PLDVMQN
girasole	BUSTOVA	VTDFNCM
tentacolo	PLIVUDI	FPRQMZD
cornamusa	BORCUSO	SDFGPLV
acquarello	FIBUNTI	MFGTND
gobba	SIPIFRE	NPLTSZM
tetano	MUGIBRI	BVCFSDR
fiordo	PIBLESE	SZVBNPL
samurai	FUCEBLO	BLDNTPV
grattugia	LOTROFE	LBDFMSN
damigiana	TUBALDO	BPLSRTV
arpa	GEFUSCO	NSBLFGQ
amido	RIMELDA	LFBVRPN
frutteto	NIMIRSA	GDPBMVP
marionetta	BIRLUFE	DPVFGSQ
tufo	SLABIVE	SGLMDPC
cloro	MABRETA	DQPBNSF
dazio	CLERUVE	RSTPMLB
fobia	GUPOBLO	NRLDPSZ
cavia	BRONOF	ZSDBRFQ
liuto	GARMEDE	FPMRDNS
spilla	DEPUCRO	GBRDZQV
zaffiro	CLEMURE	TQSDNLM
sandalo	TIBISNE	TFRBQCV

Appendix 3

The target-distractor phonological relatedness concerns the first two phonemes.

Target Words	Distractor Words	
	Phonological Related	Phonological Unrelated
mela	metallo	siringa
letto	lenticchia	frangia
stivale	starnuto	poltrona
bottiglia	bovino	mutande
ponte	posata	crema
cammello	canzone	fagioli
castello	caviglia	pancia
gatto	gasolio	bottono
chiesa	chitarra	triciclo
corona	cofano	trottola
tazza	taverna	mattone
scrivania	scultura	coperchio
cane	carriola	treccia
elefante	elastico	balcone
pesce	pensiero	fazzoletto
fiore	fischio	pigiama
mosca	mollica	tamburo
cappello	calamita	forbice
cavallo	calcolo	funghi
re	restauro	cemento
foglia	fontana	cotone
leone	lenzuolo	zattera
montagna	morso	trave
squalo	squotere	lucchetto
scarpa	scorza	moneta
gonna	gomito	trapano
tenda	tempesta	resina
cravatta	croce	dente
albero	altare	sasso
orologio	orma	bilancia

Target Words	Distractor Words	
Low Frequency	Phonological Related	Phonological Unrelated
banana	barca	farfalla
fiocco	fiaba	bastone
carota	capanna	nuvola
pagliaccio	pavone	grembiule
pettine	penisola	coperta
pipa	pillola	sgabello
asino	asola	portico
anatra	anulare	conchiglia
volpe	vortice	parrucca
rana	rasoio	petalo
guanto	guscio	bomba
aquilone	aquila	serratura
topo	torrone	freno
gufo	gusto	loggia
pera	pennello	strofa
coniglio	collisione	mansarda
razzo	raviolo	costata
sega	sentimento	tranello
sciarpa	sconti	maniglia
dondolo	dollaro	edera
scivolo	scoppio	cresta
fionda	fiamma	sapone
lumaca	lusso	soffitto
calzino	candela	racchetta
altalena	alettone	tenaglia
tigre	timone	stufa
pomodoro	postino	raggio
ombrello	omelia	bicchiere
granchio	granita	nocciolo
cerniera	cetriolo	arancia

General Discussion & Conclusions

Overall we reported three papers concerning the effects of concomitant distractors on naming pictures and reading words. In all the experiments reported we asked participants to give a response in a dual-task situation. The overt task was naming a picture or reading words aloud and the covert task was disregarding written distractor stimuli. Computational simulations were also carried out in order to (a) test the semantic version of the DRC model against the behavioural data and (b) better understand our behavioural results.

In paper 1 the main issues addressed were the effect of the phonemic length of nonword distractors in picture naming and the dynamics involved when phonological relatedness is varied between the target and distractor strings, and how this effect is modulated by the position the shared phonemes occupy in the target and distractor strings. The last experiment represents the first attempt in the psycholinguistic literature to discriminate the role of the phonemic length variable from the role of syllabic length variable in the PNWI effect. Notably, in PWI or PNWI paradigms the name of the picture is not visually available but it has to be retrieved. The first paper consists of five experimental investigations. DRC-SEM simulations follow the behavioural results.

Experiment 1 studied nonword distractor length. Pictures were paired with nonwords of different phonemic length (4-5 phonemes *vs.* 7-8 phonemes). The results showed that target pictures were named faster when presented with short distractors than when presented with long distractors. The strength of the competition from a distractor nonword will vary across the position of the string because of the serial functioning of the nonlexical route involved in the phonological assembly of the nonword distractors. The strongest competition between the two candidate phonemes would be in the first phoneme position, decreasing along the string, from left to right. The number of phonemes in the picture names was not controlled (it varied between 4 and 9 phonemes), so there will be more phonemes of the picture name receiving no interference from the distractor phonemes in the short distractor condition than in the long distractor condition.

From the previous point it follows that the more phonemes a target picture has, the greater the distractor length effect would be. Indeed pictures names with 4-phonemes would not show a distractor length effect because the amount of the interference from a 4-phoneme nonword distractor is the same as that from a longer distractor. That is, all four of the target phonemes are inhibited by the distractor's phonemes regardless of the length of the nonword distractors (long distractors *vs.* short distractors).

In contrast, for pictures with long names a higher proportion of their phonemes will receive competition from the distractor when the distractor is long than when it is short. Following this reasoning one could expect an interaction between target length and nonword distractor length.

We investigated this reasoning with a post-hoc analysis of the behavioural data collected for Experiment 1. We did this by dividing the targets into two groups on the basis of phonemic length: short pictures were those having 4,5 or 6 phonemes and long pictures those having 7, 8 or 9 phonemes. The phonemes constituting the picture name were counted according the relationship rules between letters and sounds in Italian (Lepsky & Lepsky, 1981; Job, Peressotti & Mulatti, 2006). There was a distractor length effect, no target length effect and critically, the predicted interaction between the two factors was not observed.

In the corresponding simulation of Experiment 1 long nonword distractors (7 phonemes) and short nonword distractors (4 phonemes) were paired with target pictures with 6 phonemes on average. Long distractors interfered more than short distractors in terms of the number of cycles the model required to name the target picture. That is, the DRC-SEM model simulates the nonword distractor length effect reported in first analysis carried out in experiment 1.

One of the advantages the computational modelling approach offers is that it allows the modeller to identify the exact source of any effect produced by the model. So we can ask where the nonword distractor length effect arises in the model. We find that when the distractor is long, the phonological target representation held in the phonological output buffer always has a lower activation level than when it is paired with a short nonword distractor. This is because a long nonword distractor, compared to a short nonword distractor, sends more inhibition to the target's phonological representation via the inhibitory connection that link the phoneme system to the phonological output lexicon.

Also, when we look specifically at the activations in the model's phoneme system, we see that the first phoneme of the target phonemic string is always the last phoneme of that string to reach the naming threshold (the model's reading or naming latency is determined by when the last of the target phonemes reaches the naming threshold).

If the model is tested on reading aloud or picture naming with no distractors present, all of the target word and target picture phonemes reach the naming threshold at the same time. This is because written words and picture stimuli are read or named via the lexical or lexical-semantic route that works in parallel across the phonemic length of the string active in the phoneme system.

If the model is tested in the PNWI paradigm instead, the first phoneme of the target is

the last to reach the naming threshold because in this experimental condition two sets of phonemes are activated in the phoneme system, but the phoneme system must ultimately produce only one phoneme string (the target's phonemes) as a response. The computational mechanism and principle that allows this convergence on the correct phonemes is lateral inhibition between competing phonemes.

In the model, the first phoneme to be activated in the phoneme system whenever a picture-distractor pair is presented is the first (leftmost) phoneme of the nonword distractor string. This is because the nonlexical reading route is faster than the lexical-semantic reading route to initially reach the phoneme level (but only for the earlier phonemes).

Once the first phoneme of the distractor reaches a certain amount of activation, the second leftmost phoneme will be activated in the phoneme system and so on. There will be graded activation that will be highest for the leftmost phoneme of the distractor stimulus and will gradually decrease to the rightmost distractor phoneme. The target phonemes are instead activated in parallel. How strong the competition between phonemes competing for the same phoneme slot in the output phoneme string will be is thus determined by the nonlexical computation, with the strongest competition being at the first phoneme position and the weakest at the last. Once activation of the first phoneme belonging to the target reaches and then passes the activation level of the first nonword distractor phonemes, the target phonological representation exhibits an exponential rate of activation. This event occurs earlier in model processing time when the nonword distractors are short than when they are long. In sum, then, the first phoneme of the target picture name receives stronger lateral inhibition from the corresponding phoneme of the distractor than is the case for other target phonemes, and the later a phoneme is in the target picture name the weaker will be its competition from the corresponding distractor phoneme.

In a PNWI task, manipulating both the length of the picture name and the length of the nonword distractors, the model's account here predicts an interaction between these two factors. However, in the post-hoc analysis of the human data of Experiment 1, there was no such interaction, a result inconsistent with the model, even though the model did provide an appealing account of the nonword distractor length effect in terms of the serial functioning of the nonlexical route. This predicted interaction and its absence in the experiment represented the first incongruence between the model's performance and behavioural data. The interaction took the form of longer naming latencies for long targets paired with long nonword distractors compared to the other three conditions (1) short targets/short nonword distractors; (2) short targets/long nonword distractors; (3) long targets/short nonword distractors. The final phonemes of long distractors cannot have any effect on model latencies when targets are

short. The determining factor of the model interaction seems to be the length of the targets. Only when targets are sufficient long there is a nonword distractor length effect. The obtained pattern shows how the model is sensitive to the effective number of phonemic slots involved in lateral competition in the phoneme system.

Experiment 2 explored the effect of onset phonological relatedness between the target and the nonword distractor pairs and how this effect can modulate the nonword distractor length effect previously obtained in Experiment 1. The dynamics of activation and inhibition between the target phonological representation, the target phonemes and the nonword distractor phonemes were also studied.

The human data showed a main effect of onset phonological facilitation but no main effect of nonword distractor length: instead the two factors in the experiment interacted, - for onset phonological related pairs there was no trace of nonword distractor length effect but when instead the pairs were phonologically unrelated the nonword length effect was reliable (27ms).

The REH account (Finkbeiner & Caramazza, 2006b, a; Mahon et al., 2007) cannot explain the interaction reported in the behavioural data of our Experiment 2 (and see Mulatti & Coltheart (2012); Starreveld, La Heij & Verdonchot (2013) for further discussion of the inappropriateness of the REH). Our results suggest that two of the principles of the REH are incorrect: (a) the phonological response buffer is not completely purged of the nonword phoneme string by the time the picture phonological representation reaches that buffer, and (b) the buffer can hold two phonological representations at the same time.

The aim of Experiment 3 and Experiment 4 was to further clarify the phonological/phonemic dynamics between the target phonological representation and the operation of the nonlexical route on the nonword distractor string. In Experiment 3 we studied how the end phonological relatedness variable could modulate the nonword distractor length effect. Nonword distractors were long (7 phonemes) or short (4 phonemes), and they either shared the last two phonemes with the picture name or were completely phonologically unrelated.

In this experiment there was an end facilitation phonological relatedness effect, a nonword distractor length effect, and an additive pattern between these two main effects. These results constitute a further falsification of the REH account because as mentioned before the REH posits that none of the features of the distractor could affect the target naming latencies. The human reading and speech production systems allow instead interaction and interplay/exchange of the information these systems possess belonging to the target picture and the written nonword distractor.

In Experiment 3 there were target-distractor pairs in which target and distractor differed in number of phonemes, so when target and distractor shared end phonemes these shared phonemes often occupied different absolute positions; and yet there was still end-related facilitation. This is the first evidence we obtained against any model in which phoneme positions are coded in terms of absolute position.

Experiment 4 was designed to further study whether there is any effect of the position of the shared phonemes. Target pictures were paired with onset phonological related distractors, end related distractors, or completely unrelated distractors. In contrast to previous experiments, the length of distractors in this experiment was kept constant (7 phonemes for all the three distractor conditions). Nonword distractor length was very similar on average to the phonemic length of the targets (6.3 phonemes).

There was an onset phonological relatedness effect (as also found in Experiment 2) and an end phonological relatedness effect (as also found in Experiment 3). Furthermore, the phonological relatedness effect was smaller in size when it involves the last two phonemes of the target-distractor strings than when it involves the first two phonemes of the target-distractor string. The final target-distractor phonological relatedness found in Experiment 3 was smaller in size compared to the onset phonological relatedness found in Experiment 2.

We explain this recurring result – a graded position-dependent phonological facilitatory effect – by referring to the serial functioning of the nonlexical route. According to the DRC-SEM logic, the earlier (from left to right) the shared phonemes are the higher the level of activation they will send to the target phonemes. This advantage for the initial phonemes is due to the fact that they have more time and thus a greater number of cycles in which they can send activation to (a) the target phonemes, (b) to the target phonological representation held in the phonological output lexicon. As long as the activation sent from the distractor phonemes to the target phonemes changes as a function of the position the shared phonemes occupy in the nonword distractor string (the more right the less the activation sent), the activation sent from the shared distractor phonemes to the target phonological representation held in the phonological output lexicon is the same regardless of the position the shared distractor phonemes. Whereas (a) can explain the graded phonological facilitatory effect position dependent, (b) can explain the additive effect between the nonword distractor length effect and the end phonological relatedness. However this additivity cannot be ascribed to (a).

Paper 1 also reported the results of running the respective DRC-SEM simulations of Experiment 2, Experiment 3 and Experiment 4.

In both the behavioural results of Experiment 2 and their simulation, there was an

interaction between the onset relatedness effect and the nonword distractor length. However, whereas humans showed a nonword distractor length effect only for pictures paired with unrelated nonword distractors, and the fastest picture naming latencies were for pictures paired with onset-related nonword distractors – regardless of their phonemic length – the DRC-SEM's results showed a different pattern of interaction. In the model the size of the nonword distractor length effect was greater for the onset-phonological related pairs of stimuli than for the phonologically unrelated ones.

This incongruence between the interactive patterns observed for humans and DRC-SEM happens because of the way the nonlexical route interacts with the lexical-semantic route in the model, namely, when distractors are short and onset related the facilitation of the target phonological representation by the shared phonemes is maximal because the nonword phonological computation is relatively complete by the time the target phonemes are reaching the naming threshold. When instead the nonword distractor is long the facilitation can be absorbed partially during the time required for the phonological assembly to proceed till the end of the string, so that target phonemes can reach the naming threshold before this assembly can be fully completed.

In Experiment 3 and Experiment 4 there was end-related facilitation even though in this condition the overlapping phonemes did not always occupy the same absolute position in distractor and target. DRC-SEM uses an absolute position coding scheme at the phoneme level, so we would not expect any end-related facilitation if targets and distractors have different phonemic length.

The human data of experiment 3 showed additive effects of end-relatedness and distractor length whereas DRC-SEM showed an interaction; the end-relatedness effect is reliable in the long distractor condition only. Since the last two phonemes of the short distractors occupy different absolute positions in picture name and distractor string, in the end-phonological related condition they are treated by the model as phonemes that will inhibit the shared target phonemes rather than facilitating them. The model cannot identify the last two shared phonemes of the distractors as the same last two phonemes of the picture and so they cannot prime the target phonemes. This simulation revealed the capability of the human reading system to keep track of the shared phonemes between the picture and the nonword distractor even when they do not occupy the same absolute position in the string they belong to.

From the comparison between Experiment 4 and Simulation 5 one perfectly congruent pattern emerges. The DRC-SEM model exhibits the graded phonological facilitatory position-dependent effect that the human data shows, Explaining why SEM-DRC successfully

simulates the human data of Experiment 4 is straightforward: the gradation of the facilitatory effect due to the position that the shared phonemes occupy in the nonword distractor string occurs because the nonlexical route activates the leftmost phoneme first, and continues on assembling the nonword phoneme string from left to right. As a result, the more the phoneme is to the left on the nonword string, the higher is its level of activation and consequently, the greater is the effect it can exert on the target-shared phoneme. Since the positions we tested in Experiment 4 were the ones at the extremes of the string (first two phonemes *vs.* last two phonemes), we captured the maximum position-dependent effect possible, assuming the nonlexical route operates serially from left to right.

Finally Experiment 5 in paper 1 was carried out in order to disambiguate the role of possible variables contributing in the nonword length effect we found several times. The aim of this experiment was to discriminate between phonemic length and syllabic length of the nonword distractor as the critical variable responsible of the nonword length effect we consistently found. This is because the DRC-SEM model lacks any syllabification process so any effect due to syllabic nonword length variable cannot be simulated. The number of phonemes and the number of syllables are highly correlated in printed words or nonwords, but can be at least partly independently manipulated. We jointly manipulated the number of phonemes keeping constant the syllable number (3 syllables, 6 *vs.* 7 *vs.* 8 phonemes) and the number of the constituent syllables keeping constant the phoneme number (7 phonemes, 2 *vs.* 3 *vs.* 4 syllables).

The results did not help discriminate these roles, because no nonword distractor length effect was found. A syllabic target length effect was instead revealed, controlling the number of constituent phonemes in the picture's name. All of the pictures had 8 phonemes but 3 or 4 syllables and we obtained longer naming latencies for 4-syllables target pictures. This is the first study in the picture naming literature reporting a target syllabic length effect in the PNWI paradigm. Questions arising from the results of this experiment include (1) How are pronounceable nonword distractor syllabified? (2) Is there a shared syllabification process between pictures, words and nonwords and if so how does it work? (3) In particular is it at a post-phonemic level, *i.e.* prior to the level of articulation?

Paper 2 of the thesis explored some questions left open by the behavioural and computational studies reported in Paper 1. These were:

- a. How is the nonword distractor length effect to be explained?
- b. How does the semantic-lexical pathway activate the phonology of the picture name concurrently with the activation of the phonology of the nonword distractor?
- c. What is the stage of this process that is involved in the competition or interference

with the phonological nonword distractor representation?

- d. Where is the locus of the facilitation due to the picture-distractor phonological overlap?

We addressed these questions via two experiments, a PNWI experiment and a PWI experiment, in both cases comparing behavioural data with DRC-SEM simulations.

In experiment 1 we obtained additive effects of target frequency, end phonological target-distractor relatedness and nonword distractor length. Analysis 2 of Experiment 1 showed that the facilitation due to phonological end-overlap is not modulated by the absolute position the phonemes occupy in the distractor and picture strings. The final shared phonemes could occupy the same absolute position in distractor and target, or could occur earlier in the distractor than in the target or could occur later in the distractor than in the target. The size of facilitation of picture naming latencies was the same in these three conditions. Comparison of human data obtained in experiment 1 (paper 2) to the respective simulation 1 (paper 2) implies that DRC-SEM's absolute position scheme is not an accurate representation of how phoneme position is coded in the human speech production and reading systems. In the model there was no effect of end-phonological relatedness between pictures and nonword distractors. The only way the model can show an end-relatedness effect in PNWI is when the final shared phonemes occupy the same absolute positions in the target and in the distractor (see experiment 4 and simulation 3 in paper 1 for further support on this view).

Experiment 2 of Paper 2 represents the only picture interference experiment where words were used instead of nonwords as distractors. An interaction was found between target frequency effect and onset target-distractor phonological relatedness effect, as well as the two main effects. The target frequency effect was reliable for the unrelated picture-word pairs but absent for the onset-phonological related pairs. The respective DRC-SEM simulation (simulation 2 in paper 2) showed the two main effects - congruently with human data - but an additive pattern between onset-phonological relatedness and target frequency effects such that the frequency effect was the same size in the onset-related and unrelated conditions. This discrepancy could be traced back to the set of parameters we used to simulate the PWI task (see paper 2, page. 123). When the distractor is a word its representation in the phoneme system is activated much faster than when a distractor is a nonword. In the former case the lexical-semantic route has to deal with (a) two phonological representations being activated in the phonological output lexicon and (b) the respective phonemes of the target-distractor phonological representations being activated in the phoneme system. However, what this discrepancy generally suggests is that the reading and speech production systems humans possess are much more flexible than the DRC-SEM model, in which picture target frequency

and picture-word onset-phonological relatedness seem to exert their effect at different stages of the model or independently modulate the same stage.

In paper 3 we aimed (a) to explore further the nature of the nonword length effect obtained in the PNWI task in the previous papers and (b) to explore the relationship between the factors of target frequency and target-distractor onset-phonological relatedness. We did this by means of two WNWI experiments that aimed at (a) and a WWI experiment that aimed at (b). In these tasks the target stimuli are words, rather than pictures as in the previous PNWI and PWI paradigms used in paper 1 and paper 2. The WWI paradigm has been previously used by La Heij et al. (1990). The primary task is reading aloud the target word ignoring the written distractor (nonword distractors were used in experiment 1 and experiment 2, paper 3; word distractors were used in experiment 3, paper 3). In all the three experiments reported in paper 3 the target frequency variable was manipulated (high frequency *vs.* low frequency value of target words).

Experiment 1 aimed to explore the source of the nonword length effect, manipulating the interaction between the nonlexical route and the lexical route by varying the target word's frequency. Only a main effect of target frequency was found: slower reading latencies for low frequency target words. The nonword distractor length effect was absent. We discuss the absence of the nonword length effect by referring to Mulatti et al. (2014)'s model (a description of this model is offered in the discussion section of experiment 1, paper 3). According to this model, the absence of the nonword distractor length effect occurs because the target word can be identified and tokenized before the distractor phonology has been completely assembled in the phoneme system, regardless of the distractor's phonemic length. Our results suggest that long and short distractors bring to the phoneme system the same amount of lateral inhibition.

Experiment 2 aimed to better understand the absence of the nonword length effect reported in experiment 1, paper 3. Target frequency and nonword distractor pronounceability (pronounceable *vs.* unpronounceable nonword distractors) were orthogonally varied. Consistent with experiment 1, a target frequency effect was found. A main effect of pronounceability of nonword distractors was also found: target naming latencies were shorter for target words paired with unpronounceable nonword distractors. This latter effect strongly suggests that the nonword distractors in experiment 1 were not rejected a priori i.e. not at the stage of proto-words or letter identification in Mulatti et al. (2014)'s model. The pronounceability effect found in experiment 2 speaks in favour of the nonlexical computation on the nonword pronounceable distractors, computation that was recruited in experiment 1 too, even if the nonword distractor length effect was hidden by the speed with which target

word phonology was activated and prepared for reading aloud. The results reported in experiment 2, paper 3, give strength to the speech planning account (Dimitropoulou et al., 2010) which posits that an utterance in order to be produced needs to be articulatorily planned: the nonlexical computation of unpronounceable nonwords would be abandoned because such stimuli cannot be effectively prepared to be pronounced.

Experiment 3 addressed the issue of the relative dynamics of activation of the orthographic and phonological lexical representation belonging to target-distractor word pairs. A parallelism can be found in experiment 2 reported in paper 2, in which the same experimental manipulation was carried out, but targets were pictures instead of words. This aspect constitutes the only difference between that experiment and experiment 3 of paper 3. Target frequency was jointly manipulated with onset-phonological relatedness between target-distractor pairs (the first two phonemes of target words and distractor words could be shared or phonologically unrelated). Behavioural data showed (a) a target frequency effect (congruently with experiment 1 and experiment 2, paper 3), (b) an onset-phonological relatedness effect and (c) an interaction between target frequency and onset-phonological relatedness variables: no effect of target frequency for onset related target-distractor pairs. Overall these results are congruent with the pattern of results obtained in experiment 2, paper 2 where the PWI paradigm was used.

According to Mulatti et al. (2014)'s account, the distractor would enter to the system first and it would be identified and tokenized. Once the distractor is tokenized information about its position became available to the system, consequently it would be rejected as the correct response for the primary task (read the target word, not the distractor). From this point on all of the distractor's active representations (from its letters to its phonemes) are subjected to gradual decay. The target stimulus consequently would be identified and tokenized and what the interaction and the phonological relatedness effects suggest is that the target phonemes benefit via the activity of the feedback connections from the initial distractor phonemes in the phoneme system to the target phonological representation in the phonological output lexicon. This benefit is totally evident for low-frequency targets, whereas high frequency targets might not be able to benefit as much from receiving an extra amount of activation since their phonological representations are already highly activated because of the high frequency value.

A DRC-SEM simulation of the PWI experiment involving the same variables of the experiment we are discussing here failed to show the interaction, showing an additive pattern instead (simulation 2 and experiment 2, paper 2). This might perhaps be because with human readers the articulatory gestures for targets paired with onset related distractors would benefit

by the configuration of the mouth being prepared for the articulation of the distractor's initial phoneme, before the target can be considered by the system. One way to test this account would be to study the same variables in a lexical decision experiment, where the required response does not require any articulatory motor program preparation.

The main effect of onset relatedness instead can be explained a) as facilitation due to the activation the target phonological representation receives from the distractor phonemes already active in the phoneme system or b) as interference for those pairs of stimuli without initial phonological overlap since in this phonological unrelated condition the lateral inhibition would need to be solved in the first two slots of the target phonemes. A third explanation of the onset relatedness effect is offered by the speech planning account (Dimitropoulou et al., 2010) that postulates the onset phonological relatedness effect reflects a peripheral mechanism operating at the articulatory gesture planning stage.

All in all we have shown how in the PNWI paradigm (Paper 1 and Paper 2 of the thesis) specific features of nonword distractors modulate picture naming latencies and how the DRC-SEM model succeeds in simulating some of the behavioural effects and fails to simulate others:

1. Long distractors interfere more than short ones (experiment 1, experiment 3 in Paper 1; experiment 1, in paper 2). DRC-SEM succeeds in simulating this effect.
2. Phonologically-related target-distractor pairs (onset/end related) interfere less than phonological unrelated target-distractor pairs (experiment 2, experiment 3, experiment 4 in paper 1; experiment 1, experiment 2 in paper 2). DRC-SEM simulates these effects only when there is a perfect match between the *absolute* positions the shared phonemes occupy in the target and distractor strings.
3. Onset-phonological relatedness interacts with distractor length (experiment 2 in paper 1). DRC-SEM successfully simulates this effect.
4. There is an end-phonological relatedness effect and it does not interact with distractor length (experiment 3 in paper 1; experiment 1 in paper 2). DRC-SEM failed to simulate these findings: the model showed an interaction between these two factors (simulation 4 in paper 1) and showed no end-relatedness effect when target frequency and nonword length were orthogonally manipulated (simulation 1 in paper 2).
5. There is a graded position-dependent phonological facilitatory effect (experiment 4 in paper 1): when the length of the nonword distractors is kept constant and the position of the shared phonemes is varied (i.e. onset *vs.* end *vs.* unrelated controls) the size of the phonological facilitation effect varies across the position of the string. The size of the effect is largest when the target-distractor phonological relatedness involves the

first two phonemes of the strings. DRC-SEM successfully simulates this effect (simulation 5 in paper 1).

6. The facilitation due to phonological end-overlap was not modulated by the absolute position that the phonemes occupy in both the strings and this happened both for short and for long nonword distractors (analysis 2 of Experiment 1 in Paper 2). This supports our proposal in Paper 1 that the phonemic system is characterized by a relative position-coding scheme, unlike in the DRC-SEM model where the position-coding scheme for phonemes is absolute.
7. The nonword distractor phonemic length effect does not interact with picture target frequency or with end-phonological relatedness (experiment 1 in paper 2). The DRC-SEM model failed to simulate the end-relatedness effect; on the contrary, it showed an interaction between target picture frequency and nonword distractor length (a smaller target frequency effect for pictures paired with long nonword distractors and a smaller distractor length effect for low frequency targets).

We were not able to decide whether the nonword distractor length effect was due to phonemic length or syllabic length. Experiment 5 in paper 1 was designed to address this issue but yielded a target length effect only: slower picture naming latencies for four syllables target pictures than for three syllables target pictures.

The results obtained from experiment 5 speak against a decomposition of the nonword distractor in syllabic units since we failed to show any effect on picture naming latencies of the syllabic length of the nonword distractors. However, it might be possible that 1) the nonword syllabic decomposition was hidden by the target syllabic decomposition, since we obtained a target syllabic length effect, and/or 2) the used nonword stimuli were composed by very complex and rare letter clusters, consequently the complexity of the orthographic cluster and the frequency of the syllable might have played a concomitant role hiding a possible syllable length effect (see Stenneken, Conrad & Jacobs (2007) for independent role of number of syllabic processing and orthographical processing). On the other hand our results failed to show even a nonword phonemic length effect maintaining constant the syllabic length. It seems the nonword distractors were simply ignored; it remains unclear and an open question whether their phonology was nonlexical computed and/or they syllabic information taken into consideration for naming. Participants might have used an ad-hoc inhibition-distractor strategy considering the complexity and rarity features composing the nonword stimuli, both orthographically and phonologically. As previously mentioned we did obtain a syllabic length effect for the target pictures; we thus believe that a syllabification process should be included

in any model of picture naming although the syllabic length effect in picture naming task is not well established in the literature - e.g. Santiago et al. (2000); Roelofs (2002b); Santiago et al. (2002) – furthermore, in all these mentioned studies the simultaneous control of phonemic length of the picture label was missing.

Concerning paper 3 which uses the WNWI and the WWI paradigms and comparing the two experiments of this thesis which address the same questions but with different paradigms (i.e. PWI, Experiment 2, Paper 2 and WWI, experiment 3, paper 3), we found that:

1. Pronounceable nonword distractors interfere more than unpronounceable nonword distractors (Experiment 2 in Paper 3), although the length of the pronounceable nonword distractors did not affect word reading latencies (Experiment 1 in Paper 3). This is the first discrepancy between the WNWI and PNWI paradigms. Whenever phonemic length was manipulated in the experiments, picture naming latencies were always affected by distractor nonword length, apart from Experiment 2 in paper 1 where an interaction between distractor length and onset phonological relatedness was obtained. However we cannot conclude that the pronounceability effect is due to the phonological assembly of the pronounceable nonword string carried out by the nonlexical route. This is because in paper 1 we failed to find a clear distinction between the syllable length effect and the phonemic length effect. Indeed in Experiment 5 we failed to observe a distractor length effect. The nonword distractor pronounceability effect might be due to a syllabification process but we are instead inclined to suggest that the source of this effect is at an earlier stage, at the phonemic stage, as our data all in all suggest.
2. Comparing the two experiments studying the effects of picture target frequency and onset phonological relatedness, indicates a congruent pattern of results: (a) faster naming latencies for high frequency targets, (b) faster naming latencies for onset related target-distractor pairs, (c) interaction between these two factors: there was no target frequency effect in the phonological target-distractor related pairs (experiment 2 in paper 2 and experiment 3 in paper 3). DRC-SEM failed to show the interaction in PWI between target frequency and phonological relatedness; instead it showed an additive pattern (simulation 2, paper 2).

Hence the major conclusions we can draw from the experimental and computational work reported throughout the thesis:

- I. The semantic lexical pathway should be more independent of the number of phonemic slots involved in lateral competition.

- II. The phonemic coding position implemented in the current version of the DRC-SEM is anchored to the absolute position and this is why the current model failed on some of the reported simulations.
- III. It seems that inhibition in the DRC-SEM model is sensitive to the level of activation of its units, for instance in the phoneme system, i.e. the more a phoneme is active, the more strongly it can be inhibited.
- IV. In WNWI tasks the nonlexical route is recruited for the computation of the phonology of pronounceable nonword distractors. Letter-detector sets are built for both unpronounceable and pronounceable nonword distractors but the unpronounceable stimuli do not require the nonlexical phonological assembly. Overall our data seem to strengthen the proposal that when the human reading system detects an illegal phoneme sequence – i.e. when the nonword is constituted by a string of consonant letters – the translation from orthography to phonology is abandoned (Dimitropoulou et al., 2010).
- V. Nonword distractors are never identified. According to Mulatti et al. (2014)'s view, identification corresponds to activation in one of the orthographic units, held in the orthographic input lexicon, having reached the identification threshold – i.e. an interesting level of activation. Following their proposal, only words can be identified since nonwords cannot be represented in the orthographic lexicon. Furthermore, the range of time nonwords can affect the target processing is limited by the time taken to the system to identify the target. It is still not clear, however, when the information concerning the position of the nonword distractor became available to the system but we are inclined to exclude the possibility that it happens when the stimulus is a proto-word because the nonlexical computing on the nonword distractor would be a cost only for the reading system. What would be the advantage for the reading system of assembling the nonword distractor phonology knowing its position (namely, the fact that it is the distractor stimulus and needs to be inhibited)?
- VI. Our WWI data (reported in experiment 3, paper 3) find a possible explanation in two distinct accounts (a) the model proposed by Mulatti et al. (2014); and (b) the speech planning account (Dimitropoulou et al., 2010). We propose further investigations using the lexical decision paradigm to discriminate between these two hypotheses.
- VII. Many cognitive mechanisms are involved in the experimental paradigms we used, such as spatial and visual attention, cognitive control of task performance, monitoring response mechanism. None of these are implemented in any current models of reading and speech production. Despite this, the DRC-SEM model is

partially able to simulate our PWI and PNWI data.

Conclusions

We developed a PNWI paradigm, with a solid experimental procedure that allows the scientific community to replicate, generalize and compare the results. We also developed a new experimental paradigm, the WNWI that uses nonword as distractors rather than words.

From this thesis it emerges that in these paradigms nonword distractors are not ignored, despite the instruction to name the picture or the target word while ignoring the written nonword distractors. The human reading system cannot ignore a written word printed upon the imperative picture or centrally printed in the WWI paradigms; furthermore, this happens even for unfamiliar written stimuli as nonword distractors.

A syllabification process needs to be conceived within the functional and structural architecture of any model of speech production. We found a target syllabic length effect: four-syllable target pictures are read slower than three-syllable target pictures. It remains unclear whether it is the phonemic length or the syllabic length of the nonword distractor that is the critical variable that causes the nonword distractor length effect we repeatedly observed (but see Nickels & Howard (2004) for neuropsychological evidence supporting the role of number of phonemes). The DRC-SEM model exhibited a nonword distractor length effect even when this effect was absent in the human data (i.e. experiment 2 *vs.* simulation 3 in paper 1). We reported the opposite situation too, where humans shown a nonword distractor length effect but the model failed to exhibit the effect (i.e. the post-hoc analysis of Experiment 1 *vs.* simulation 2 in paper 1).

Apart from these incongruities, since the model simulated the nonword distractor length effect in most of the cases, we propose that the nonword distractor length effect is due to the phonemic length. However, the model we adopted lacks a syllabification process and experiment 5 (paper 1) challenges the proposed account. All in all, we report data in favour of a) the serial left-to-right operation of the nonlexical route and b) the intervention of post-phonemic processes intervening in planning the picture name response facing the inhibition and rejection of the nonword distractor as the response. Some of the stages that might be involved are for instance preparation of articulatory gestures and their implementations. The prominent role of these stages in dual task paradigms are further highlighted by the results of experiment 3 reported in paper 3 of this thesis. We also see the possibility to study further these issues further using the lexical decision paradigm.

A possible continuation of paper 1 and paper 2 is the simulation of the behavioural

data using a future version of the Italian CDP++ model (Perry, Ziegler & Zorzi, 2014). This model is a model of reading aloud and visual word recognition. The current version can read stimuli up to three syllables. In order to use our stimuli we need a version of that model that can process stimuli consisting of more than three syllables and that can simulate the picture-naming task.

More importantly the results reported here demonstrate that in the human reading and speech production systems position coding at the phoneme level uses a relative position-coding scheme opposite to the absolute position-coding scheme adopted in the current version of the DRC-SEM model.

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