ERP correlates of language production modifications in ageing

Valente, Andrea

How to cite

VALENTE, Andrea. ERP correlates of language production modifications in ageing. 2014. doi: 10.13097/archive-ouverte/unige:34551

This publication URL: https://archive-ouverte.unige.ch//unige:34551
Publication DOI: 10.13097/archive-ouverte/unige:34551

UNIVERSITÉ
DE GENÈVE

FACULTÉ DE PSYCHOLOGIE
ET DES SCIENCES DE L'ÉDUCATION

Section de Psychologie

Sous la co-direction du Professeur LAGANARO Marina/ Professeur ZESIGER Pascal

---

ERP CORRELATES OF LANGUAGE PRODUCTION MODIFICATIONS IN AGEING

THESE

Présentée à la Faculté de psychologie et des sciences de l'éducation
de l'Université de Genève pour obtenir le grade de Docteur en **Psychologie**

par

Andrea VALENTE

de

ITALIE

Thèse No 559

GENEVE

12/2013
(Mois, Année)

Numéro étudiant: 10.348.795

Section de Psychologie

Membres du jury de thèse:

LAGANARO Marina (PhD supervisor)
Univesity of Geneva - FPSE

ZESIGER Pascal
University of Geneva - FPSE

MICHEL Christoph
University of Geneva – Faculté de Medicine

KLIEGEL Matthias
University of Geneva – FPSE

ALARIO François-Xavier
University of Aix-Marseille - LPC

Table of contents

Abstract

Cognitive ageing is characterized by an asymmetric pattern of modifications. Language abilities are usually well preserved in relation to other more vulnerable functions such as memory and attentional competences (e.g. Horn & Cattell, 1967). In the language system, a further asymmetry has been observed between language comprehension – usually well maintained – and language production, which does present age-related declines (e.g. Thornton & Light, 2006).

The aim of this doctoral thesis is to investigate the nature of language production modifications in the healthy elderly speaker, by focusing on the cognitive mechanisms underpinning the main characteristic observed in older speakers, namely the increasing word finding difficulty occurring as age increases.

Behavioral and neurophysiological measures have been associated in order to pursue this objective. Functional brain imaging techniques, as for instance topographic ERP analysis, allow high temporal resolution and provide important information on the time course of information processing during the performance of theoretically relevant experimental tasks. This point is of particular salience when addressing the issue of the validity of theoretical models accounting for age-related modifications in language production and can provide additional information if compared to the exclusive use of behavioral paradigms.

These advantages have been exploited to interpret data in the light of the most articulated theoretical model trying to account for word finding problems in elderly speakers, that is the Transmission Deficit Model (MacKay & Burke, 1990).

After an introduction on the characteristics of language ageing, we will present a novel methodological approach to topographic ERP analysis, useful to better identify the encoding processes unfolded in a determined period of electrophysiological stability. This methodology

can be also applied to the study of language ageing, with the aim of pinpointing more precisely which steps of information processing are selectively affected by the ageing process.

Then, we will present two studies more directly aimed at examining age-related changes in word production. In the first study we investigated the time course of diverging ERP correlates between a group of younger and older adults in picture naming – a task in which an information flow between lexical and phonological levels is implied -, and compared it to a picture-word verification task, which does not imply lexical-phonological processing. Results only partially confirmed predictions of the Transmission Deficit Model. In fact, inter-age divergences in both tasks were also observed in an early time-window of encoding, unlikely to reflect lexical-phonological processes. These divergences, localized in a more semantic time-window, significantly correlated with the level of accuracy, which was significantly lower in older adults with respect to younger adults in the picture naming task, and higher in the word-picture verification task.

In the second study, a paradigm of picture-word interference previously utilized by Taylor & Burke (2002) to examine age-related modifications in the lexical to phonological pathway for production has been associated with ERP analysis. Results of the Taylor & Burke (2002) study revealed that older adults did not benefit from the facilitation provided by the presentation of picture with homophone names (e.g. ball), which were semantically related with the non-depicted meaning of the picture (e.g. prom). This finding has been interpreted as the evidence of an age-related weakening in the transmission of priming from lexical to phonological nodes.

In our study, distractors' negative SOA was increased (from -150 ms to -500 ms), on the basis of the hypothesis that the lack of facilitation in the top-down priming conditions could be explained by the fact that in older adults the activation of an higher rate of lexical competitors - caused by a richer semantic network – could lead to the priming of an higher rate of phonological nodes if compared to younger adults, therefore obscuring facilitation at the phonological level. Behavioral results showed that with a distractor SOA of -500 ms, facilitation in reponse latencies in the top-down priming condition emerged also in older adults. ERP results again revealed the presence of inter-age divergences also in an early time-window of encoding.

Chapter 1: Introduction and theory

1. Introduction and theory

In the following section we will introduce the theoretical framework of the present doctoral thesis. Approaches to the study of language and cognitive ageing will be presented, followed by an introduction on the main characteristics of healthy language ageing and a section concerning the utilization of ERPs in the study of language production.

1.1. Language and cognitive ageing

The most commonly reported complain among elderly people is their increasing difficulty in finding words in everyday life circumstances (Rabbitt, Maylor, McInnes, Bent & Moore 1995). Historically, research on cognition and ageing adopted an approach preferentially focused on the decline and depletion of cognitive competences along the ageing process. This in spite of the fact that ageing is largely characterized by asymmetric patterns of decrement. The main observable asymmetry is the global maintenance of language abilities – and more generally of crystallized intellectual abilities, such as vocabulary knowledge or general information retrieval - in relation to other cognitive functions which are more vulnerable to ageing-dependent decrements, as attentional and mnestic competences or more generally "fluid" intellectual abilities – as for instance the learning of new information and associative memory capacities. Early research on cognitive ageing brought evidence that older adults showed a significant decline in tasks involving the use of fluid abilities in concomitancy with a better performance in tasks implying crystallized abilities (Horn & Cattell, 1967).

In the domain of language ageing it is customary to distinguish between two fundamental approaches to the study of ageing and cognition: information-universal and information-specific theories (e.g. Burke, MacKay & James, 2000).

1.2. Language specific vs. non-language specific theories

According to non-language specific theories, ageing would affect cognitive functions in an aspecific and even fashion. In other words information-universal theories predict that ageing will yield consequences which are independent of the specific architecture of a particular kind of information processing, making no distinctions for instance between different representational units hypothesized in the domain of language processing and rather assuming an indistinct disruption of all language subsystems.

The general reference of information-universal theories is the *resource theory*, which stems from the observation that there is a limit in the information processing capacity of humans (e.g. Miller, 1956). In this framework, ageing would constitute one of the factors negatively affecting the availability of resources necessary to perform specific operations faster than younger adults (e.g. Hasher & Zacks, 1979; Murphy, Craik, Li & Schneider, 2000).

The interpretation of the term *resource* have been progressively clarified and restricted to a limited set of concepts. In language and ageing the term is now more frequently utilized with reference to either speed, inhibition or memory (Burke & Shafto, 2008). Here we will focus on the two main types of information-universal theories of cognitive ageing, namely *general slowing* and *inhibition deficit* theories.

General slowing theories are usually regarded as the oldest and more paradigmatic example of information-universal theories and suggest the implication of one single major factor. According to such theory, ageing would yield a reduction in the speed of information treatment and therefore on the amount of operations which can be executed (e.g. Salthouse, 1985, 1996; Myerson et al., 1990). These modifications take place indistinctly and universally, in the sense that they will exert an influence on cognitive functioning independently of the specific task or mental operations involved.

Two mechanisms are proposed to account for the age-related decrement in performances: cognitive operations would suffer from a reduction in speed such as to adversely affect completion in a limited time, and the centralization of peripheral information to a central processor would slow down to the point in which earlier components of information would decay before successful integration.

A second kind of information-universal theory is the *inhibition deficit hypothesis*. According to this theory, ageing exerts its effects by weakening inhibitory processes regulating attentional and mnestic processes. That is, elderly adults would encounter more difficulties in inhibiting irrelevant information, which would finally cause a disruption in the use of the relevant information (Hasher & Zacks, 1988; Zacks & Hasher, 1994, 1997). Such assumptions have been for instance utilized to account for the fact that elderly adults are more prone to go off topic in the course of their conversations (e.g. Arbuckle, Nohara-LeClair & Pushkar, 2000).

Overall, the main pitfall of information-universal theories is the lack of capacity to account for the asymmetric modification patterns observed in language ageing. In fact, they lack the explanatory ability to account for the fact that specific language functions are subject to an age-related decline while others are spared. For instance, the *inhibition deficit hypothesis* suggests inhibitory processes to be active in both language comprehension and production, an assumption which is at odds with the observation that language comprehension and production are far from being equally degraded by the ageing process (e.g. Burke, 1997), or that in the domain of production different language subsystems (i.e. semantics and phonology) are unevenly affected.

These asymmetric patterns of modifications are better accounted for by information-specific theories, which postulate a purely linguistic nature of the age-related language modifications occurring with ageing and selectively circumscribe it at the level of specific language subsystems. So far, the most articulated theory of this kind is the *Transmission Deficit Model* (MacKay & Burke, 1990) that will be more exhaustively described further on.

1.3. General characteristics of language ageing

The first and main asymmetry in language abilities in elderly adults is the one between language comprehension and production. There is general agreement on the fact that language comprehension abilities are usually well maintained in ageing (e.g. Burke, MacKay & James, 2000), contrary to language production, which conversely does present age-related declines.

Not all language modifications occurring with age are strictly linguistic in their nature, for instance the fact that elderly speakers resort to less complex syntactic structures in relation to younger adults has been interpreted as the outcome of a decline in the availability of resources in the memory domain, rather than to strictly linguistic factors (Kemper, Herman & Lian, 2003).

When the focus is centered on language production, a second and determinant asymmetric pattern emerges between the processing of semantic and phonological information. Semantic representations and retrieval is usually spared when not significantly improved in elderly speakers (see Thornton & Light, 2006; Burke & Shafto, 2008 for reviews). Elderly adults usually show a richer vocabulary and better performances at tests of general knowledge if compared to younger speakers (Schaie, 2005; Beier & Ackerman, 2001) and show greater semantic interference effects (Taylor & Burke, 2002), interpreted as a sign of a more solidly connected semantic system; this observation has been interpreted as the outcome of a more solidly connected semantic system.

The core property characterizing healthy language ageing is the increasing word finding difficulty (e.g. Mortensen, Meyer, & Humphreys, 2006; Neumann, Obler, Gomes, & Shafer, 2009). Such difficulty in accessing lexical representations declines in many ways: in elderly speakers word finding latencies usually increase and spontaneous speech presents more vague terms, more frequent and longer empty pauses, an higher verbosity accompanied by lower informativeness (Bortfeld, Leon, Bloom, Schober, & Brennan, 2001).

The fundamental manifestation of word finding failures in the older age is the Tip of the Tongue phenomenon (ToT), a particular condition - exemplifying the ridge between the semantic-syntactic (lemma) and phonological (lexeme) levels of encoding (e.g. Levelt, Roelofs & Meyer, 1999) – in which the retrieval of the complete phonology of a word is impossible despite the strong feeling of knowing that word. There is large evidence that ToTs states become significantly more frequent as age increases (e.g. Burke, MacKay, Worthley & Wade, 1991).

Since word retrieval difficulties do not necessarily manifest in spontaneous speech, they have been isolated and tested experimentally mainly by means of the picture naming task, in which the association between words and pictures is more strictly determined. Overall, the evidences gathered both in cross-sectional and longitudinal studies have shown that elderly speakers name pictures less accurately and slower than younger speakers (e.g. Connor, Spiro, Obler & Albert, 2004; Goral, Spiro, Albert, Obler & Connor, 2007; Nicholas, Connor, Obler & Albert, 1998, Verhaegen & Poncelet, 2012; Morrison, Hirsh & Duggan, 2003 in a verb-picture naming task; but see Goulet, Ska & Kahn, 1994). This particular tendency has been utilized to confirm predictions of the Transmission Deficit Model.

1.4. The Transmission Deficit Model

To this day, the most articulated information-specific theory addressing the issue of language modifications along the ageing process - and more specifically to try to account for the increasing difficulty in lexical access - is the Transmission Deficit Model (MacKay & Burke, 1990; from now on TD Model).

The TD Model is built on an interactive activation model of language, the Node Structure Theory (from now on: NST; MacKay, 1987). An illustration of the language production system in the NST is illustrated in Figure 1.

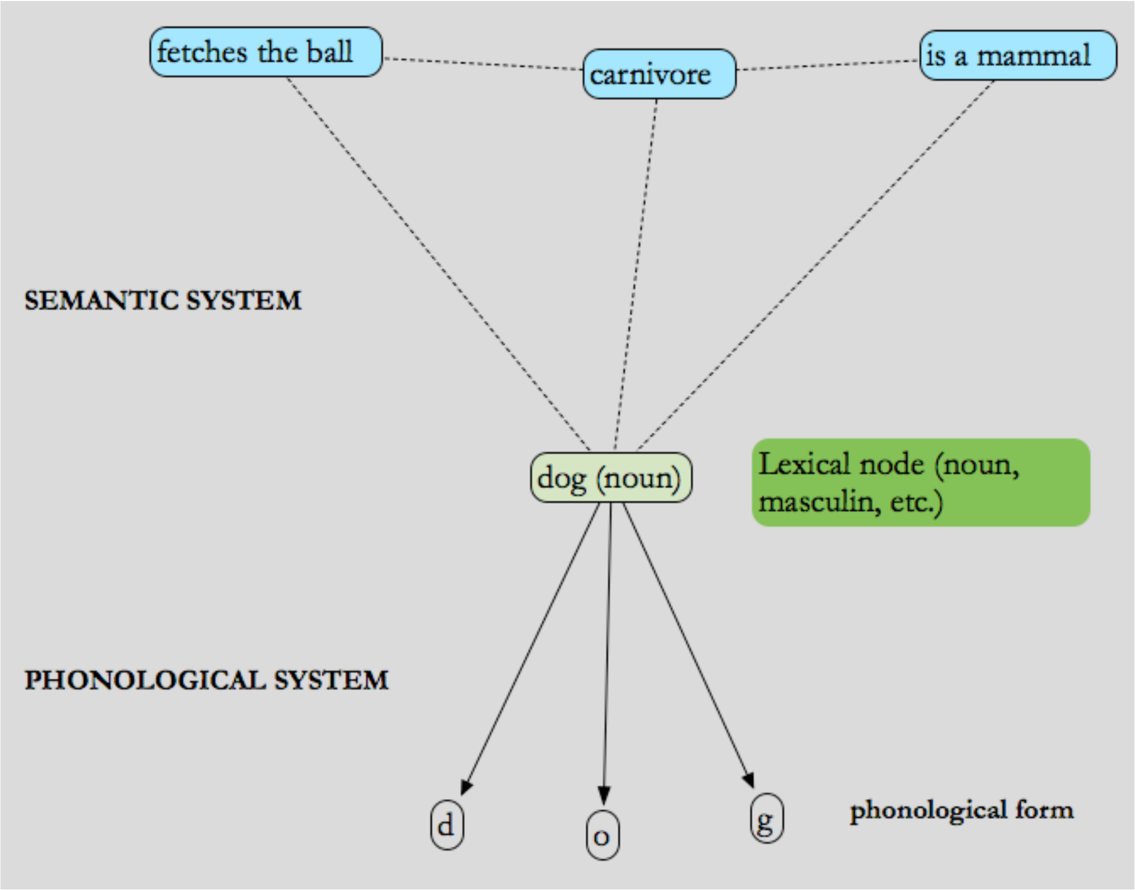


FIG 1 Node Structure Theory, representation of the production system for the word "dog".

As in similar interactive activation models of language (e.g. Dell, 1986), the NST is constituted of a vast network of elementary processing units (the nodes) hierarchically organized in systems and postulates the same levels of information processing which are recognized by the great majority of linguistic theory, that is a semantic, syntactic and phonological representational level. Each level is characterized by the kind of information stored and processed in it: the semantic system represents concepts which underlie words (lexical nodes), phrases and propositions (but containing no phonological information) and the phonological system containing information as syllables, consonant clusters, vowels and phonological features.

The NST postulates two basic processes: activation and priming. Activation corresponds to the conscious retrieval of information represented in a node whereas priming implies the preparation of information for possible activation. The activation of a node causes the priming of all nodes that are connected to it. Comprehension and production abilities are directly linked to the speed of transmission and amount of priming between units.

In error-free speech production, thoughts are translated into speech through the serial activation of nodes; starting from concept nodes in the semantic system, subsequently retrieving the corresponding most activated lexical nodes that finally activate the phonological nodes and allow retrieval of a target word.

The TD Model accounts for word retrieval difficulties in elderly speakers by postulating an age-related selective weakening in the transmission of priming between lexical and phonological nodes (top-down priming in the NST), giving rise to a failure in the retrieval of the complete phonology of target words. Along with frequency of use and recency of use, Burke et al. (1991) identify ageing as one of the main factors affecting the weakening of connections. Ageing would in fact give rise to a reduction in the rate and amount of priming transmitted across the critical connections. Nevertheless, the functional outcomes of the priming disruption are variable and implicit in the specific structure of the memory systems assumed by the NST, which allows the TD Model to account for asymmetric modification patterns. For instance, bottom-up connections from phonological onto lexical nodes are characterized by a convergent pattern of many phonological nodes onto one single lexical node. This allows offset for the weakening of priming in one single connection since the lexical node is assumed to receive enough priming from the spared connections. Likewise, connections between nodes in the semantic system are convergent and highly distributed, so that the disruption of one single connection would not severely affect the retrieval of information in a semantic node. Conversely, the top-down priming pathway for production from lexical nodes to phonological nodes requires each single connection to be active for the retrieval of the complete phonology of a particular target word to be possible. This makes language production particularly vulnerable to priming transmission deficits (see Figure 2 for a simplified illustration).

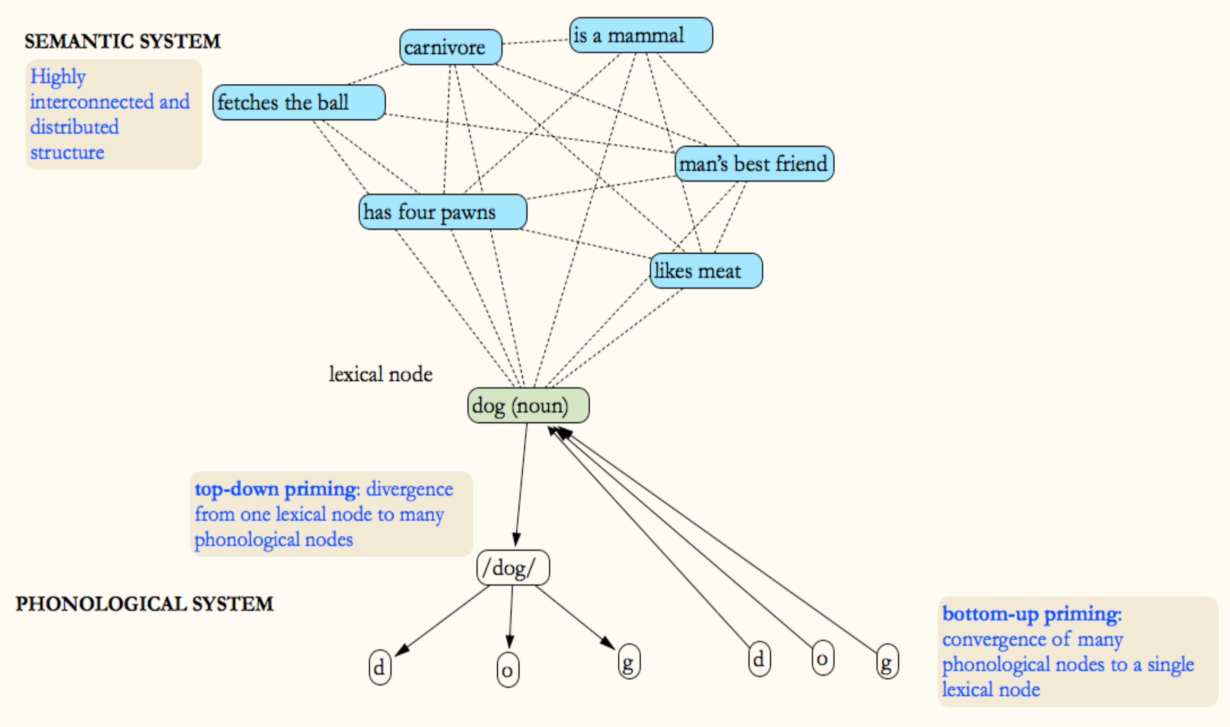


FIG 2 Simplified representation of the priming pathways in the NST.

Hence, in Tip of the Tongue states, semantic information about a target word is retrieved through the activation of a lexical node in the semantic system; nevertheless a partial inability to retrieve the phonology of the target word remains due to the top-down priming transmission deficit (e.g. Burke et al., 1991).

In sum the TD Model has the advantage to account for asymmetric modifications in the language system and explains age-related word finding difficulties as the outcome of a priming transmission deficit in the lemma-to-phonological-form pathway for production. The TD Model has been evaluated in a number of studies utilizing the paradigm of experimentally induced ToTs to test the hypothesis that ToTs are caused by a weakening in the priming transmission from lexical to phonological nodes. Cross & Burke (2004) addressed the issue of whether ToTs are caused by alternate words - that is more accessible alternatives receiving activation and preventing the retrieval of a target word -, or rather by a priming transmission weakening, as postulated by the TD Model. They utilized a competitor priming paradigm in which younger and older adults were asked to name famous fictional characters (e.g. Eliza Doolittle) and subsequently name a picture of a celebrity playing the role of this character (for instance Audrey Hepburn as Eliza Doolittle). Overall, results showed that ToTs in older adults were independent of prior naming of a related character, rather endorsing the hypothesis that ToTs are caused by a priming transmission weakening, as assumed by the TD Model, and that persistent alternates are more of a consequence than a cause of ToTs.

In a study aimed at evaluating the TD Model's account of ToT states, Abrams, White & Eitel (2003) investigated the influence of specific phonological components (first letter, single syllable or first phoneme of a target word) in the resolution of experimentally induced ToTs states in three distinct experiments. Results revealed that primes sharing the first letter or phoneme with the target word did not help ToT states resolution, whereas primes sharing the first syllable with the target did facilitate retrieval of the complete phonology of the target word. This observation was interpreted as an evidence of the fact that the priming of more than one phoneme could offset priming transmission deficits from lexical to phonological nodes and lead to the activation of a phonological representation common with the target, finally allowing retrieval of the target word.

Along the same lines, White & Abrams (2002) investigated the effects of phonological priming of syllables on ToT states resolution in three age groups (young, young-old and old-old adults). ToTs were induced experimentally and participants were asked to read a list containing primes sharing either the first, middle or last syllable with the target word. Effects of phonological primes sharing the first syllable with the unretrieved word on ToT resolution were affected by age; in fact, primes sharing the first syllable with the target facilitated complete phonology retrieval in young and young-old, but not in old-old adults. This evidence was again interpreted as a confirmation of the TD model prediction of a comparatively greater, and less likely to be countervailed, priming transmission decline in elderly speakers.

Taylor & Burke (2002) utilized a picture-word interference paradigm built in the framework of an interactive activation model of language production. The aim of the authors was to directly examine the TD Model's predictions by utilizing different experimental conditions capable of testing the priming pathways assumed by the Node Structure Theory.

In two experiments, younger and older adults were asked to name pictures preceded by auditory word distractors which could be semantically related (e.g. the picture of a table preceded by the word "chair"), phonologically related (e.g. the picture of a frog preceded by the word "frost"), unrelated or semantically related to a non depicted meaning (e.g. the picture of a ball was preceded by the word "prom" which is related to the lexical node "dance ball"). In the latter condition the double priming triggered by the activation of the same phonological form "ball" is assumed to speed up response latencies (Cutting & Ferreira, 1999). Results showed that, contrary to younger adults, elderly participants didn't benefit of that specific double top-down priming from lexical to phonological nodes, confirming the hypothesis of a weakening in the lemma-to-phonological form connections occurring with ageing.

To our knowledge, the only study that tried to investigate the TD Model’s predictions by means of the ERP methodology is the one by Neumann et al. (2009). The authors had younger and older participants perform an implicit picture naming task in a go/no go paradigm in which phonological factors were controlled. Participants had to make a segmental (first phoneme) or syllabic (one or two syllables word) decision. An ERP component reflecting response inhibition to phonological processing (the N2d) and the visual evoked potential (VEP) to pictorial stimuli were compared between age groups. Results showed no differences at the level of the VEP, allowing the authors to rule out the hypothesis of a general slowing occurring indistinctly with ageing. Conversely, older adults had slower latencies both behaviorally and at the level of the ERP component associated with phonological processing; this observation was interpreted as a verification of the TD Model assumptions, according to which the priming transmission deficit occurring along the ageing process would manifest itself in a more difficult and delayed access to phonological codes if compared to younger adults.

To summarize, the majority of studies conducted to this day to examine the TD Model's predictions concluded in favor of its basic assumptions, that is that the increasing word finding decline in elderly speakers is due to a more difficult access to phonological information, explained as the cause of a priming transmission deficit occurring with age between the lexical and the phonological levels of encoding.

1.5. Event related potentials and time course of word production

The encoding levels postulated by models of word production – as well as evidence in favor of the TD Model - have been originally investigated with a variety of chronometric paradigms aimed at gathering information on their dynamics and time course (see Levelt et al., 1999 for a review). More detailed information on the temporal dynamics of such functional components have been subsequently achieved by resorting to the use of neuroimaging techniques, such as ERP and MEG, allowing an even more precise insight in the chronometric structure of the encoding levels (e.g. Indefrey, 2011).

Considering the relevance of picture naming tasks in the study of word production processes - and more specifically for the study of age-dependent modifications in language production abilities and for the TD Model, we will focus here on research conducted with the purpose of identifying the neurophysiological correlates of the encoding processes involved in word production.

Historically, a variety of methods have been utilized to track the temporal dynamics of the information processing steps involved in word production. Chronometric studies have pursued the aim of targeting specific processes by manipulating experimental conditions (e.g. Jescheniak and Levelt, 1994). In particular, priming and interference paradigms have been utilized to track temporal relationships between different encoding levels (Schriefers, Meyer, & Levelt, 1990). Careful manipulation of semantic and phonological relationship between the prime and the target word and the manipulation of distractors' SOAs allowed determining the time course of the encoding levels postulated in accessing content words. Finally and more importantly, studies have resorted to the use of EEG and event-related potentials technique (ERPs) allowing the researcher to track temporal information with a millisecond range precision. In this domain several different paradigms have been utilized, from delayed picture naming in which a temporal delay is introduced between the presentation of a picture and response execution (Cornelissen et al, 2004; Jescheniak et al, 2003; Laganaro, Morand, & Schnider, 2009; Vihla, Laine, & Salmelin, 2006), to implicit naming tasks in which participants are asked to perform a motor response only when a particular class of stimuli is presented and to inhibit in other cases (Rodriguez-Fornells et al., 2002; Schmitt, Münte, & Kutas, 2000; Thorpe, Fize, & Marlot, 1996; Van Turennout, Hagoort, & Brown, 1998; Zhang & Damian, 2009; Jescheniak et al., 2002) to overt picture naming tasks (see Ganuschack et al., 2011; Strijkers & Costa, 2011 for a critical review of EEG/MEG speech production studies), in which participants are typically asked to name pictures appearing on a computer screen. This last research line has the advantage of involving an overt production of target words and of associating it with the EEG technique, which is particularly suitable to address the problematic raised by the study of language ageing, in reason of its capacity to provide the researcher with precise information on the time course of the encoding stages implied in the performance of theoretically relevant tasks.

As highlighted below, models of word production assume that the act of naming a picture is accomplished by going through a sequence of encoding substages, namely visuo-semantic processing, lemma selection and phonological/phonetic encoding (Glaser, 1992; Levelt et al., 1999). Some controversy still exists around the dynamics of the information processing steps involved in the process of word production, namely between discrete models assuming that each encoding stage has to be completed before the information can pass to the next one, or interactive models in which different encoding stages are assumed to be cascaded, that is activated in parallel (e.g. Dell, 1986; MacKay, 1982). Such distinction is of particular pertinence in the domain of language ageing, since the TD Model is built in the framework of an interactive activation model (MacKay, 1987) whereas the most advanced integration of psycholinguistic and neuroimaging data rely on discrete models (e.g. Indefrey & Levelt, 2004). By the way, notwithstanding the controversy around the kind of information flow between distinct encoding levels, the great majority of word production models postulate the same representational levels.

In the following example, the encoding stages one must go through to name a picture will be summarized according to serial models, since the time-course of encoding processes is so far better modeled in such framework: visual processing and object recognition - in which semantic properties of the picture are retrieved from the semantic system -, and a formulation process (Levelt et al., 1999) in which language gets involved and which is constituted by the selection of a target lemma among competitors and finally by phonological and phonetic encoding.

Recent efforts have been made to provide a precise temporal partitioning of the substages mentioned above by gathering experimental evidences from different studies (Indefrey & Levelt, 2004; Indefrey, 2011). Such effort lead to an estimate for mean production latencies of the time course of the encoding levels implied in word production (an illustration of such temporal signature is presented in Figure 3).

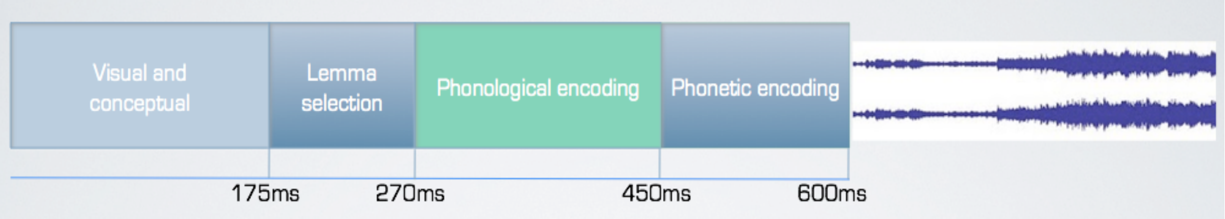


FIG 3 Time course of the encoding processes involved in word production, from picture presentation to articulation (Indefrey & Levelt, 2004).

This estimate serves as a good commencement to investigate the dynamics of modifications in word production processes along ageing by allowing, for example, comparison of the dynamics of the encoding levels triggered by the performance of theoretically salient tasks in different age groups. By way of example, the TD Model postulates that major inter-age differences in word production would be localized at the level of phonological encoding; this is based on the assumption that a priming transmission weakening between the lexical and phonological levels of encoding would result in a more difficult and delayed access to phonological codes. In the study by Neumann et al. (2009) described in the previous section, this assumption was examined with ERP methodology. Nevertheless, an implicit picture naming task in a go/no go paradigm was utilized, providing only indirect measures of language processing. Moreover, authors adopted an *a priori* approach, focusing solely on the phonological processing time window at the risk of overlooking inter-age differences in other salient time periods and didn't provide measures of older adults' cognitive status, which could help to disentangle purely linguistic from mnestic and attentional abilities.

The main purpose of this doctoral thesis is to examine such predictions by coupling tasks involving overt production with ERP topographic analysis and a technique that allows covering the entire encoding process from stimulus presentation to response (Laganaro & Perret, 2011).

1.5.1 ERP topographic analysis on overt language production ERPs

ERP studies in the domain of language production are usually based on canonical waveform analysis, in which voltage deflections calculated against a common reference are averaged and compared across different experimental conditions (e.g. Strijkers & Costa, 2010).

In spite of the important insights this approach has provided to the study of language, waveform analysis does suffer from some limitations. First, statistical outcomes of waveform analyses are dependent on the particular reference electrode the researcher decides to adopt.

Even though the choice of a specific reference is usually guided by reasonable assumptions, it remains an arbitrary choice. More importantly, in waveform analysis it is customary to focus on isolated components with an active risk of overlooking effects in other important time-windows (e.g. Murray et al., 2008). These limitations are overcome by topographic ERP analysis, which is a methodology yielding a segmentation of group-averaged ERPs in periods of topographic stability assumed to reflect different stages of information processing (Murray, Brunet & Michel, 2008; Pascual-Marqui, Michel & Lehmann, 1995). The segmentation is obtained by the application of mathematical clustering algorithms yielding a compression of data in a limited series of topographic template maps better explaining the whole dataset variability (see Figure 4 for an illustration of the principles of topographic analysis). This methodology is independent of the reference electrode (Michel et al., 2001, 2004) and insensitive to pure amplitude modulations across conditions (topographies of normalized maps are compared).

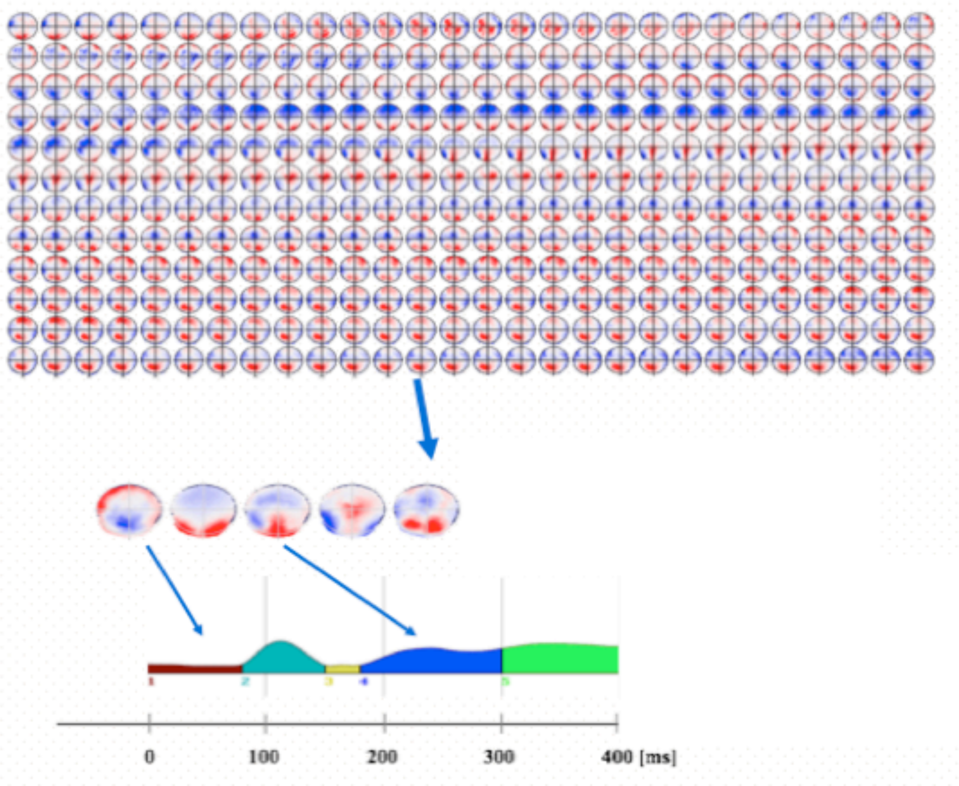


FIG 4 Illustration of the principles of topographic analysis. The complete dataset is compressed in a limited series of topographic template maps, with additional information on their time course. The colors under the Global Field Power represent each different period of stable topographic configuration.

In topographic analysis group-averaged and subject-average ERPs are used and template maps issued from the spatio-temporal segmentation of ERP recorded during the performance of different tasks are compared on a time point by time point basis with subject-averaged ERPs (procedure referred to as "fitting"; Murray et al., 2008, see Figure 5 for an illustration). This leads to the labeling of each time point in each subject-averaged ERP with the template map bearing the highest spatial correlation with it. Results are then used to determine if a specific template map is characterizing a particular experimental condition or whether different conditions are affecting the duration or response strength of a template map.

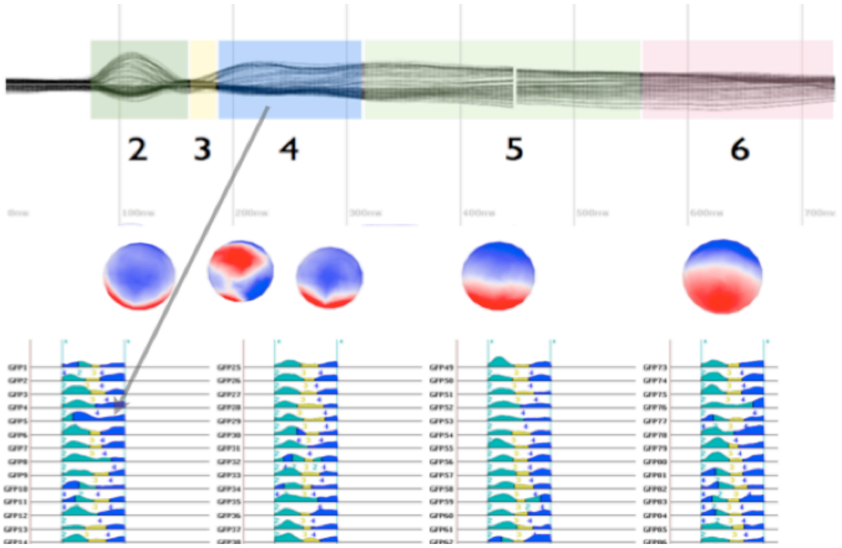


FIG 5 Illustration of fitting procedure in which a time point by time point comparison between template maps, issued from the segmentation of group-averaged ERP covering the entire processing window, and subject-averaged ERP is carried out.

The benefits brought by topographic analysis over canonical waveform derive from the fact that being based on modifications of the spatial distributions of voltage values at the scalp, statistical outcomes are not affected by the specific reference electrode one decides to adopt (Murray et al., 2008). Reference-free measures, such as the strength of response (Global Field Power) or topographic modulations as a function of time (Global Dissimilarity) can be calculated and used for comparisons between different experimental conditions. The reference-free nature of topographic analysis can provide more detailed and complete information and free the researcher from the need for a priori hypotheses such as focusing on isolated components at the risk of possibly overlooking effects in other time-windows (Murray et al., 2008).

These advantages can provide important information for the purpose of studying language modifications with ageing, in which the key point concerns modifications of the encoding processes induced by ageing, and the question of whether these modifications are globally and evenly distributed across all encoding processes (according to information-universal theories) or rather primarily located in specific time windows (as postulated by the TD Model) -

constitute the salient object of investigation and can be approached with no a priori hypotheses concerning the processing steps bearing the main differences.

2. Research question and approach

As illustrated in the introduction, the great majority of studies addressing the issue of the increasing word finding problems in elderly speakers adopted behavioral paradigms and chronometric techniques aimed at evaluating the predictions of a priming transmission deficit from lexical to phonological nodes.

Behavioral paradigms constitute an important part of the research process but, even when more complex priming paradigms are utilized (e.g. Taylor & Burke, 2002), they can only inform on the outcome of a particular cognitive process, whereas they lack the capacity of providing detailed information on the exact time course of the encoding stages one must go through in order to perform specific cognitive tasks. In other words, experimental evidence is solely capable of suggesting conclusions that are logically plausible in relation to the theoretical models. By the way, obtaining information on the temporal signature of the encoding stages involved in theoretically relevant tasks is particularly important when one decides to assess in detail the validity of these theoretical models.

In the present doctoral thesis, behavioral data will be associated with a brain imaging technique capable of providing detailed insight into the precise chronometric structure of the encoding stages implied in tasks that are particularly relevant from a theoretical point of view.

To this aim we will first present a novel methodological approach to ERP data useful to establish connections between periods of topographic stability and the encoding processes involved in word production. Subsequently, we will present a study in which age-related differences occurring with age were addressed by investigating the time course of diverging ERP correlates between younger and older adults in both a picture naming and a word-picture interference task in which lexical phonological processes should not involved. Finally, we will present a study in which we adopted the same paradigm utilized by Taylor & Burke (2002) to directly examine the TD Model's assumptions concerning word production modifications in ageing.

In the following section we will present the three chapters corresponding to three research papers, which constitute the present work and illustrate their relation with the general problematic addressed by the present thesis.

3. ERP correlates of word production predictors: A multiple regression analysis on trial-by-trial topographies

In the first paper (Chapter 2) a novel methodological approach to ERPs analysis developed during my doctoral thesis will be presented. This method was applied to overt picture naming with the aim of verifying the time course of word encoding on the entire time window of encoding from picture onset to response articulation (Laganaro & Perret, 2011).

As mentioned in the introduction, the common procedure in topographic ERP analysis involves the fitting procedure to be conducted through the comparison of each time point in each subject-averaged ERP with the template map issued from the spatio-temporal segmentation of group-averaged ERP bearing the highest spatial correlation with it (cfr. par. 1.5.1).

In the methodology we developed the time point by time point comparison between group-averaged and individual ERPs was conducted at a single trial level instead of in the subject-average ERPs. Mixed-effect regression analyses on single trial ERPs during the performance of an overt picture naming task were then conducted, allowing to pinpoint the influence of specific psycholinguistic factors on the duration of periods of topographic stability. Results were quite consistent with general accounts in the literature relatively to the time course of word production processes, namely showing an influence of pre-lexical and semantic variables in early time-windows and of phonological and phonetic factors on late time windows (e.g.

Indefrey & Levelt, 2004). All this has an additional benefit: the single trial approach allows in fact preserving all the variability, which is usually lost when average responses are utilized (e.g. De Lucia et al., 2007).

In relation to the problematic of word production modifications occurring with ageing - in which the core issue is how and when the encoding processes involved in word production differ as age increases - this methodology is of particular salience, in fact by allowing to better identify the encoding processes unfolded in a determined period of topographic stability - reducing the need to rely on external accounts of the time course of word production processes (e.g. Indefrey & Levelt, 2004; Indefrey, 2011) which do present some pitfalls - it allows to examine more directly predictions by current theories on word production modifications in ageing and to pinpoint precisely which steps of information processing are selectively affected by the ageing process.

4. Ageing effects on word production processes: an ERP topographic analysis

The second paper (chapter 3) constitutes the first step towards the study of word production modifications in ageing. In general, the TD Model has been investigated by resorting to chronometric or naming accuracy techniques (e.g. Rastle & Burke 1996; White & Abrams, 2002; Taylor & Burke, 2002). The fact that older adults showed longer naming latencies and lower naming accuracy, presented an higher rate of TOTs or didn't benefit from priming from lexical to phonological levels of encoding has been interpreted as a confirmation of the TD Model's predictions. Except for one study which utilized the ERP methodology (Neumann et al., 2009) to investigate the TD Model, our impression is that no effort to obtain a closer look on neurophysiological correlated of encoding processes modifications across age groups has been systematically made so far.

The aim of this study was to collect evidence of modifications in word production processes in ageing by combining behavioral and neurophysiological measures; the aim was pursued by investigating the time course of diverging ERP correlates between two age groups (younger and older adults) in two experiments: a classical picture naming paradigm and a word-picture interference task in which - according to accounts in the literature (e.g. Stadthagen-Gonzalez, Damian, Pérez, Bowers & Marín, 2009) lexical phonological processes are not involved. Results of this study showed that older adults were less accurate than younger adults in naming pictures, confirming the decrease in naming accuracy occurring with ageing (Goral et al. 2007; Connor et al., 2004; Nicholas et al., 1998 but see Goulet et al., 1994). However, the inter-age ERPs comparison of both the picture naming and word-picture verification task revealed age-related modifications in an early encoding time window usually associated in the literature with semantic processing, both correlating with accuracy. In the picture naming task inter-age amplitude differences were also observed in a later time window compatible with phonological encoding. Overall, results seem to suggest that lower naming accuracy in older adults could be the consequence of a more difficult semantic-to-lexical processing; the more distributed semantic network of older adults could in fact lead to a less effective activation of the target lemma due to the priming of a greater number of competitors. In other words, the decrease in naming accuracy would not represent a stand-alone decline in the retrieval of phonological information, as postulated by the TD Model, but rather be the consequence of modifications at an earlier encoding time window.

In the light of these results, we decided to examine more extensively the TD Model's predictions by adopting the same experimental paradigm utilized by Taylor & Burke (2002).

5. Ageing and the lemma-to-word-form priming transmission: investigating the transmission deficit model with ERP topographic analysis.

In the third paper (Chapter 3), we will present a study in which the fundamental experimental paradigm utilized to verify predictions of the TD Model (Taylor & Burke, 2002), namely the top-down priming paradigm (see section 1.4) has been utilized in association with neurophysiological measures in younger and older adults. This picture-word interference paradigm, originally introduced by Cutting & Ferreira (1999) to investigate discrete vs. cascaded processing, is derived from the NST interactive activation model and is directly aimed at a verification of the priming weakening hypothesis proposed by the TD Model. This study is aimed at further exploring the results of the previous study that are not completely in line with the TD Model.

6. General conclusions

In the last chapter of the present thesis (Chapter 5), conclusions will be drawn by integrating results of our studies and current knowledge on word production modifications occurring with ageing.

Chapter 2: ERP correlates of word production predictors: A multiple regression analysis on trial-by-trial topographies

ERP correlates of word production predictors: A multiple regression analysis on trial-by-trial topographies[1]

Andrea Valente, Audrey Bürki, Marina Laganaro

FAPSE, University of Geneva, Switzerland

Corresponding Author:

Andrea Valente: andrea.valente@unige.ch, valentea78@gmail.com

Keywords: ERP, single trial, language production, picture naming, encoding processes, psycholinguistic variables

Tables: 2

Figures: 3

---

[1] This paper is in the process of revision and will be resubmitted within the month of December 2013.

Abstract

A major effort in cognitive neuroscience of language is to define the temporal and spatial characteristics of the core cognitive processes involved in word production. One approach consists in studying the effects of linguistic and pre-linguistic variables in picture naming tasks. So far, studies have analyzed event-related potentials (ERPs) during word production by examining one or two variables with factorial designs. Here we extended this approach by investigating simultaneously the effects of multiple theoretical relevant predictors in a picture naming task. High density EEG was recorded on 31 participants during overt picture naming (N=100). ERPs were extracted on a trial-by-trial basis from picture onset to 100 msec before the onset of articulation. Mixed-effects regression models were conducted to examine which variables affected production latencies and the duration of periods of stable electrophysiological patterns (topographic maps). Results revealed an effect of pre-linguistic variables, i.e. visual complexity and concept familiarity, from 50 to 180 msec after picture presentation, a result consistent with the proposal that this time period is associated with visual and object recognition processes. Three other variables, word age of acquisition, name agreement and image agreement, influenced response latencies and modulated ERPs from ~380 msec to the end of the analyzed period. These results demonstrate that single trial topographic analyses on the entire processing period allow one to pinpoint the precise time-course of multiple word production predictors at once.

Introduction

The representations and processes underlying word production have been studied extensively for more than three decades with various experimental approaches, including the analysis of speech errors (e.g., Dell, 1990; Fromkin, 1971; Garrett, 1980), chronometric paradigms (Bock, 1996) and event-related potential (ERP) approaches (Ganushchak, Christoffels, & Schiller, 2011). Most chronometric studies involve picture naming tasks where the dependent variable is the time interval between picture presentation and the onset of articulation (see Johnson, Paivio, & Clark, 1996 for a review). In many of these picture naming experiments, the properties of the words (e.g., frequency, age of acquisition, length) or of the pictures (e.g., visual complexity) are manipulated. On the basis of the influence that such properties exert on picture naming latencies relative to their influence on response times in other tasks (e.g. word-picture matching, Jescheniak and Levelt, 2004), inferences are drawn on the organization of words in memory and/or on the processes underlying their production. More recently, event-related potential (ERP) studies have begun to examine which time periods are modulated by specific psycholinguistic variables, in order to associate these effects with the time course of underlying encoding processes. Both approaches have specific limitations due to methodological constraints. On the one hand, behavioral chronometric methods allow the investigation of several relevant variables simultaneously, but can only infer the time course of their effects on the basis of task comparisons (e.g. Alario et al., 2004). On the other hand, ERP studies allow insight into the time periods affected by specific variables, but usually investigated a few variables at a time (e.g. Cheng et al., 2010; Strijkers, Costa & Thierry, 2010). The present research provides a novel and complementary approach by investigating simultaneously the effects of multiple theoretically relevant psycholinguistic variables on ERPs covering the entire word encoding period from picture onset to articulation. In the following we will briefly review the psycholinguistic approaches and ERP studies that have examined the time course of word encoding, before describing the approach of the present study.

Models of word production agree on the fact that speakers have to go through a sequence of three major cognitive processes before they can articulate the name corresponding to a picture (e.g., Glaser, 1992; Levelt, Roelofs, & Meyer, 1999), although different claims are made regarding the dynamics of these encoding processes (Dell, 1986; 1988). The first process involves visual processing and leads to object recognition. The second process involves the activation of the corresponding concept. It is only at the third processing stage that language gets involved, with the encoding of the corresponding word. This step, often referred to as the formulation process (e.g., Levelt et al., 1999) has been extensively detailed in the psycholinguistic literature and is assumed to entail several processing sub-stages: lexical selection, phonological encoding and phonetic encoding. Lexical selection corresponds to the retrieval from the mental lexicon of a lemma, i.e. a semantically and syntactically specified representation (lexical-semantic processes). The word's phonological representation or lexeme is specified during phonological encoding (lexical-phonological processes); then, on the basis of the abstract phonological codes, syllable-sized articulatory gestures and their temporal relationships are either computed or retrieved (phonetic encoding) before articulation can start. The average time needed to start articulating a word from picture onset is less than a second. More recently, a major effort has been devoted to characterizing the precise time course of these processes, that is, their respective order and duration. As is evident from previous reviews (Indefrey & Levelt, 2004; Indefrey, 2011) this issue is particularly complex and our current knowledge, which relies on the comparison of disparate sources of evidence, is still incomplete.

Information about when and how the different encoding processes unfold can be extracted from different sources (see Indefrey & Levelt, 2004 for a comprehensive review). A first way to obtain such information is to design paradigms that target specific processes. However, these approaches do not allow one to estimate the time course of specific processes directly. For instance, Jescheniak and Levelt (1994) had participants performing a picture word matching task and subtracted an approximation of the time devoted to response preparation and execution from the overall response times to conclude that it takes less than 150 msec to access lexical concepts. Another approach to gain insight into the time course of word production processes is the use of priming or interference paradigms where the prime (an auditory or visually presented word distractor) occurs at different time points relative to picture presentation (or SOA, for stimulus onset asynchrony e.g., Glaser & Dungelhof, 1984). Distractors typically have a phonological, semantic or sometimes syntactic relationship with the target word. Depending on the SOA at which a given distractor type affects responses, conclusions have been drawn on the temporal relationship between specific encoding processes (e.g., Schriefers, Meyer, & Levelt, 1990), while not necessarily on their precise time course.

A third important source of information on the time course of cognitive processes comes from EEG or MEG studies with event-related potentials, which allow one to track temporal information with a precision at the millisecond range. Different paradigms have been used so far, including delayed picture naming tasks (Cornelissen et al, 2004; Jescheniak et al, 2003; Laganaro, Morand, & Schnider, 2009; Vihla, Laine, & Salmelin, 2006), implicit naming or metalinguistic tasks (e.g., Rodriguez-Fornells et al., 2002; Schmitt, Münte, & Kutas, 2000; Thorpe, Fize, & Marlot, 1996; Van Turennout, Hagoort, & Brown, 1998; Zhang & Damian, 2009; Jescheniak et al., 2002) and, more recently, overt picture naming (see Ganuschack et al., 2011; Strijkers & Costa, 2011 for a critical review of EEG/MEG speech production studies). ERP paradigms using overt picture naming paradigms are the most relevant as they truly involve an overt production of the target words. Studies conducted so far with this task have addressed one step or sub-step of the production process each. They have usually involved a manipulation of the experimental conditions (e.g., semantic context, Aristei, Melinger, & Abdel Rahman, 2011; Blackford et al., 2012; Costa, Strijkers, Martin & Thierry,. 2009) or of the materials, using factorial or semi-factorial designs, i.e. with two subsets of items varying in terms of a specific predictor being compared (e.g., name agreement, Cheng et al., 2010; age of acquisition, Laganaro & Perret, 2011; lexical frequency, Levelt et al., 1998; Strijkers et al., 2010). In the present study, we extend this second approach, by considering most variables described in previous chronometric and ERP studies at once. Moreover, we examine the influence of these variables on experimentally defined periods of electrical stability (topographic maps or event-related brain potential microstates) on the whole word encoding process, from picture onset to articulation. This analysis is likely to inform us on two different issues. Firstly, ERP modulations by variables that can be unambiguously attributed to given word encoding processes will provide precise information on the time course of these specific processes. Secondly, if effects are found for variables whose attribution still lacks empirical support, our findings, together with existing estimates of the time course of the production process, will allow us to propose a specific locus for these variables.

Based on the existing literature, the following variables were included in our analysis: Visual complexity, Concept familiarity, Image agreement, Name agreement, Lexical frequency, Age of acquisition, Word length, Phonological neighborhood, and Phonotactic probability. Figure 1 shows these variables and the processing level with which they have been associated in previous studies. Further details on each variable are provided below.

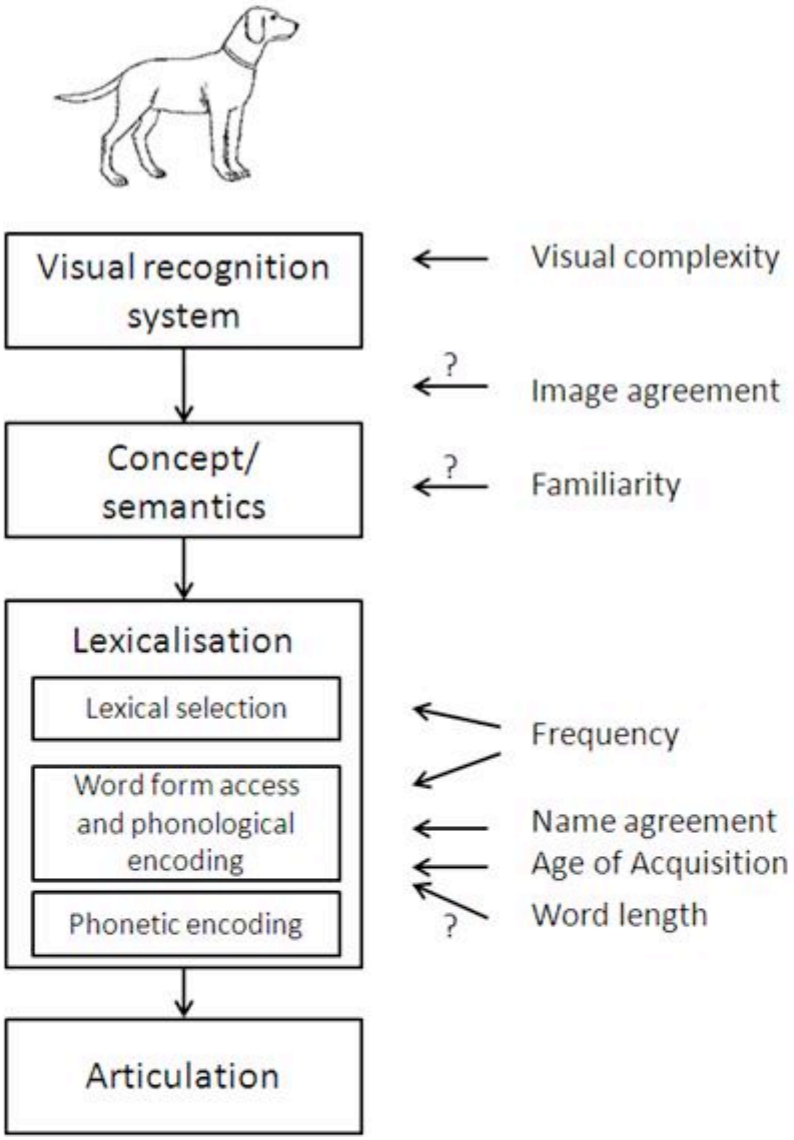


Figure 1. Picture naming model adapted from Alario et al. (2004), with an indication of the psycholinguistic factors exerting an effect on each specific encoding substage (according to the literature review). We have adapted this figure to include more variables and clarify whether the locus is supported by empirical data or not

Visual complexity, defined as "*the amount of detail or intricacy of line in a picture*" (Snodgrass & Vanderwart, 1980), has been associated with object recognition. Empirical evidence in favor of this insofar intuitive hypothesis has recently been found by Martinovic, Gruber and Müller, (2008). The authors reported that the visual complexity of line drawings modulated waveforms in the P1 range, a time window likely associated with visual processes and object recognition. Note also that whereas a few studies found increasing response latencies for more complex pictures (Alario et al., 2004; Attneave, 1957), other studies failed to find differences in response latencies between high and low complexity pictures (Barry et al., 1997; Bonin et al., 2002; Bonin et al., 2003; Cuetos, Ellis, & Alvarez, 1999; Jannssen, Pajtas, & Caramazza, 2011; Paivio et al., 1989; Snodgrass & Yuditsky, 1996) or reported the opposite effect, i.e. decreased production latencies for more complex pictures (Szekely et al., 2005).

Concept familiarity, defined as "*the degree to which participants come in contact with or think about the concept*" (Snodgrass & Vanderwart, 1980, p. 183) has been hypothesized to affect the links between picture representations and their semantic representations (Hirsh & Funnell, 1995). To our knowledge, however, this hypothesis has not been confirmed empirically. As for the previous variable, effects of concept familiarity on picture naming latencies have not been reported systematically. A few studies found increasing response latencies for less familiar pictures (Ellis & Morrison, 1998, Snodgrass & Yuditsky, 1996), while other studies failed to find differences in response latencies between items of high versus low familiarity (Alario et al., 2004; Barry et al., 1997; Dell'Acqua et al., 2000; Bonin et al., 2002, 2003).

Lexical frequency refers to how often the word is used in a language. Shorter response latencies for more frequent words have been reported many times in the psycholinguistic literature (e.g., Alario et al. 2004; Barry, Morrison, & Ellis, 1997; Ellis & Morrison, 1998; Griffin & Bock, 1998; Jesheniak & Levelt, 1994). Note however that the effect of lexical frequency is mostly found in factorial designs and often disappears when Age of Acquisition is controlled for or entered in a regression model (Barry et al, 2001; Barry, Morrison, & Ellis, 1997; Bonin et al., 2002; Carrol & White, 1973; Morrison, Ellis, & Quinlan, 1992, but see Barry et al., 1997, Snodgrass & Yuditsky, 1996; Ellis & Morrison, 1998). Some authors attribute the effect of lexical frequency to lexical (lemma) selection (Alario, Costa, & Caramazza, 2002; Dell, 1990; Navarrette et al., 2006) while others attribute it to phonological encoding (Jesheniak & Levelt, 1994; Levelt et al., 1999). Recent research suggests an effect of lexical frequency at both processing stages (Knobel, Finkbeiner, & Caramazza, 2008; Kittredge et al., 2008). An ERP study by Strijkers et al., (2010) reported waveform divergences between high and low frequency words at 180 msec after picture presentation. The authors suggested that this time period corresponds to the initiation of lexical selection.

Image agreement refers to the strength of association between a picture and the mental object it represents. Effects of image agreement on naming latencies have been found in several studies (Barry et al., 1997, see also Alario et al, 2004). Snodgrass & Vanderwart (1980) hypothesized that this measure would affect image recognition. To our knowledge, no empirical arguments have yet come to back up this view.

Name agreement is a measure of the degree of association between the picture and the corresponding modal name. It is estimated by examining the number of different names participants provide for a given picture. It has been shown that when participants give many different names for a same picture (low name agreement), production latencies are longer (Alario et al., 2004; Barry et al., 1997; Kan & Thomspon-Schill, 2004; Lachman, Shaffer, & Hennrikus, 1974; Paivio et al., 1989; Snodgrass & Yuditsky, 1996; Vitkovitch & Tyrrell, 1995). Name agreement does not affect object decision reaction times, suggesting that the effect of this variable on naming responses occurs during lexical retrieval, and/or during phonological encoding (Johnson, Paivio, & Clark, 1996, Alario et al., 2004). In line with this hypothesis, Cheng et al. (2010) reported an effect of Name Agreement on ERPs in a silent picture naming task at 290 msec from picture onset, a time window usually associated with phonological encoding processes. Note that these authors also found an early influence of Name agreement in the P1 time window (around 120 msec after picture onset). According to the authors, this early influence could reflect the enhanced recruitment of visual attentional resources for pictures with low relative to high name agreement.

Age of acquisition (AoA) refers to the age at which a given word is learnt. Numerous studies have shown that words acquired earlier are named with shorter latencies. The effect appears to be similar with subjective estimates of AoA (e.g., Chalard & Bonin, 2006; Morrison & Ellis, 1995) and with objective measures taken from corpora of child speech (Ellis & Morrison, 1998; Morrison, Chappell, & Ellis, 1997). Reliable effects have also been found when frequency is controlled for (Barry, Hirsh, Johnston, & Williams, 2001). Although some authors have ascribed AoA effects at lexical-semantic encoding stages

(Belke et al., 2005; Johnson & Barry, 2005), most studies converge towards a lexical-phonological locus (Morrison & Ellis, 1995; Morrison et al., 1992), including recent neuropsychological research (Kittredge, Dell, Verkuilen & Schwartz, 2008) and ERP data (Laganaro & Perret, 2011; Laganaro, Valente, & Perret, 2012).

Word length: Studies on the influence of word length on picture naming latencies have reported mixed outcomes (see Cuetos, Ellis, & Alvarez, 1999; Roelofs, 2002; Santiago et al., 2000 for shorter latencies for shorter words and Damian et al., 2010; Dell'Acqua et al., 2000; Snodgrass and Yuditsky, 1996; Bachoud-Lévi et al., 1998 for null effects). As for the attribution of this effect, most models of word production assume that longer words should take longer to be named due to the sequential insertion of phonemes in the metrical structure during phonological encoding. Hence, if length does have an effect, we can assume it is located after lexical retrieval.

More recently, other variables such as phonological neighborhood density (Vitevitch 2002; Vitevitch & Sommers, 2003) and phonotactic probability (Vitevitch, Armbuster, & Chu, 2004) have been shown to affect speech production. The precise locus of the effect of these variables is still controversial. However, as they were not considered or balanced across conditions in previous studies, they may have influenced the outcome through their correlation with other predictors.

Building on previous chronometric and ERP studies, the present research aims at determining the time course of picture naming latencies predictors, this time course being instantiated in specific and experimentally defined periods of electrical stability (topographic maps or event-related brain potential microstates). Topographic analysis is a reference-independent measure of electrical potential variations in the brain. The main theoretical assumption of this approach is that different topographic maps are generated by different cerebral sources and supposedly different cognitive processes (Michel et al., 2009). These analyses do not only provide an insight into when processes differ but also into "how they differ in terms of likely underlying neurophysiologic mechanisms" (Murray, Brunet, & Michel, 2008, p. 249). Another advantage of topographic analysis over waveform analysis is that it is not affected by the choice of a particular reference electrode (see Michel et al., 2009).

The topographic analysis entails a spatio-temporal segmentation of the ERPs in periods of electrophysiological stability (topographic maps), along with precise information regarding their time course. The application of this analysis to stimulus- and response-aligned ERPs adapted to each individual production latency (following Laganaro & Perret, 2011), allows us to cover the entire encoding process from picture onset to articulation and to capture those encoding processes that are truncated when fixed stimulus-aligned ERP time-windows are analyzed. The standard procedure in topographic analysis requires a time point by time point computation of the spatial correlation between the template maps observed in the group-average ERP in *n* different experimental conditions and individual ERP data. This methodology allows one to investigate for instance the association between template maps and particular experimental conditions (e.g. Murray et al., 2008) or to look for differences in the duration of periods of stable electrophysiological stability across experimental conditions (e.g. Laganaro et al., 2012). This in turn allows one to draw conclusions about the dynamics of the cognitive processes involved in these different conditions. In the present study, we will conduct mixed-effects regression analyses to determine the influence of multiple variables on picture naming latencies and single trial ERPs.

This approach has several advantages. Firstly, given that many variables can be considered at once, it provides information on the time course of the whole production process rather than on a single processing step. This is important, as estimations of the time course of word production can be more precise if extracted from a single experiment rather than from different studies. Secondly, the inclusion of many variables also ensures that a given variable is significant over and above the effect of other variables. Thirdly, this methodological approach enables the use of continuous variables rather than categorical ones. As underlined by several researchers (e.g., Baayen 2010; Balling, 2008), factorial designs have many disadvantages when compared to regression designs, including loss of power and influence of confounding variables. A similar methodological approach, involving multiple regression analyses between ERPs and psycholinguistic factors, has been introduced by Hauk et al. (2006) in a visual word recognition study.

Method

Participants

31 undergraduate students (7 men), recruited at the University of Geneva participated in the study. They were all native French speakers, aged between 18 and 36 (mean = 24). They were all right-handed as determined by the Edinburgh Handedness Scale (Oldfield, 1971). Twenty-one participants performed the picture naming task in the framework of the present study. In order to reach at least 2000 trials, this group was completed by 10 additional subjects from a previous study using the same material and procedure (Laganaro et al., 2012). They were selected among the participants with the highest rate of uncontaminated EEG epochs.

The participants gave their informed consent and were paid for their participation.

Material

The stimuli were 120 words and their corresponding black and white line drawings from two French databases (Alario & Ferrand, 1999; Bonin et al., 2003), from which a subset of 100 items was selected. The retained 100 words were those with the highest rate of correct responses and of uncontaminated EEG epochs across the participants (see pre-analyses). The stimuli characteristics are provided in Appendix 1.

Procedure

Participants were tested individually in a soundproof dark room. They sat 60 cm in front of the computer screen. Pictures were presented in constant size of 9.5 cm X 9.5 cm (approximately 4.52° of visual angle) on a grey screen. Before the experiment, participants were familiarized with all the pictures and their corresponding names on a paper sheet. An experimental trial had the following structure: a fixation sign was presented for 500 msec followed by the presentation of a picture on the screen for 2000 msec. Participants were asked to name the picture as quickly as possible. A 2000 msec blank screen was displayed before the next trial. Items were presented in different pseudo-random orders for each participant, which were controlled to avoid for semantically or phonologically related items to appear in direct succession. The experiment lasted about 15 min and started with four warming-up filler trials.

Behavioral analyses

Each spoken response was first checked for accuracy. No-responses, wrong responses (i.e. the participant produced a different name than the one expected), hesitations and/or auto-corrections during articulation were considered errors. A total of 50 responses (1.6% of the total) were excluded.

Response times (defined as the time between the onset of picture presentation and the onset of the verbal response) were precisely defined on the basis of the spoken responses' spectrogram. We further excluded the 62 responses (2% of the total) with a response time below 500 msec or above 1500 msec.

EEG recording and pre-analysis

A high density EEG (128 channels covering the scalp) was recorded, using the Active-Two Biosemi system (Biosemi V.O.F. Amsterdam, Netherlands). Signals were sampled at 512 Hz and the band-pass filters were set between 0.16 and 100 Hz. Post-acquisition analyses were conducted with the Cartool Software (Brunet et al., 2011). Stimulus-aligned epochs – from picture onset to 450 msec - and response-aligned epochs - covering from -550 msec to 100 msec before the onset of each single verbal response - were extracted and band-pass filtered between 0.2 and 30 Hz. All epochs with out-of-range amplitudes (± 100 µV) were first excluded. The remaining epochs were then visually checked for undetected artifacts caused by eye blinking or muscular activity. Contaminated epochs were excluded from the averaging process. Bad channels were interpolated on each epoch following a 3D spline interpolation method. Only epochs for which both stimulus-aligned and response-aligned ERPs were available were retained. Stimulus and response-aligned ERPs were merged together on the basis reaction times for each trial and the overlapping ERP from the response-aligned signal was removed. This procedure is designed to obtain an ERP covering the whole time window of encoding, from picture onset to 100 msec before the initiation of articulation (see Laganaro & Perret 2011; Laganaro et al., 2012 for further applications). It was applied to single epochs (single trials, N= 2693), to epochs averaged across subjects (N=31) and across items (N=100).

ERP analysis

A topographic pattern analysis was carried out. Topographic analysis allows compressing variability of ERPs with a procedure called "spatio-temporal segmentation" in a series of template maps which summarize and explain at best the data (usually the grand-average). This spatio-temporal segmentation was applied to the subject averaged-data using a TAAHC clustering algorithm (Pascual-Marqui et al., 1995). In order to exclude brief periods of topographic instability, a given stable ERP topography had to be present for at least 20 msec to be retained. A combination of cross-validation and Krzanovski-Lai criteria was adopted to select the optimal number of template maps. The Krzanovski-Lai criterion is based on the analysis of the curvature of the dispersion curve (W), which represents a quality measure of the segmentation. The KL value, representing a relative measure of such curvature, usually reaches the peak in correspondence with the optimal clustering (Murray et al., 2008). We then compared the template maps obtained in the segmentation of the group-averaged ERPs with each individual ERP, in this case with the single trial evoked potentials, this procedure is called "fitting". In the fitting procedure, each time point of each individual ERP is labeled on the basis of the spatial correlation it bears with one of the template maps issued from the segmentation of the grand-average. A set of fitting time-windows is determined based on the results of the group-averaged segmentation; the template maps included in such time windows are then fitted back in the same time window of each individual ERP. The procedure is therefore temporally constrained and requires at least two template maps to be included in a particular time window. This procedure provides information on the presence of each stable topographic configuration time point per time point and therefore also on their duration at the individual level. Statistical analyses are then carried out on these two measures between and across conditions or groups.

Statistical analyses and selection of independent variables

Behavioral and EEG responses were analyzed by means of mixed-effects regression models (e.g., Baayen, Davidson, & Bates, 2008; Goldstein, 1987; 1995). All statistical analyses were conducted with the statistical software R (R Development Core Team, 2007) and mixed-effects models were computed with the package lme4 (Bates & Sakar, 2007). Statistical analyses on behavioral responses aimed at determining the predictors of picture naming latencies (i.e., time between onset of picture and onset of articulation) in our dataset. Statistical analyses on ERPs aimed at determining the predictors of the duration of the stable topographic maps defined by the spatio-temporal analysis described above. In each regression model, participants and items were entered as crossed random effects and the same set of variables was entered as fixed effects. When a given predictor could be represented by more than one measure, we examined the influence of each of these measures in separate models. For instance, lexical frequency can be measured by counting the number of occurrence of a given word in a collection of books (written lexical frequency), or in film subtitles (spoken lexical frequency). In French, the two measures are available. We thus conducted two statistical models, one with written frequency and another with spoken frequency. This was done to ensure that the absence of an effect for a given variable was not due to the selection of the wrong measure and favor the use of measures that best accounted for our dataset.

Measures accounting for the following five predictors were taken from either Bonin et al. (2003) or Alario and Ferrand (1999) databases (these two databases provide similar measures for different sets of pictures): the v*isual complexity of the pictures (VCom)*, *concept familiarity (CFam)*, *Image agreement* (*IAgr*), *Age of acquisition* (*AoA*) and *Name agreement (NAgr).* Name agreement was represented with two measures, the percentage of participants who produced the modal name, and the H measure (see Snodgrass and Vanderwart, for details). We also considered (the logarithm of) *lexical frequency (LexF),* as given for Films and Books by Lexique (New et a., 2001), word length (*number of phonemes* and *number of syllables.)* and the Levenshtein phonological measure distance (i.e., mean Levensthein distance (LD) from the stimulus to its 20 closest neighbours, the LD between two words being defined as the minimum number of insertions, deletions or substitutions required to generate one word from the other, see Yarkoni, Balota, & Yap, 2008*)* as a measure of phonological neighborhood density. Finally, and following Vitevich and Luce (2004) we computed two measures of phonotactic probability, *Positional segment frequency and Positional diphone frequency* (i.e., sum of log frequencies of all words that contain a given segment or diphone in a given position, divided by the log frequency of all words with a segment/diphone in this position).

We systematically examined the pairwise comparisons between our predictors. These correlations are provided in Appendix 4. In a given statistical model, the predictors that were correlated above 0.3 were orthogonalized. Orthogonalization between two variables was performed as follows. We first ran a linear model in which variable B predicted variable A. We then used the residuals of this linear model instead of the raw values for variable A as fixed effect in the mixed-effects model. This way, both variables could be included in the model without introducing collinearity. Note that when a residualized variable had a significant influence on the dependent variable, we further checked that the effect remained when the raw measures were considered. This was always the case.

The order of the predictors in a given model was first decided at random. When a given predictor was significant, the model was rerun with this variable entered last. This procedure ensured that any effects of the given predictors are significant over and above the variation explained by the other predictors in the model. Finally, and following Baayen (2008), residuals of the regression model larger than 2.5 times the standard deviation were considered outliers and removed.

Results

Behavioral results (production latencies)

The dataset considered in the analyses contained the 2693 data points for which participants had produced a correct response and whose epoch was considered in the ERP analysis. The mean production latency was 805 msec (sd = 181 msec). The Box-Cox test (Box & Cox, 1964) indicated that the reciprocal transformation was the most appropriate transformation for our data. We thus used the inverse of the latencies as our dependent variable. Results revealed main effects of age of acquisition, name agreement, image agreement and number of syllables. Production latencies increased with age of acquisition and decreased with higher name and image agreement. In addition, bisyllabic words were produced with shorter latencies than monosyllabic words. None of the other predictors was significant (all ps>0.5). Statistical values for each significant predictor are presented in Table 1. Note also that each significant predictor remained significant when random slopes allowing for participants and items to vary with regard to this predictor were entered in the model except for number of syllables. This suggests that this effect was driven by a subset of words or participants only. The R2 of the model (square of correlation between the model's predictions and the observed reaction times, e.g., Baayen and Milin, 2010) was 0.52.

Models conducted for each (unresidualized) variable separately (one variable per model only) revealed again significant effects for name agreement, image agreement, age of acquisition and number of syllables only (see Appendix 3).

Table 1. Summary of the mixed effects regression model for the response latencies.

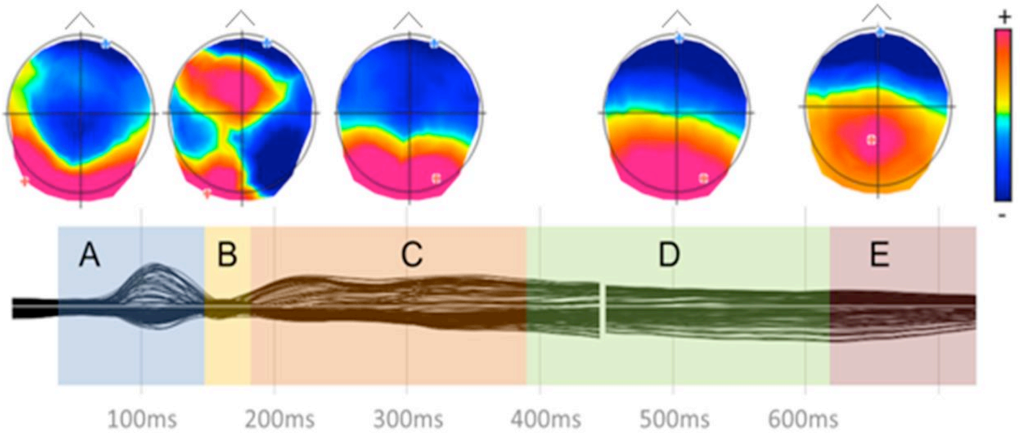
	β	t	p
Familiarity	$6.72\ 10^{-7}$	0.07	> 0.5
Visual complexity	$-5.87\ 10^{-6}$	-0.7	= 0.5
Positional diphone frequency	$3.40\ 10^{-4}$	0.5	> 0.5
Lexical frequency	$-1.58\ 10^{-6}$	-0.2	> 0.5
Phonological Levenshtein distance	$-1.37\ 10^{-5}$	-0.5	> 0.5
Age of acquisition	$7.29\ 10^{-5}$	4.1	< 0.0001
Name agreement	$-5.24\ 10^{-6}$	-5.2	< 0.0001
Image agreement	$-3.20\ 10^{-5}$	-2.8	< 0.01
Nb syllables	Mono versus bi : $-4.83\ 10^{-5}$ Bi versus tri $6.64\ 10^{-6}$ Mono versus tri $-3.77\ 10^{-5}$	-2.7 0.28 -1.5	< 0.01 >0.5 >0.1

In this model, familiarity is residualized with visual complexity, positional diphone frequency is residualized with number of syllables and the Levensthein distance measure, Lexical frequency is residualized with age of acquisition, image agreement and the Levensthein distance measure, and the Levensthein distance measure is residualized with number of syllables

ERPs

The spatio-temporal segmentation of the grand average from picture onset to 100 msec before articulation onset yielded 5 different topographic patterns, which accounted for 95.88% of the overall variance in the data (see Fig. 2). Three time windows were chosen for the fitting procedure, based on the result of the segmentation on the group-average and in order to include at least two map templates in each period : from 50 to 180 msec, from 180 to 460 msec and from 460 msec to 100 msec before articulation. The fitting time-windows were set within rather than at the end of the time-periods of stable electrophysiological activity (topographic maps) to account for between subject and item variability: map templates crossing the fitting borders were entered in the two consecutive fitting periods (maps "A", "B" in the first fitting period, "B", "C", and "D" in the second period, "D" and "E" in last period). In order to ensure that the five topographic maps were not driven by random noise in the trial by trial data, we first performed a topographic consistency test (TCT, Koenig and Melie-Garcia, 2010) on the trial ERPs from a subset of randomly selected items. This analysis revealed that periods of consistent topographic patterns across single trials extended from ~70ms to the end of the analyzed period (100ms before articulation), with the exception of a short period of topographic inconsistency from ~150 to ~180ms in all examined items (see Appendix 2).

A computation of Map presence was then performed separately in ERP trials, items and subjects. Results are summarized in Figure 2.



	Map A	Map B	Map C	Map D	Map E
Trials (N=2693)	92%	89%	92%	98%	99%
Items (N=100)	100%	54%	100%	100%	99%
Subjects (N=32)	90%	35%	94%	94%	90%

Figure 2. Top: Grand-average ERPs (128 electrodes) from onset to 100 msec before articulation and temporal distribution of the topographic maps revealed by the spatio-temporal segmentation, with map templates for the six stable topographies (positive values in red and negative values in blue with display of maximal and minimal scalp field potentials). Bottom: presence of each map template in the fitting in the trials, items and subject ERPs.

Map B was much less present in the subjects' and items' averaged ERPs than in single trials. Crucially for the single trial analysis carried out here, all maps appeared in at least 89% of the trials. The four variables found to affect production latencies were entered as fixed predictors in each regression analysis along with the other psycholinguistic variables as covariates. This ensured that the effects of some were not by products of their correlations with other variables.

Results of the mixed effects regression model for each stable electrophysiological pattern are summarized in Table 2. The durations of all maps except Map "C" were predicted by at least one predictor. The duration of the first stable electrophysiological activity (Map "A") was predicted by *visual complexity* and *concept familiarity*. Its duration decreased with increased visual complexity and with low familiarity. The duration of the following map ("B") was also affected by visual complexity. Map D, which started around 380 msec after picture onset was modulated by *Name Agreement, word Age of Acquisition* and *Image Agreement*. It lasted longer for late-acquired words, for words with low name agreement and low image agreement values. The last stable pattern (map "E" in Figure 2) had a longer duration for late-acquired words and words with low name agreement values.

Table 2. Summary of the mixed-effects regression model for the duration of periods of stable electrophysiological activity (topographic maps).

	Map A: ~ 50-140 msec β, t, sign.	Map B : ~140-180 msec β, t, sign	Map C: ~180-380 msec β, t, sign	Map D: ~ 380-620 msec β, t, sign	Map E: ~ 620 – articulation β, t, sign
VCom	-0.62, t=-2.26 *	-1.6, t=-2.53 *			
CFam	0.71, t=2.14 *				
IAgr				-7.2, t=-2.61 **	
NAgr				-1.1, t=-4.38, ***	-0.68, t=-4.77 ***
AoA				10.28, t=2.40, *	7.44, t=3.0 **
(R2)	*(25)*	*(29)*		*(32)*	*(33)*

*: p<.05; **: p<.01; ***: p<.001
VCom: visual complexity; CFam: Concept Familiarity; IAgr: Image Agreement; NAgr: Name Agreement; AoA: Age of Acquisition.

Discussion

The aim of the present work was to get insight into the dynamics of word production in picture naming tasks. To this end, we analyzed the effects of a set of theoretically relevant variables on response times as well as on an electrophysiological measure, namely the duration of periods of stable EEG activity (topographic maps). A multiple regression approach was implemented on trial by trial ERPs covering the entire encoding period from picture onset to 100 msec before articulation. This approach allowed us to select the variables that truly influenced response times in our dataset and to pinpoint the exact time windows at which these variables exerted their influence.

Three out of the larger set of examined variables had robust independent effects on production latencies: *word age of acquisition, name agreement,* and *image agreement.* Overall, these results confirm previous published data on the predictors of picture naming latencies. Effects of name agreement, age of acquisition and image agreement have indeed been reported in many studies (see Alario et al., 2004 for reviews). The five remaining variables (lexical frequency, visual complexity, familiarity, word length, phonological neighborhood, and phonotactic probability) have also been reported to affect production latencies in previous studies but much less systematically, especially when multiple regression designs were used (see Alario et al., 2004). Crucially for our purposes, the three variables which had an effect on RTs also significantly affected the duration of periods of topographic stability. The results are summarized in Figure 3. In what follows, we will discuss these results in the light of previous psycholinguistic and ERP findings.

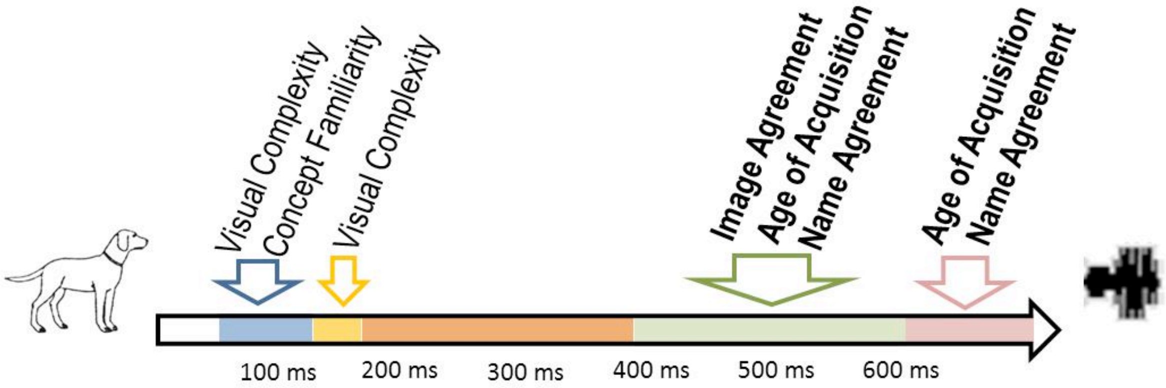


Figure 3. Summary of the time course of the significant predictors in the ERP analyses. Variables that also affected RTs are in bold.

Name agreement modulated the duration of two stable electrophysiological patterns in the time window extending between approximately 380 after picture onset and 100 msec before articulation (Maps "D" and "E" in Figure 2). The duration of these two maps decreased with higher name agreement values. Name agreement is an objective measure of the degree of association between the picture and its modal name.

Low agreement values can have two alternative sources: either the picture is visually ambiguous, or it has several possible names. The finding that the effect of Name agreement occurs rather late in the production process suggests that in the present study, the effect results from the latter and likely takes place during the word's phonological encoding. The erroneous responses provided for our stimuli by the participants in Alario and Ferrand (1999) and Bonin et al. (2003) comfort this hypothesis as the majority of errors are synonyms of the modal name. This finding is in line with previous attributions of this effect to lexical retrieval and/or phonological encoding (Johnson et al., 1996, Alario et al., 2004, see the

Introduction) as well as with Cheng et al. (2010) who reported an influence of Name agreement around 290 msec after picture onset. As already noted in the Introduction, Cheng et al. also found an effect of Name Agreement around 120 msec after picture onset, i.e. in the P100 range. Possibly, this early effect resulted from visual properties of the pictures. Given, however, that in the Cheng et al. study the participants performed a covert picture naming task, comparisons with the present study are not straightforward.

Word *age of acquisition* also modulated the duration of the two last periods of stable electrophysiological patterns. The duration of topographic Maps D and E increased for late-acquired words. As reviewed in the Introduction, most studies converge towards a lexical-phonological locus of AoA effects (Chalard & Bonin, 2006; Kittredge, 2008; Morrison & Ellis, 1995; Morrison, et al., 1992). The temporal signature of word Age of Acquisition has been investigated by Laganaro and Perret (2011) and Laganaro et al. (2012) in a picture naming task, with ERP topographic analyses. The authors found that word age of acquisition modulated ERPs at ~350-400 msec after picture presentation (for an overall response time of 800 msec), a time window compatible with lexical-phonological encoding processes. The present results corroborate these findings. Note that according to Indefrey's (2011) estimate, phonological encoding is engaged between 275 and 450 msec after picture onset. Importantly, however, this estimation is based on mean response latencies of 600 msec. An earlier ERP investigation on the time course of word production comparing different response latencies indicated that lexical (lemma) selection can be lengthened in case of slower production speed (Laganaro et al., 2012), thus delaying phonological encoding (shifting it to the right on the temporal axis); this also seems to be the case in the present data, as mean production latencies are about 800 msec.

An interesting aim for further studies will be to determine whether the effects of AoA and Name Agreement on the two last successive periods of topographic stability are independent (i.e., name agreement and age of acquisition affect separately each of these periods of stability) or related (the effect on the last period is determined by the previous one). It is worth noting here that very few other studies have concerned specifically the very last time periods of the production process (i.e., after phonological encoding). According to previous models and estimates (e.g., Indefrey, 2011), the last time period preceding articulation should correspond to the process of phonetic encoding.

Image agreement modulated the duration of the stable topographic configuration ranging from approximately 380 to 620 msec after picture onset. Higher image agreement yielded shorter durations of map D. The concept of Image agreement was formalized by Snodgrass & Vanderwart (1980). These authors asked participants to judge the degree to which a picture would correspond to the mental object of that picture's name. Barry et al. (1997, see also Alario et al., 2004) found that the higher these scores, the shorter the naming latencies. These authors hypothesized that image agreement has its influence during object recognition. Accordingly, it should modulate ERPs in an early time-window, associated with pre-linguistic processes. This suggestion was rather intuitive, based on the fact that IA should code the prototypicality of the picture for a given object. Our results are clearly at odds with this interpretation, since IAgr modulated ERPs in the same time-window as AoA and NAgr, i.e. in the time window associated with lexical-phonological processes. This finding clearly questions the association of Image Agreement with pre-linguistic processes, and rather suggests that it refers to the link between the picture and its name. Possibly IAgr and NAgr reflect the same underlying predictor but are measured differently (as is evident from the low correlation between the two measures (r=0.2) and their independent effects on response times and map durations). When asked to estimate Image Agreement, participants are first presented with the name of the picture to rate, and this information likely plays a major role on their ratings. Unlike Name agreement values, however, Image agreement measures are based on subjective estimated strengths between the picture and the concept. Raters will thus differentiate, for instance, between pictures with a single possible noun, pictures with many nouns among which one is clearly dominant, and pictures with many nouns without a clear favorite. By contrast, Name agreement measures are based on the objective number of responses provided for a given picture. Consequently, they should not differentiate between the two first categories. It is also worth noting here that the effect of Image agreement, unlike that of NAgr and AoA, does not extend to the following map. This suggests that the mechanisms that are responsible for two consecutive effects for NAgr and AoA do not have a general character.

Two variables, the visual complexity of the pictures and concept familiarity modulated ERPs but did not affect RTs. *Visual complexity* modulated the duration of the first period of EEG stability, in the time window ranging from 50 to about 140 msec after stimulus presentation and of the second topographic map (from ~140 to ~180 msec). The upper boundary of the visual complexity effect likely indicates that the limit of pre-linguistic processing in picture naming lays at approximately 180 msec. The shorter duration for more complex pictures likely reflects the fact that pictures can be recognized faster the more details they contain; this is in agreement with studies reporting shorter production latencies for more complex pictures (Szekely et al., 2005, but see Alario et al., 2004). The effect falls within the P1 range, traditionally associated with visual processing. Similar results have been reported by Martinovic et al. (2008, exp. 2) who compared ERPs of pictures with high versus low visual complexity in a gender decision task. Visual complexity did not affect response times, but modulated ERPs in the P1 range with higher amplitudes and increased evoked gamma-band activity, but also earlier peak latency for high complexity relative to low complexity pictures.

Concept familiarity influenced ERPs in the time window from 50 to 140 msec. Hence, like visual complexity, concept familiarity modulated ERPs in early time-windows, usually associated with visual processing and object recognition (Thorpe et al., 1996). As such, these results confirm the pre-linguistic locus of these effects on picture naming. Note however that the time period corresponding to the second topographic map is characterized by low topographic consistency (see Fig 2 and Appendix 2); therefore, results on map "B" are less reliable than on all other time periods. This could explain the counter-intuitive finding that this map is shorter for less familiar words.

Interestingly, the duration of the stable electrophysiological activity in the time window ranging from about 180 to about 380 msec was not affected by any of the variables considered in our study. This period of topographic stability covers a time window which has been previously associated with lexical selection (e.g., Strijkers et al., 2010, see also Indefrey, 2011). The only variable whose influence is thought to originate at least partly during lexical selection is lexical frequency. In the present study, there was no effect of this variable on response times or on any of the periods of topographic stability whatever the lexical frequency measure (spoken or written) considered. The fact that lexical frequency was introduced in the statistical model as a continuous variable represents a possible explanation for the lack of lexical frequency effects. Effects of continuous measures of lexical frequency are often not found to be influent in multiple regression analyses (Bonin et al., 2002; Chalard et al., 2003, Dell'Acqua et al., 2000),while they arise in factorial designs where the difference between frequency conditions is maximized (Strijkers et al., 2010). The lexical frequency norms used in the present study come from a large French corpus (New et al., 2004), which has been validated in lexical decision tasks (New et al., 2007) but not in picture naming tasks using small sets of items. Actually, previous picture naming studies using continuous lexical frequency measures from the same French database reported frequency effects with large sets of stimuli (400 words in Alario et al., 2004; 300 in Bonin et al., 2003), but failed to report lexical frequency effects with sets involving 200 or less items (Bonin et al., 2002; Chalard et al., 2003). Thus, the lack of effect on the topographic map C may be due to a lack of power.

In addition to documenting important theoretical issues on the time course of word production in picture naming, this research opens up new methodological prospects. So far, previous research on language production using event-related potentials relied on factorial designs. As underlined by several authors, factorial designs have several drawbacks, including lack of systematic control of potential confounds, and loss of statistical power. By contrast, the methodology used here does not suffer from these downsides and, as such, is particularly valuable for language studies, where the properties of the linguistic materials are salient variables. Moreover, in classical analyses, ERPS are averaged across subjects. Consequently, the statistical models do not provide information about the variance related to the items, and one may question whether their outcomes can truly be generalized across words (e.g., Barr, Levy, Scheepers, & Tily, in press). It is worth noting that several observations in our data suggest that our approach is extremely robust. Firstly, each topographic map revealed by the spatio-temporal segmentation on the grand-average ERPs was present in at least 89% of the single trials (up to 100% for some maps). Secondly, the rate of topographic map presence was comparable or higher in single trials than in items or subjects averaged ERPs. Moreover, the TCT analysis revealed high consistency across trials, except in the short time period ranging from ~150 to ~180ms after picture onset. As previously advocated in other cognitive domains (Tzovara et al., 2012) a high rate of stable electrophysiological map presence licenses a trial by trial approach.

To conclude, the classical mental chronometry approach in cognitive psychology holds that any increase in response latency by a given variable reflects an underlying processing cost. The ERP analysis applied here to picture naming data allowed us to associate the cost generated by psycholinguistic variables to the duration of stable electrophysiological processes. This approach identified the time windows at which visual complexity, concept familiarity, Name agreement, Age of acquisition and Image agreement exert their influence and provided novel and precise information on the time course of word production processes.

Acknowledgements This research was supported by Swiss National Science Foundation grants no. PP001-118969 and PP00P1_140796 to Marina Laganaro.

References

Alario, F.X., Costa, A., & Caramazza, A. (2002). Hedging one's bets too much? A reply to Levelt (2002). *Language & Cognitive Processes, 17(6)*, 673-682.

Alario, F.X., & Ferrand, L. (1999). A set of 400 pictures standardized for French: norms for name agreement, image agreement, familiarity, visual complexity, image variability, and age of acquisition. *Behavior Research Methods, Instruments & Computers, 31,* 531-552.

Alario, F.X., Ferrand, L., Laganaro, M., New, B., Frauenfelder, U.H., & Segui, J. (2004). Predictors of picture naming speed. *Behavior Research Methods, Instruments & Computers, 36*, 140-155.

Aristei, S., Melinger, A., & Abdel Rahman, R. (2011). Electrophysiological chronometry of semantic context effects in language production. *Journal of Cognitive Neuroscience, 23*, 1567-1586.

Attneave, F. (1957). Physical determinants of the judged complexity of shapes. *Journal of Experimental Psychology, 53,* 221-227.

Baayen, R. H. (2008). Analyzing Linguistic Data. A Practical Introduction to Statistics Using R. Cambridge University Press.

Baayen, R.H., & Milin, P (2010). Analyzing reaction times. *International Journal of Psychological Research, 3 (2)*, 12-28

Baayen, R.H. (2010). A real experiment is a factorial experiment? *The Mental Lexicon, 5 (1)*, 149-157.

Baayen, R.H., Davidson, D.J., & Bates, D.M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language, 59*, 390-412.

Bachoud-Lévi, A.C., Dupoux, E., Cohen, L. & Mehler, J. (1998). Where is the length effect? A cross-linguistic study of speech production. *Journal of Memory and Language, 39(3),* 331-346.

Balling, L.W. (2008). A brief introduction to regression designs and mixed-effects modelling by a recent convert. *Copenhagen Studies in Language* 36, pp. 175-192.

Barr D., Levy R., Scheepers C., & Tily H.J. (in press). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language.*

Barry, C., Hirsh, K.W., Johnston, R.A., & Williams, C.L. (2001). Age of acquisition, word frequency, and the locus of repetition priming of picture naming. *Journal of Memory and Language, 44*, 350-375.

Barry, C., Morrison, C. M., & Ellis, A.W. (1997). Naming the Snodgrass and Vanderwart pictures: Effects of age of acquisition, frequency, and name agreement. *Quarterly Journal of Experimental Psychology, 50A*, 560-585.

Bates D.M., & Sarkar D. (2007). lme4: Linear mixed-effects models using S4 classes. R package version 0.9975–12.

Belke, E., Brysbaert, M., Meyer, A. S., & Ghyselinck, M. (2005). Age of acquisition effects in picture naming: Evidence for a lexical-semantic competition hypothesis. *Cognition, 96,* B45-B54. doi:10.1016/j.cognition.2004.11.006

Blackford T., Holcomb P., Grainger J., & Kuperberg G.R. (2012). A funny thing happened on the way to articulation: N400 attenuation despite behavioral interference in picture naming. *Cognition, 123(1)*, 84-99.

Bock, K. (1996). Language production: methods and methodologies. *Psychonomic Bulletin & Review, 3*, 395-421.

Bonin, P ., Chalard, M., Méot, A., & Fayol, M. (2002). The determinants of spoken and written picture naming latencies. *British Journal of Psychology, 93*, 89-114.

Bonin, P., Peereman, R., Malardier, N., Mot, A., & Chalard, M. (2003). A new set of 299 pictures for psycholinguistic studies: French norms for name agreement, image agreement, conceptual familiarity, visual complexity, image variability, age of acquisition, and naming latencies. *Behavior Research Methods, Instruments, & Computers, 35,* 158-167.

Box, G. E. P., & Cox, D. R. (1964). An analysis of transformations. *Journal of the Royal Statistical Society, Series B, 26*, 211-252.

Brunet, D., Murray, M.M., & Michel, C. M. (2011). Spatiotemporal analysis of multichannel EEG: CARTOOL. *Computational Intelligence and Neuroscience, 2011, Article ID 813870*. doi:10.1155/2011/813870.

Carroll, J. B., & White, M. N. (1973). Age-of-acquisition norms for 220 picturable nouns. *Journal of Verbal Learning & Verbal Behavior, 12*, 563-576.

Chalard, M., Bonin, P., Méot, A., & Boyer B., & Fayol M. (2003). Objective age-of-acquisition (AoA) norms for a set of 230 object names in French: Relationships with other variables used in psycholinguistic experiments, the English data from Morrison et al. (1997) and naming latencies. *European Journal of Cognitive Psychology*, *15,* 209-245

Chalard, M., & Bonin, P. (2006). Age-of-acquisition effects in picture naming: Are they structural and/or semantic in nature? *Visual Cognition, 137(8),* 864-883.

Cheng X., Schafer G., & Akyürek E. G., (2010). Name agreement in picture naming: An ERP study. *International Journal of Psychophysiology, 76(3)*, 130-141.

Cornelissen, K., Laine, M., Renvall, K., Saarinen,T., Martin, N., & Salmelin, R. (2004). Learning new names for new objects: cortical effects as measured by magnetoencephalography. *Brain and Language, 89*, 617–622.

Costa, A., Strijkers, K., Martin, C., & Thierry, G. (2009). The time course of word retrieval revealed by event-related brain potentials during overt speech. *Proceedings of the National Academy of Science,, 106*, 21442–21446.

Cuetos, F., Ellis, A.W., & Alvarez, B. (1999). Naming times for the Snodgrass and Vanderwart pictures in Spanish. *Behavior Research Methods, Instruments, & Computers, 31*, 650-658.

Damian, M. F., Bowers, J. S., Stadthagen-Gonzalez, H., & Spalek, K. (2010). Does word length affect speech onset latencies in single word production? *Journal of Experimental Psychology: Learning, Memory & Cognition, 36*, 892-905.

Dell, G. S. (1986). A spreading-activation theory of retrieval in sentence production. *Psychological Review 93,* 283–321.

Dell, G. S. (1988). The retrieval of phonological forms in production: Tests of predictions from a connectionist model. *Journal of Memory and Language, 27,* 124–42.

Dell, G. S. (1990) Effects of frequency and vocabulary type on phonological speech errors. *Language and Cognitive Processes, 5,* 313–49.

Dell'Acqua, R., Lotto, L., & Job, R. (2000). Naming times and standardized norms for the Italian PD/DPSS set of 266 pictures: direct comparisons with American, English, French, and Spanish published databases. *Behavior Research Methods, Instruments, and Computers, 32,* 588–615.

Ellis, A. W., & Morrison, C. M. (1998). Real age-of-acquisition effects in lexical retrieval. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 24,* 515-523.

Fromkin, V. A. (1971). The Non-Anomalous Nature of Anomalous Utterances. *Language, 47(1),* 27-52.

Ganushchak, L. Y., Christoffels, I., & Schiller, N. (2011). The use of electroencephalography (EEG) in language production research: A review. *Frontiers in Language Sciences, 2*, 208.

Garrett, M. F. (1980). Levels of processing in sentence production. In B. Butterworth (Ed.), Language production: Vol. 1. Speech and talk (pp. 177–220). San Diego, CA: Academic Press.

Glaser, W. R., & Düngelhoff, F.J. (1984). The time course of picture-word interference. *Journal of Experimental Psychology: Human Perception and Performance, 10(5),* 640-654.

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

Goldstein, H. (1987). Multilevel models in educational and social research. London, Griffin.

Goldstein, H. (1995). Multilevel Statistical Models , Halstead Press, New York.

Griffin, Z.M., & Bock, K. (1998). Constraint, word frequency, and levels of processing in spoken word production. *Journal of Memory and Language, 38,* 313-338.

Hauk, O., Davis, M.H., Ford, M., Pulvermüller, F. & Marslen-Wilson, W.D. (2006). The time course of visual word recognition as revealed by linear regression analysis of ERP data. *Neuroimage, 30,* 1383-400.

Hirsh, K.W., & Funnell, E. (1995). Those old, familiar things: Age of acquisition, familiarity and lexical access in progressive aphasia. *Journal of Neurolinguistics, 9,* 23-32.

Indefrey, P. (2011). The spatial and temporal signatures of word production components: A critical update. *Frontiers in Psychology, 2,* 1–16.

Indefrey, P., & Levelt, W., (2004). The spatial and temporal signatures of word production components. *Cognition, 92,* 101–144.

Janssen, N., Pajtas, P., & Caramazza, A. (2011). A set of 150 pictures with morphologically complex English compound names. Norms for name agreement, familiarity, image agreement and visual complexity. *Behavior Research Methods, 43*, 478-490.

Jescheniak, J. D., & Levelt, W. J. M. (1994). Word frequency effects in speech production: Retrieval of syntactic information and of phonological form. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20*, 824-843.

Jescheniak, J. D., Schriefers, H., Garrett, M. F., & Friederici, A. D. (2002). Exploring the activation of semantic and phonological codes during speech planning with event-related brain potentials. *Journal of Cognitive Neuroscience, 14,* 951-964.

Jescheniak, J. D., Schriefers, H., & Hantsch, A. (2003). Utterance format affects phonological priming in the picture-word task: Implications for models of phonological encoding in speech production. *Journal of Experimental Psychology: Human Perception and Performance, 29,* 441-454.

Johnson, C., Paivio, A., & Clark, J. M. (1996). Cognitive components of picture naming. *Psychological Bulletin, 120(1),* 113-139.

Johnston, R.A., & Barry, C. (2005). Age of acquisition effects in the semantic processing of pictures. *Memory and Cognition, 33,* 905-912.

Kan, I.P., & Thompson-Schill, S. L. (2004). Selection from perceptual and conceptual representations. *Cognitive, Affective, & Behavioral Neuroscience, 4,* 466-482.

Kittredge, A.K., Dell, G.S., Verkuilen, J., & Schwartz, M.F. (2008). Where is the effect of frequency in word production? Insights from aphasic picture-naming errors. *Cognitive Neuropsychology, 25,* 463-492.

Knobel, M., Finkbeiner, M., & Caramazza, A. (2008). The many places of frequency: Evidence for a novel locus of the lexical frequency effect in word production. *Cognitive Neuropsychology, 25(2),* 256-286.

Koenig, T., & Melie-García, L. (2010). A method to determine the presence of averaged event-related fields using randomization tests. *Brain Topography, 3,* 233–242.

Lachman, R., Shaffer, J.P., & Hennrikus, D. (1974). Language and cognition: Effects of stimulus codability, name-word frequency, and age of acquisition on lexical reaction time. *Journal of Verbal Learning & Verbal Behavior, 13*, 613-625.

Laganaro, M., Valente, A., & Perret, C. (2012). Time course of word production in fast and slow speakers: a high density ERP topographic study. *Neuroimage, 59,* 3881-3888.

Laganaro, M., & Perret, C. (2011). Comparing electrophysiological correlates of word production in immediate and delayed naming through the analysis of word age of acquisition effects. *Brain Topography, 24,* 19–29.

Laganaro, M., Morand, S., & Schnider, A. (2009). Time course of evoked-potential changes in different forms of anomia in aphasia. *Journal of Cognitive Neuroscience, 21(8),* 1499-1510.

Levelt, W. J. M., Praamstra, P., Meyer, A. S., Helenius, P., & Salmelin, R. (1998). An MEG study of picture naming. *Journal of Cognitive Neuroscience, 10,* 553–567.

Levelt, W. J. M., Roelofs, A., & Meyer A. S. (1999). A theory of lexical access in speech production. *Behavioral and Brain Science, 21,* 1–38.

Levelt, W.J.M., Praamstra, P., Meyer, A. S., Helenius, P., & Salmelin, R. (1998). An MEG study of picture naming. *Journal of Cognitive Neuroscience, 10,* 553–567.

Martinovic, J., Gruber, T., & Müller, M.M. (2008). Coding of Visual Object Features and Feature Conjunctions in the Human Brain. *PLoS ONE 3(11):* e3781. doi:10.1371/journal.pone.0003781

Michel, C.M., Koenig, T., Brandeis, D., & Gianotti L.R.R. (2009). Electric neuroimaging. Cambridge: Cambridge University Press.

Morrison, C.M., & Ellis, A. W. (1995). The roles of word frequency and age of acquisition in word naming and lexical decision. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21,* 116-133.

Morrison, C. M., Chappell, T. D., & Ellis, A. W. (1997). Age of acquisition norms for a large set of object names and their relation to adult estimates and other variables. *Quarterly Journal of Experimental Psychology, 50A,* 528-559.

Morrison, C.M., Ellis, A. W., & Quinlan, P. T. (1992). Age of acquisition, not word frequency, affects object naming, not object recognition. *Memory and Cognition, 20,* 705-714.

Murray, M.M., Brunet, D., & Michel C. (2008). Topographic ERP analyses, a step-by-step tutorial review. *Brain Topography, 20,* 249-269.

Navarrete, E., Basagni, B., Alario, F.X., & Costa, A. (2006). Does word frequency affect lexical selection is speech production? *Quarterly Journal of Experimental Psychology, 59, 1681-1690*.

New, B., Brysbaert, M., Veronis, J., & Pallier, C. (2007). The use of film subtitles to estimate word frequencies. Applied Psycholinguistics, 28, 661-677.

New, B., Pallier, C., Brysbaert, M., Ferrand, L. (2004) Lexique 2 : A New French Lexical Database. Behavior Research Methods, Instruments, & Computers, 36 (3), 516-524

Oldfield, R.C., (1971). The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia, 9*, 97–113.

Paivio, A., Clark, J. M., Digdon, N., & Bons, T. (1989). Referential processing: Reciprocity and correlates of naming and imaging. *Memory and Cognition, 17,* 163-174.

Pascual-Marqui R.D., Michel C.M., & Lehmann D. (1995). Segmentation of brain electrical activity into microstates, model estimation and validation. *IEEE Transactions on Biomedical Engineering, 42*, 658–65.

Rodriguez-Fornells, A., Schmitt, B. M., Kutas, M., & Münte, T. (2002). Electrophysiological estimates of the time course of semantic and phonological encoding during listening and naming. *Neuropsychologia, 40,* 778–787.

Roelofs, A. (2002). Syllable structure effects turn out to be word length effects: Comment on Santiago et al. (2000). *Language and Cognitive Processes, 17,* 1-13.

Santiago, J., MacKay, D. G., Palma, A., & Rho, C. (2000). Sequential activation processes in producing words and syllables: Evidence from picture naming. *Language & Cognitive Processes, 15,* 1-44.

Schmitt, B.M., Münte, T.F., & Kutas, M. (2000). Electrophysiological estimates of the time course of semantic and phonological encoding during implicit picture naming. *Psychophysiology, 37,* 473–484.

Schriefers, H., Meyer, A. S. & Levelt, W.J. M. (1990). Exploring the time course of lexical access in language production: Picture-word interference studies. *Journal of Memory and Language, 29(1),* 86-102.

Snodgrass, J.G., & Vanderwart, M. (1980). A standardized set of 260 pictures: Norms for name agreement, image agreement, familiarity, and visual complexity. Journal of Experimental Psychology: *Human Learning & Memory, 6,* 174-215.

Snodgrass, J. G., & Yuditsky, T. (1996). Naming times for the Snodgrass and Vanderwart pictures. *Behavior Research Methods, Instruments, & Computers, 28*, 516-536.

Strijkers, K., & Costa, A. (2011). Riding the lexical speedway: a critical review on the time course of lexical access in speech production. *Frontiers in Psychology, 2*, 356.

Strijkers, K., Costa, A., & Thierry, G. (2010). Tracking lexical access in speech production: electrophysiological correlates of word frequency and cognate effects. *Cerebral Cortex, 20*, 912–928.

Szekely, A., D'Amico, S., Devescovi, A., Federmeier, K., Herron, D., Iyer, G., Jacobsen, T., Arévalo, A. L., Vargha, A., & Bates, E. (2005). Timed action and object naming. *Cortex, 41(1),* 7-26.

Thorpe, S., Fize, D., & Marlot, C. (1996). Speed of processing in the human visual system. *Nature, 381*, 520–522.

Tzovara, A., Murray, M.M., Plomp, G., Herzog, M.H., Michel, C.M., & De Lucia, M., (2012). Decoding stimulus-related information from single-trial EEG responses based on voltage topographies. *Pattern Recognition, 45 (6),* 2109–2122.

Van Turennout, M., Hagoort, P., & Brown, C. M. (1998). Brain activitity during speaking: From syntax to phonology in 40 milliseconds. *Science, 280,* 572-574.

Vihla, M., Laine, M., & Salmelin, R. (2006). Cortical dynamics of visual/semantic vs. phonological analysis in picture confrontation. *Neuroimage, 33,* 732–738.

Vitevitch, M. S. (2002). The influence of phonological similarity neighborhoods on speech production. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 28,* 735-747.

Vitevitch, M.S. & Sommers, M.S. (2003). The facilitative influence of phonological similarity and neighborhood frequency in speech production in younger and older adults. *Memory & Cognition, 31,* 491-504.

Vitevitch, M.S. & Armbruster, J. & Chu, S. (2004). Sublexical and lexical representations in speech production: Effects of phonotactic probability and onset density. *Journal of Experimental Psychology: Learning, Memory and Cognition, 30,* 514-529.

Vitkovitch, M., & Tyrrell, L. (1995). Sources of disagreement in object naming. *Quarterly Journal of Experimental Psychology, 48A*, 822-848.

Yarkoni, T, Balota, D.A., & Yap, M.J. (2008). Moving Beyond Coltheart's N: A New Measure of Orthographic Similarity. *Psychonomic Bulletin & Review, 15,* 971-979.

Zhang, Q. & Damian M.F. (2009). The time course of segment and tone encoding in Chinese spoken production: an event-related potential study. *Neuroscience 163 (1),* 252-65.

APPENDIX 1

Stimuli used in the Experiment and their properties

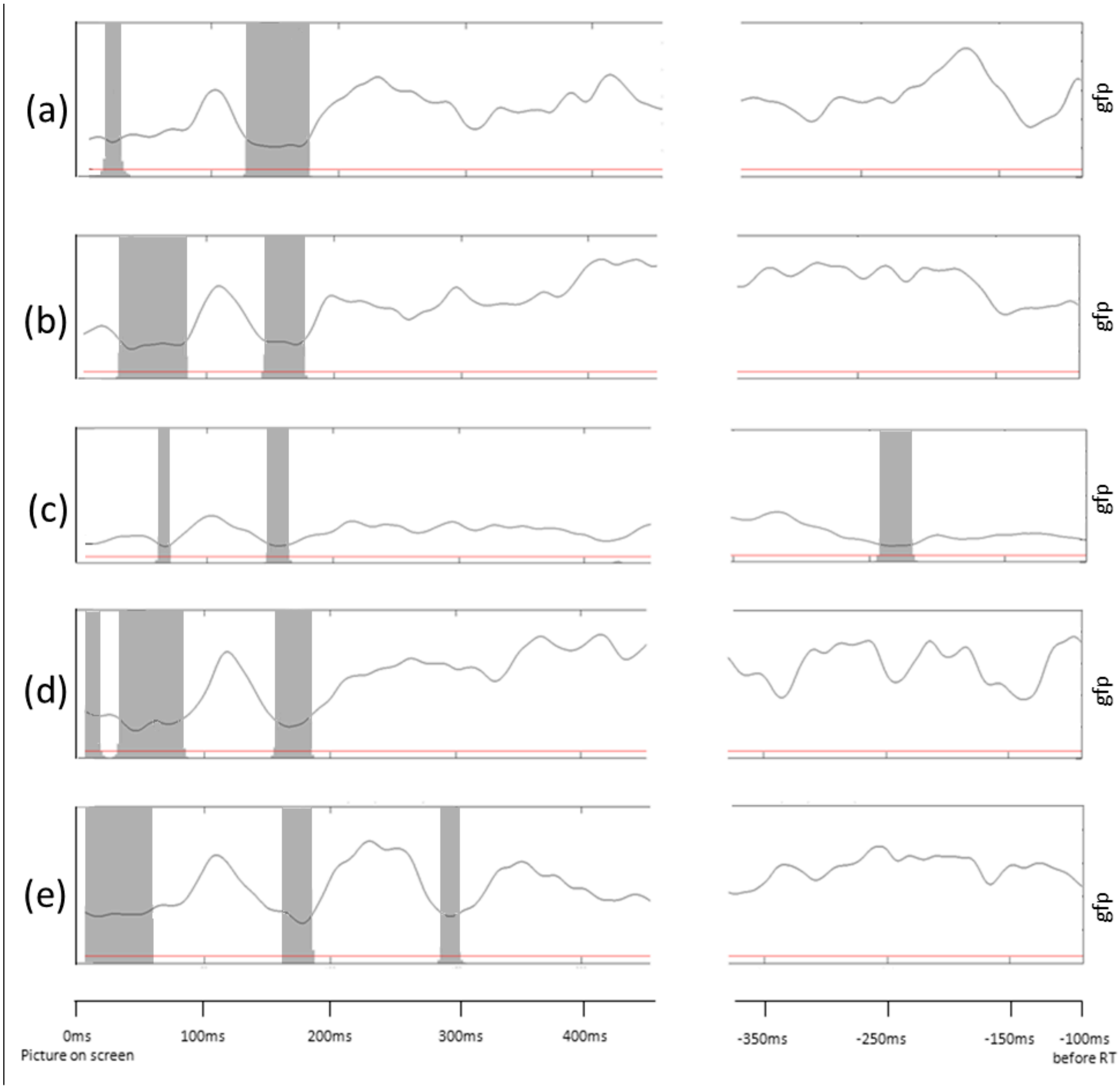
Item	Name agreement (H)	Name agreement (%)	Image agreement	Concept familiarity	Visual complexity	Age of Acquisition	Log Lexical freq. (movies)	Lexical freq. (Frantext)	N.of syllables	Positional segment freq.	Positional diphone freq.	Phonological Levenshtein distance
mean	*0.16*	*93.03*	*3.63*	*3.01*	*2.99*	*2.17*	*1.10*	*20.02*	*1.79*	*0.25*	*0.02*	*1.56*
SD	*0.21*	*8.29*	*0.73*	*0.89*	*0.97*	*0.48*	*0.46*	*30.94*	*0.68*	*0.12*	*0.02*	*0.43*
abeille	0.47	65.00	3.63	2.43	4.93	1.88	0.7	3.2	2	0.16	0.008	1.85
allumette	0.00	100.00	4.95	4.05	1.65	2.40	0.7	5.5	3	0.29	0.023	1.90
ananas	0.00	100.00	4.77	2.73	4.52	2.46	0.5	2.1	3	0.23	0.009	1.80
âne	0.00	100.00	4.20	2.07	3.59	2.08	1.1	10.8	1	0.09	0.003	1.00
araignée	0.15	96.00	3.03	2.20	3.21	2.15	1.1	8.3	3	0.31	0.021	1.95
arc	0.00	95.00	4.40	1.85	3.30	2.40	0.7	29.7	1	0.21	0.010	1.00
arrosoir	0.00	96.00	4.00	2.27	2.72	2.31	0.1	1.5	3	0.39	0.037	2.40
avion	0.29	98.00	3.93	2.63	3.17	1.92	2.0	34.7	2	0.12	0.008	1.45
bague	0.00	96.00	2.63	4.00	2.28	2.32	1.4	9.1	1	0.18	0.012	1.00
baignoire	0.00	100.00	4.35	4.40	3.05	2.40	1.1	7.2	2	0.29	0.030	1.95
balai	0.00	93.00	3.77	4.10	2.28	1.95	1.0	7.7	2	0.28	0.029	1.00
balançoire	0.00	98.00	3.57	2.47	1.69	1.84	0.5	1.8	3	0.49	0.046	2.80
banane	0.00	100.00	4.60	3.87	1.21	1.58	0.9	2.5	2	0.30	0.023	1.70
boîte	0.26	80.00	2.70	2.97	1.21	1.65	1.9	58.8	1	0.19	0.020	1.30
botte	0.40	96.00	2.47	3.73	2.69	2.04	0.9	5.6	1	0.15	0.003	1.00
bougie	0.00	91.00	4.03	3.60	2.45	1.96	0.9	10.7	2	0.20	0.010	1.50
briquet	0.61	100.00	4.30	3.95	2.15	2.30	1.0	7.6	2	0.28	0.026	1.25
brosse	0.15	96.00	2.67	4.23	2.69	1.77	0.9	11.4	1	0.21	0.010	1.70
bureau	0.00	72.00	3.20	4.60	2.97	2.65	2.2	97.8	2	0.25	0.015	1.35
cadeau	0.00	100.00	1.25	2.95	3.75	1.75	2.0	18.7	2	0.27	0.020	1.00
cage	0.00	93.00	3.13	1.80	4.38	2.27	1.2	22.2	1	0.22	0.018	1.00
camion	0.00	100.00	2.77	3.23	2.90	1.62	1.7	18.2	2	0.30	0.027	1.75
canapé	0.34	65.00	3.17	4.40	2.31	2.16	1.3	10.0	3	0.44	0.031	1.95
canard	0.29	93.00	3.47	2.50	2.97	1.85	1.2	9.6	2	0.43	0.043	1.20
canne	0.31	95.00	4.35	3.30	4.45	3.45	1.0	16.6	1	0.24	0.021	1.00
carotte	0.00	98.00	4.47	3.90	3.07	1.58	0.5	2.5	2	0.43	0.050	1.25
ceinture	0.41	98.00	4.23	4.13	1.93	2.42	1.3	20.9	2	0.31	0.014	1.55
cendrier	0.16	96.00	3.30	4.00	2.62	2.85	0.7	5.9	3	0.52	0.056	1.95
cerise	0.29	98.00	3.77	3.13	1.34	2.00	0.6	2.5	2	0.38	0.024	1.90
cerveau	0.15	98.00	3.37	2.80	3.34	3.12	1.8	28.2	2	0.33	0.036	1.60
chaîne	0.67	91.00	2.93	2.93	2.72	2.69	1.5	45.7	1	0.10	0.004	1.15
champignon	0.00	96.00	3.67	2.90	3.00	2.35	0.6	4.2	3	0.21	0.012	2.65
chapeau	0.00	100.00	2.93	2.83	2.38	1.62	1.7	42.5	2	0.21	0.014	1.35
chien	0.00	100.00	2.23	3.80	2.76	1.19	2.2	69.7	1	0.04	0.004	1.50

cigarette	0.29	98.00	3.93	4.10	2.17	2.38	1.6	40.5	3	0.48	0.056	2.80
ciseau	0.34	100.00	4.50	4.07	2.24	2.00	0.3	2.4	2	0.21	0.014	1.60
citron	0.00	100.00	4.83	3.63	1.72	1.88	1.0	8.1	2	0.34	0.033	1.50
cloche	0.15	96.00	3.70	2.10	3.00	2.19	1.0	15.1	1	0.15	0.006	1.55
collier	0.47	100.00	3.90	3.33	1.79	1.86	1.3	9.0	2	0.33	0.036	1.55
commode	0.15	76.00	3.30	4.27	2.83	2.96	0.6	23.5	2	0.21	0.022	1.80
crabe	0.00	78.00	4.13	2.10	4.10	2.38	0.8	5.0	1	0.26	0.026	1.45
cravate	0.00	93.00	3.80	3.33	2.66	2.38	1.2	15.5	2	0.41	0.035	1.90
croissant	0.00	100.00	4.77	3.77	2.93	2.04	0.4	13.7	2	0.36	0.033	1.55
cube	0.34	100.00	3.80	2.80	1.15	2.25	0.4	6.4	1	0.15	0.004	1.40
dent	0.47	85	4.2	2.1	3.6	2.15	1.2	9.0	1	0.11	0.002	1.00
douche	0.78	91.00	2.33	4.87	3.72	2.23	1.5	10.4	1	0.14	0.005	1.15
échelle	0.00	96.00	3.97	2.70	2.59	2.27	1.2	48.5	2	0.12	0.004	1.90
éléphant	0.00	100.00	3.90	1.40	4.55	2.04	1.0	5.7	3	0.14	0.007	1.85
escargot	0.00	98.00	3.77	2.30	3.00	1.88	0.6	2.4	3	0.29	0.028	2.65
flèche	0.00	98.00	3.83	1.53	1.93	2.52	1.0	14.1	1	0.13	0.009	1.50
fraise	0.00	89.00	3.03	3.20	2.76	1.81	0.8	2.7	1	0.20	0.017	1.40
gâteau	0.00	93.00	2.87	3.67	2.34	1.27	1.6	9.8	2	0.25	0.021	1.35
girafe	0.00	100.00	4.47	1.30	4.97	2.12	0.6	1.0	2	0.30	0.019	1.95
gomme	0.29	75.00	3.95	3.30	2.55	3.35	0.6	6.8	1	0.08	0.002	1.45
grenouille	0.67	80.00	4.17	1.87	3.69	1.92	0.8	6.0	2	0.20	0.012	1.90
guitare	0.15	100.00	4.57	2.90	3.45	2.50	1.1	7.5	2	0.36	0.031	1.90
jambon	0.57	75.00	2.65	2.50	3.25	2.70	1.0	6.7	2	0.09	0.004	1.75
jumelles	0.00	85.00	3.63	2.07	4.52	2.80	0.8	9.0	2	0.19	0.014	1.95
jupe	0.00	83.00	2.37	3.23	1.66	1.65	1.0	18.1	1	0.09	0.006	1.40
lapin	0.00	100.00	4.07	2.67	3.14	1.65	1.4	10.4	2	0.19	0.012	1.45
lion	0.00	96.00	3.53	1.50	4.17	1.69	1.2	16.9	1	0.05	0.001	1.10
luge	0.26	91.00	2.83	1.90	3.28	2.81	0.3	1.0	1	0.08	0.003	1.35
maïs	0.56	93.00	3.90	3.10	4.21	2.60	0.9	6.8	2	0.28	0.024	1.75
marteau	0.15	96.00	2.33	2.10	2.90	2.19	1.1	10.3	2	0.41	0.065	1.65
miroir	0.47	90.00	4.70	3.35	2.50	2.60	1.4	37.1	2	0.45	0.042	1.80
montagne	0.29	96.00	2.83	2.67	2.93	1.88	1.6	44.3	2	0.25	0.022	1.80
moto	0.00	93.00	3.60	3.00	5.00	2.23	1.4	8.0	2	0.22	0.013	1.15
mouton	0.00	67.00	2.90	1.83	3.59	1.65	0.9	11.1	2	0.20	0.009	1.35
niche	0.15	80.00	4.43	1.83	2.17	2.42	0.5	4.4	1	0.10	0.003	1.10
nid	0.00	96.00	3.77	2.17	4.90	2.23	1.1	13.1	1	0.08	0.001	1.00
noix	0.00	100.00	4.00	4.00	2.20	2.00	1.1	8.7	1	0.09	0.016	1.00
note	0.29	95.00	4.25	4.10	4.10	2.10	1.5	48.2	1	0.12	0.003	1.00
palmier	0.00	96.00	3.83	2.10	3.76	3.19	0.4	2.6	2	0.46	0.054	1.90
panier	0.00	98.00	2.63	2.30	4.59	1.92	1.2	16.3	2	0.38	0.039	1.60
pantalon	0.15	100.00	3.40	4.87	2.28	1.54	1.5	29.3	3	0.35	0.030	2.00
papillon	0.00	93.00	4.37	2.33	4.10	1.92	1.0	13.0	3	0.41	0.044	1.90
passoire	0.73	74.00	3.57	3.67	3.64	3.12	0.4	1.5	2	0.48	0.058	1.80
peigne	0.00	98.00	3.83	3.87	2.69	2.00	0.8	6.8	1	0.16	0.009	1.00
piano	0.00	93.00	3.80	3.10	4.72	2.00	1.4	20.6	2	0.23	0.007	1.95

plume	0.00	98.00	4.20	2.30	3.66	2.16	0.9	28.1	1	0.18	0.013	1.35
poing	0.00	95.00	2.90	3.40	1.20	1.50	1.2	26.3	1	0.13	0.004	1.35
poire	0.00	93.00	4.40	3.37	1.14	1.81	0.8	6.4	1	0.27	0.024	1.15
pont	0.30	90.00	2.30	3.20	1.45	2.15	1.7	61.2	1	0.14	0.001	1.00
prise	0.00	87.00	1.83	3.60	2.55	2.92	1.4	84.6	1	0.27	0.045	1.00
pyramide	0.00	100.00	4.50	1.67	2.34	3.19	0.8	5.3	3	0.49	0.031	2.70
requin	0.00	91.00	3.83	1.87	2.28	2.85	1.0	1.3	2	0.17	0.032	1.30
sapin	0.29	100.00	3.70	3.45	2.65	1.95	0.8	7.2	2	0.25	0.015	1.55
seringue	0.29	93.00	4.31	2.20	3.72	3.50	0.7	2.5	2	0.20	0.004	1.70
singe	0.43	93.00	3.03	1.40	3.41	1.80	1.4	10.4	1	0.11	0.003	1.45
ski	0.00	93.00	4.03	2.73	2.83	2.64	1.2	4.7	1	0.16	0.003	1.25
soleil	0.00	100.00	3.53	4.37	1.14	1.42	2.1	227.1	2	0.29	0.023	1.85
souris	0.29	85.00	4.27	2.27	3.38	1.62	1.4	26.0	2	0.36	0.035	1.15
tabouret	0.00	93.00	3.60	3.80	2.24	2.20	0.6	7.8	3	0.38	0.032	1.95
tambour	0.00	96.00	3.77	1.57	2.79	2.15	0.9	9.1	2	0.24	0.011	1.85
toit	0.00	100.00	4.35	3.95	2.85	2.00	1.6	33.0	1	0.13	0.015	1.05
tortue	0.00	100.00	4.10	2.03	3.28	1.92	0.7	4.4	2	0.30	0.036	1.85
train	0.67	93.00	2.87	3.97	4.69	1.73	2.4	161.6	1	0.16	0.019	1.00
vache	0.00	89.00	3.40	2.63	3.59	1.60	1.6	18.5	1	0.17	0.008	1.25
valise	0.43	98.00	2.77	3.90	3.48	2.23	1.5	23.8	2	0.32	0.033	1.75
vélo	0.41	89.00	4.20	3.37	4.17	1.80	1.5	13.0	2	0.21	0.011	1.65

APPENDIX 2

Results of the topographic consistency test across single trials are displayed for 5 items (a): ananas – pineapple-; (b): cloche – bell-; (c) cravate –tie-; (d): champignon -mushroom; (e): valise – suitcase) for stimulus-aligned and response aligned ERPs with the GFP amplitude displayed on the y-axes and time on the x-axes. The grey bars represent periods of topographic inconsistency.



APPENDIX 3

Results of the mixed effects models for Response times conducted for each predictor separately

Predictor	β	t	P value
Visual complexity	$3.09\ 10^{-06}$	0.29	$p > 0.7$
Concept familiarity	$-1.06\ 10^{-07}$	-0.009	$p > 0.9$
Lexical frequency films	$-1.39\ 10^{-06}$	-0.17	$p > 0.8$
Lexical frequency books	$4.33\ 10^{-06}$	0.46	$p > 0.6$
Lexical frequency factorial	$-1.05\ 10^{-05}$	-0.52	$p > 0.6$
Image agreement	$-4.17\ 10^{-05}$	-3.14	$p < 0.01$
Name agreement (%)	$-6.25\ 10^{-06}$	-5.87	$p < 0.00001$
Name agreement (H)	$8.61\ 10^{-05}$	1.81	$p = 0.07$
Age of Acquisition	$7.48\ 10^{-05}$	3.73	$p < 0.001$
Nb of phonemes	$-1.49\ 10^{-05}$	-1.88	$p > 0.05$
Nb syllables	Mono vs bi: $-6.08\ 10^{-05}$ Mono vs tri: $-5.69\ 10^{-05}$	-2.83 -1.89	$p < 0.01$ $p > 0.05$
Positional segment frequency	$-1.05\ 10^{-04}$	-1.19	$p > 0.2$
Positional diphone frequency	-0.00048	-0.71	$p > 0.4$
Phonological levensthein distance	$-4.16\ 10^{-05}$	-1.78	$p > 0.05$

APPENDIX 4

Correlation between independent variables before residualisation

	Name agreement (H)	Name agreement (%)	Image agreement	Concept familiarity (FAM)	Visual complexity (COM)	Age of Acquisition (AA)	Log Lexical freq. (movies)	Lexical freq. (Frantext)	N.of syllables	Positional phoneme freq.	Positional diphone freq.	Phonological Levensthein distance
NAH	1	-0.291	-0.100	0.170	0.077	0.179	0.116	0.058	-0.105	-0.039	-0.047	-0.075
NAP		1	0.196	0.040	-0.136	-0.190	0.009	-0.004	0.104	0.119	0.106	0.081
Image Agr			1	-0.095	0.029	0.185	-0.366	-0.258	0.224	0.183	0.070	0.198
FAM				1	-0.374	-0.113	0.283	0.288	0.046	0.166	0.160	-0.072
COM					1	0.164	0.035	-0.113	-0.005	-0.125	-0.114	-0.076
AA						1	-0.268	-0.182	0.042	0.123	0.129	0.122
FreqMovies							1	0.774	-0.140	-0.156	-0.087	-0.198
FreqText								1	-0.160	-0.101	-0.035	-0.139
N. of Syl									1	0.664	0.515	0.772
Phon.Freq										1	0.894	0.546
Diphon.Freq											1	0.400
Levenst.Dist.												1

Chapter 3: Ageing effects on word production processes: an ERP topographic analysis

Ageing effects on word production processes: an ERP topographic analysis[2]

Andrea Valente, Marina Laganaro

FAPSE, University of Geneva, Switzerland

Corresponding Author:

Andrea Valente: andrea.valente@unige.ch, valentea78@gmail.com

Keywords: ERP, Transmission deficit model, word production, picture naming, encoding processes, healthy language ageing

Tables: 2

---

[2] A revised version of this paper has been submitted the 16th of December, 2013.

Abstract

The increasing word finding difficulty is one of the most commonly reported and investigated characteristics of healthy language ageing. The most accredited theory trying to account for such observation (the TD model; McKay & Burke, 1990) postulates an age-related weakening in the top-down lemma-to-word form pathway, leading to insufficient priming of a word's phonology. The TD model thus predicts that decreased transmission from lexical to phonological nodes occurring in elderly speakers should manifest itself in a delayed access to phonological codes. To bring neurophysiological evidence of modifications in word production planning during the ageing process we investigated the time course of diverging ERP correlates between groups of younger and older adults in a picture naming task compared to a picture-word verification task, where lexical-phonological processes are not involved.

Older adults showed lower naming accuracy in the picture naming task whereas performance at a picture-word verification task – which is assumed to involve extensive semantic processing – was better if compared to the younger adults group.

Between-age ERP divergences were observed in both tasks in an early time-window (between 150 and 250 ms after picture onset), compatible with visuo-semantic processing, namely the retrieval of semantic properties of depicted objects. In picture naming, ERP amplitude differences between age groups were also observed in a later time window (after 400 ms) compatible with phonological encoding. We interpret older adults' lower naming accuracy primarily as a consequence of modifications originating at an early visuo-semantic encoding stage, which are only secondarily ascribable to lexical-phonological processes.

Introduction

A common assumption dating back to early research on cognitive ageing is that language processing abilities are globally maintained during ageing in comparison to other cognitive functions such as memory or attentional competences (Cattell, 1963). More recent research has nevertheless highlighted an asymmetric pattern of modifications in language abilities, primarily between language comprehension - which is globally spared - and language production, which conversely does present age-related declines (e.g. Burke, MacKay & James, 2000). In the domain of language production not all age-related modifications are strictly linguistic in nature. For instance the reduction in the complexity of syntactic structures produced by elderly people is most probably ascribable to working memory decline, rather than to frankly linguistic changes (Kemper, Herman & Lian, 2003).

The most prominent age-related modification in language production, as well as the most commonly reported complain among elderly people (Rabbitt, Maylor, McInnes, Bent & Moore 1995), is the increasing word finding difficulty (e.g. Mortensen, Meyer, & Humphreys, 2006; Neumann, Obler, Gomes, & Shafer, 2009). This modification manifests with increasing word finding latencies, as well as the inability to find the intended word.

Word finding difficulties have direct consequences on several aspects of language production. Discourse in older adults shows a higher rate of vague terms, a higher frequency and duration of empty pauses, and an increasing use of pronominalized forms, or forms with an ambiguous coreference (Ulatowaska, Cannito, Hayashi & Fleming, 1985). In general, older adults tend to be less informative and to show higher verbosity and disfluency, a sign that has been interpreted as the reflection of an increasing decline in lexical access (Bortfeld, Leon, Bloom, Schober, & Brennan, 2001). Several interpretative models have been provided to account for the underlying cognitive process responsible for the increased age-related word finding difficulty. Most of them are based on arguments issued mainly from behavioral experimentation. Our aim here is to confront such interpretations to event-related electrophysiological (ERP) data, taking advantage of the advances in the field of the dynamics of word encoding and production.

In the following section we will review the manifestations of age-related word finding difficulties along with the main interpretative models and their experimental arguments, before presenting the advantages of an ERP approach to the question of changes in the processes underlying word retrieval in ageing.

Manifestations and interpretative models of age-related word finding difficulties

The investigation of word finding decline in elderly speakers highlighted a further asymmetric pattern of modification between the processing of semantic and phonological information.

In fact, semantic representations and processes seem to be globally spared when not improved in the old age (see Thornton & Light, 2006; Burke & Shafto, 2008 for reviews); older adults display a richer vocabulary (Schaie, 2005), better general knowledge performances (Beier & Ackerman, 2001) and greater semantic interference effects, which have been interpreted as the outcome of a richer semantic network (e.g. Taylor & Burke, 2002). This kind of result has been reported repetitively and interpreted as the outcome of a more solid connection structure of the semantic system, yielding a more effective priming convergence to lexical representational units (see Laver & Burke, 1993 for a review).

In spite of preserved semantic knowledge and lexical–semantic processes, age-related word finding problems have been interpreted as the consequence of a selective decline in word form retrieval. One argument for this asymmetry is the Tip of the Tongue phenomenon (TOT), which becomes more frequent as age increases (Burke, McKay, Worthley & Wade, 1991; Burke & Shafto, 2004; James & Burke, 2000). The TOT is a particular condition, exemplifying the distinction between semantic-syntactic and phonological word representations (e.g. Levelt, Roelofs, & Meyer, 1999), as it is characterized by the temporary inability to retrieve the phonology of a word, in spite of the strong feeling of knowing the target word, that is in accessing its lexical semantics.

Since word finding problems can be easily circumvented in spontaneous speech, one way to experimentally highlight lexical access deficits in elderly speakers has been to resort to the picture naming paradigm, in which constraints are given concerning the word to be associated with a particular picture. The majority of picture naming models agree on the fact that the task entails several processing substages (e.g., Glaser, 1992; Levelt et al., 1999), from visuo-perceptive analysis, leading to the recognition of the depicted object, to a conceptual substage during which semantic properties of the object are retrieved from the semantic system, to lexical selection, namely the activation of an appropriate linguistic item within the mental lexicon (the lemma) which will trigger retrieval of the word form (the lexeme), and finally to the implementation of an articulatory program.

Because of the conceptually driven nature of the task, and the involvement of an information flow between lexical and phonological levels, picture naming is particularly well suited to investigate age-related declines in lexical access, and has been widely utilized for this purpose (e.g. Connor, Spiro, Obler & Albert, 2004; Goral, Spiro, Albert, Obler & Connor, 2007; Nicholas, Connor, Obler & Albert, 1998). Taken together, results at picture naming tasks indicate that older adults name pictures less accurately (but see Goulet, Ska & Kahn, 1994) and slower (Verhaegen & Poncelet, 2012; Morrison, Hirsh & Duggan, 2003 in a verb-picture naming task) than younger adults, supporting the hypothesis of an increasing word finding difficulty, even though controversies may exist about the age at which the naming decline starts to become evident, or about the factors influencing such decline (Connor et al., 2004; Feyereisen, 1997; Nicholas et al., 1998).

Further efforts have been deployed to achieve an understanding of the cognitive and neurophysiological aspects underlying the word finding modification in older adults. Approaches addressing the issue of modifications of language competences in the old age can be divided in two main groups: theories postulating a purely linguistic nature of these modifications, and general theories assuming either the onset of an inhibition deficit (Zacks & Hasher, 1997), or a generalized slowing across all processing stages indiscriminately, including both sensory and cognitive slowing (e.g. Myerson, Hale, Wagstaff, Poon & Smith, 1990; Salthouse, 1996). By the way, general slowing theories usually lack the capacity to account for the core property of language ageing, namely the asymmetric modification patterns (see Thronton & Light, 2006).

The pattern of changes described above is more efficiently accounted for by theories postulating domain-specific modifications, as the Transmission Deficit Model (from now on TD model; McKay & Burke, 1990), which is the most articulated model aiming to account for age-related word finding problems. The TD model was built on an interactive activation model of language production (the Node Structure Theory: MacKay, 1987). In this model, language competences are represented as a function of the amount and speed of priming transmission between representational units. The TD model postulates a selective age-related weakening in connections between semantic, lexical and phonological nodes. In such a framework, word retrieval failures are accounted for by the selective weakening of the top-down pathway for production from lexical to phonological nodes. The reason why a deficit in the transmission of priming across connections is more likely to occur between the lexical and the phonological nodes is intrinsic in the representational structure of the Node Structure Theory. The semantic system is more protected from transmission deficits because of its highly interconnected structure; the disruption of one single connection between semantic nodes would not prevent activation of the same nodes through alternative highly distributed routes, whereas the breakdown of one single connection from lexical to phonological nodes would be sufficient to prevent successful retrieval of the entire phonological form of a target word (Taylor & Burke, 2002). The implicit theoretical assumption in such a model is that phonological representations, as well as semantic representations, are well maintained in the old age, but access and retrieval of the former will become increasingly more difficult in reason of the transmission priming breakdown between levels (e.g.; Nicholas, Obler, Albert & Goodglass, 1985). The TD model has been examined in several studies, most of them concluding in favor of its assumptions (e.g. Neumann, Obler, Gomes & Shafer, 2009; Taylor & Burke, 2002; Abrams, White, & Eitel, 2003; Cross & Burke, 2004; Rastle & Burke, 1996; White & Abrams, 2002). In a picture-word interference task, Taylor & Burke (2002) showed that older adults did not benefit, in comparison to younger adults, of the “top-down” priming from lexical to phonological nodes. Results were interpreted as the evidence of a selective impairment of the priming transmission between these two representational levels. Some authors have nonetheless hypothesized that a certain degree of semantic degradation also occurs in older adults, mainly above their 70s (Barresi, Nicholas, Obler & Albert, 2000). Results of a longitudinal study revealed that older adults in their 70s presented a higher rate of cases in which a previous successful naming performance was followed by later test session failures in naming. This observation was interpreted as a sign of semantic degradation. Verhaegen & Poncelet (2013) showed a decline in performance at a semantic assessment task in older adults in their 70s, and reported a significant correlation between such decline and their reduced performance in picture naming.

ERP approaches in the study of changes in the dynamics of word encoding and production

Despite the wide use of picture naming tasks associated with complex interference experimental paradigms (e.g. Taylor & Burke, 2002), these behavioral approaches do not allow a direct insight into the time course of the encoding processes implemented during the performance of relevant tasks, as the encoding processes responsible for the effects need to be inferred by manipulating experimental conditions. More direct insight into the timing of word production and its age-related modifications can be achieved with high temporal resolution neuroimaging techniques such as EEG and ERPs. The only study aimed at investigating the TD model's predictions by means of ERP methodology we are aware of (Neumann et al., 2009), addressed the issue of whether age-related word finding problems were due to general slowing, or instead to linguistic processing delays, as postulated by the TD model. The authors investigated phonological monitoring during picture naming in older and younger participants. Results revealed no significant differences between age groups in visual processing (the VEP component), whereas older adults presented a later N2d component, associated with phonological processing. The authors concluded that the priming transmission deficit between lexical and phonological nodes caused an age-related delayed access to phonological codes, endorsing the TD model's predictions. However, Neumann et al. (2009) only used indirect measures of phonological processing (a metalinguistic go/no go paradigm), and the study was guided by an *a priori* assumption. In fact, the authors only focused on phonological encoding and did not examine ERPs in other potentially relevant time windows.

Recent developments in ERP analyses allow the use of overt production paradigms to study word production processes more directly. Here we take advantage of these ERP approaches to investigate the time course of word production in a picture naming task in younger and older adults with a combination of behavioral (response latencies) and neurophysiological measures (ERPs with topographic map analysis, see below). The use of a functional brain imaging technique providing high temporal resolution will allow us to obtain a deeper insight and a more detailed account on the exact time course of the processing stages involved in the performance of specific tasks, with the additional benefit of considering the whole time window of encoding from picture presentation to response.

In both EEG and ERP signals the global electric field remains stable over periods on tenth of milliseconds before changing rapidly into a different stable configuration of the potential map (Lehmann & Skrandies, 1984). Topographic ERP analysis is a methodology yielding a segmentation of group-averaged ERPs in periods of stable topographic configurations. These periods are assumed to reflect different stages of information processing (Pascual-Marqui, Michel & Lehmann, 1995). In relation to waveforms analysis, this methodology offers the benefit of providing a reference-free measure of brain activity. Statistical outcomes are consistent and do not vary depending on the adopted reference electrode. Moreover, topographic analysis does not require focusing on isolated components, since the entire time-window of encoding from stimulus presentation to response can be wholly considered (Murray, Brunet & Michel, 2008). This point is of particular importance for the purpose of the present study. In fact, the salient object of investigation here is whether differences in the encoding processes implemented by different age groups are evenly distributed across different encoding stages (e.g. according to general slowing theories of ageing), or rather concentrated in specific time-windows (as postulated by the TD model). Finally, topographic analysis allows us to investigate age-related changes in word production without the need for *a priori* hypotheses concerning the encoding process bearing the main differences.

Recent efforts in psycholinguistics research aimed at obtaining an increasingly more precise estimate of the time course of the encoding processes involved in picture naming (Indefrey & Levelt, 2004; Indefrey, 2011; Strijkers, Costa & Thierry, 2010), allow us to associate the neurophysiological correlates of word production observed in particular time-windows with the underlying cognitive processes. More precisely, according to the TD model, the age-related disruption in the priming transmission between the lexical and phonological nodes would result in inter-age differences in a relatively late time-window of encoding compatible with phonological processing.

In the present study a name-picture verification task was used in addition to the picture naming task. This is a paradigm widely exploited in psycholinguistics research (e.g. Jescheniak & Levelt, 1994; Santiago, MacKay, Palma, & Rho, 2000) mainly to pinpoint non-lexical processes. In the picture-word verification task a word is presented, either aurally or visually, and then suddenly followed by a picture. From the moment the picture is presented, participants are asked to decide as quickly as possible whether the word and the picture are matching, and are usually asked to perform a button press “yes/no” response.

In the picture-word verification task the long exposure to the written word is thought to entail a complete encoding before picture onset, spanning from orthographic to semantic stages.

According to accounts in the literature, the picture-word verification task is likely to subtend a conceptual matching (Stadthagen & Gonzalez, 2009; Theios & Amrhein, 1989) in which participants access semantic content of both the stimuli (word and picture) and compare them on the basis of their semantic features. Thus, according to the TD model, ageing should not modulate performance of this task, as it does not involve lexical-phonological encoding. On the other hand, any inter-age ERP differences in time-windows usually associated with pre-lexical processes in picture naming, should be mirrored in the picture-word verification task.

Method

Participants

A total of 45 participants (14 men) participated in the study, divided in two age groups (24 younger and 21 older subjects). Younger participants were recruited within undergraduate students, older adults through advertisement in a local trade journal.

Younger adults were aged 18-30 (mean: 22.8; 3 men) and older adults were aged 60-80 (mean: 68.1; 8 men). They all gave informed consent and were remunerated for their participation in the study. All participants were native French speakers, right-handed according to the Edinburgh Handedness Scale (Oldfield, 1971), with no history of brain damage and with normal or corrected-to-normal vision. All the participants underwent short attentional and executive tasks, namely the Attentional Matrices (Spinnler & Tognoni, 1987) and the Trail Making Test (Tombaugh, 2004). The results (accuracy and speed) showed that all participants were in the normal range for their age and education.

In the Trail Making Test, older adults performed significantly slower than younger adults ($t(32)=-4.04$, $p<.001$). In the Attentional Matrices, only accuracy (i.e. the number of targets correctly checked by participants across the three parts) was examined and no differences appeared across groups ($t(43)<1$).

Material

Items consisted in a subset of 120 words and their corresponding black-and-white line drawings taken from two French databases (Alario & Ferrand, 1999; Bonin, Peerman, Malardier, Méot & Chalard, 2003). All pictures and their corresponding words had a name agreement over 75%, (mean = 92.5%) to ensure that participants give the same name for a same picture (see Alario, Ferrand, Laganaro, New & Frauenfelder, 2004). The stimuli were monosyllabic (N=40), bisyllabic (N=60) and trisyllabic (N=20) words of lexical frequency varying from 0.13 to 227 occurrences per million words (mean = 17.3) in the French database Lexique (New, Pallier, Brysbaert & Ferrand, 2004). The same 120 stimuli were used for the two tasks and consisted in 280 x 280 pixels black-line pictures. In the picture-word verification task, two different conditions were created: match and no-match. Half of the items constituted the match condition, for which the target word and picture corresponded. The other 60 items were used for the non-match condition (e.g. the French word "abeille" – bee – was matched with the image of a roof). No-match conditions were created by associating words and pictures from the 60 items. The material was controlled in order to avoid semantic or phonological relations between words and pictures belonging to the same trial. The 120 corresponding written words were presented in Courier New 18-point font, in white on a gray background.

Procedure

Participants were tested individually in a soundproof cabin; they all sat at about 60 cm from the computer screen. Trials were controlled with the E-Prime software (E-Studio). Stimuli appeared in a pseudo-randomized order, which differed across participants.

A short familiarization preceded the trials: subjects were shown the complete set of 120 images associated with the corresponding word in order to prevent possible doubts or non-recognitions during tasks performance. Participants were then given the instructions for each task, which started with a set of training items. The participants underwent the picture naming and the picture-word verification task (as well as a word reading task, which will not be included here) in a counterbalanced order.

Picture naming

Each trial consisted of a fixation cross presented for 500 ms, followed by a 200 ms blank screen. Pictures were then presented for 1500 ms on a gray screen. Participants were instructed to name the pictures overtly, as quickly and accurately as possible. Vocal responses were recorded by means of a microphone and digitized for further verification. Participants had 2000 ms to name the picture; responses not entered in this interval were classified as a "no response". A blank screen lasting 2000 ms was displayed before the next trial.

For older adults some timing parameters were changed, as longer response latencies were expected according to the literature reviewed above (Verhaegen & Poncelet, 2012; Morrison, Hirsh & Duggan, 2003): the buffer size time (i.e. the audio recording time) was slightly extended (500 ms) in both tasks to be sure to record longer latencies responses (up to 2500 ms).

Picture-word verification

Each subject was presented with 120 trials, 60 match and 60 no-match, but across subjects all items appeared in each condition. Each trial consisted of a fixation cross presented for 500 ms, followed by a 200 ms blank screen, the word was then presented for 2000 ms and followed by the picture presented for 1500 ms. The inter-trial interval lasted 2000 ms for younger adults and 3500 ms for older adults. Subjects had to press a button with the right hand in case of a match condition (yes-response) and another one with the left hand in case of no-match condition (no-response).

EEG acquisition and pre-analyses

EEG was recorded using the Active-Two Biosemi EEG system (Biosemi V.O.F. Amsterdam, Netherlands) with 128 channels covering the entire scalp. Signals were sampled at 512 Hz with band-pass filters set between 0.16 and 100 Hz.

In the picture naming task, stimulus-aligned (forward) epochs of 450 ms and response-aligned (backward) epochs of 450 ms were averaged across subjects and age-groups. Response-aligned epochs were time-locked to 100 ms before the onset of articulation of each individual trial; stimulus-aligned epochs were locked to the moment the picture appeared on screen in the two tasks. For the spatio-temporal topographic analysis (see below), the stimulus-aligned and response-aligned data of each subject were combined according to each individual subject's RT in the picture naming task by removing the overlapping signal. That means that the individual averaged data (and the group grand-average) covered the actual word encoding time from onset (picture on screen) to 100 ms before articulation (Laganaro & Perret, 2011).

In the picture-word verification task stimulus-aligned epochs of 400 ms were averaged.

In the pre-analysis, in addition to an automated selection criterion rejecting epochs with amplitudes reaching +-100 µV, each trial was visually inspected, and epochs contaminated by eye blinking, movements or other noise were rejected and excluded from averaging. ERPs were then bandpass-filtered to 0.2–30 Hz and recalculated against the average reference. A minimum of 60 trials were averaged for each subject in each task.

Behavioral analyses

Production latencies (reaction times), separating stimulus onset from the beginning of articulation in the picture naming task, were systematically checked by means of speech analysis software (Check Vocal, Protopapas 2007) allowing to visualize both waveforms and spectrograms of each response. Response latencies in the picture-word verification task were automatically computed on the basis of the button press response with the E-Prime software (E-Studio). RT data were fitted with a linear regression mixed model (Baayen, 2008) and accuracy data with a generalized linear mixed-effects model for binomially distributed outcomes (Jaeger, 2008) with the R-software (R-project, R-development core team 2005; Bates and Sarkar, 2007), including participants and items as random effect variables.

ERP analyses

The ERPs were first subjected to a sampling point-wise ERP waveform analysis to determine the time periods presenting local differences in amplitudes between age groups. However, amplitude variations of

ERP traces can descend from a modulation in the strength of the electric field, from a global topographic difference of the electric fields (revealing distinguishable brain generators), or from latency shifts of similar brain processes. To differentiate these effects, a spatio-temporal segmentation was performed on the group-averaged ERPs to determine topographic differences across groups and statistically validate them in the responses of single subjects as described below.

This approach allows to resume and compress all the EEG dataset into a limited number of topographic template maps which best explain data variability, with additional information concerning the duration of stable periods in different tasks and conditions.

Any modification of the spatial configuration of the electric field on the scalp is interpreted as revealing a difference in the distribution of the underlying intracranial sources and therefore of the information processing stage involved (Pascual-Marqui et al., 1995).

Waveform analyses

Electrode-wise and sampling point-wise (every ~2 ms) unpaired t-tests were computed across age-groups on evoked potentials' amplitudes for each data set, i.e. on stimulus-aligned and on response-aligned ERPs in picture naming, and on the stimulus-aligned ERPs in the picture-word verification task. To correct for multiple comparisons only differences spreading over at least 5 out of 128 electrodes and lasting at least 30 ms were retained with an alpha criterion of .01.

Spatio-temporal segmentation of ERPs (global topographic pattern analysis)

First, a topographic Anova (from now on: Tanova) was run on each sampling point to identify periods of significant topographic modulation between groups. This procedure involves a non-parametric randomization test to the global dissimilarity measures between different experimental conditions or groups (Murray et al., 2008), and was useful to determine the time periods in which different topographies were present between age groups for each task separately (picture naming and picture-word verification). The same time-period criterion of 30 consecutive ms was applied.

Then, two distinct spatio-temporal segmentations were performed on the group-averaged ERPs of both age groups in each task, using a modified hierarchical clustering analysis (Michel, Thut, Morand, Khateb, Pegna & Grave de Peralta, 2001; Pascual-Marqui et al., 1995) - the agglomerative hierarchical clustering (Murray et al., 2008). The spatio-temporal segmentation procedure compresses the variability of ERPs in a series of template maps, which summarize the data and serve to determine which topographic template best explains participants' ERP responses in each group. A temporal post-processing was added to the process of segmentation. Segments with duration of less than 15 time frames (about 30 ms) were excluded and reassigned to neighbor clusters sharing the higher spatial configuration. Moreover, maps sharing a spatial correlation of more than .95 were merged together. Each spatio-temporal segmentation yields a set of quality measures useful to choose, among alternatives, the best segmentation. A combination of cross-validation and Krzanovski-Lai criteria was used to choose the optimal number of template maps explaining at best the group-averaged datasets across conditions.

Two distinct spatio-temporal segmentations were issued, one on both the Grand-averages of younger and older adults in the picture naming task, and the other on the Grand-average of younger and older adults in the picture-word verification task. Afterwards, the sequence of template maps observed in the group-averaged data was statistically tested by comparing each of these maps with the moment-by moment scalp topography of individual subject-averaged ERPs in each age group. This algorithm, referred to as 'fitting' can inform on how template maps issued on the segmentation of the group-averaged ERPs are actually present in individual ERPs, by producing a labeling of each time point for each of the individual subjects' ERP according to the Grand Average's template map with which it best correlates spatially, yielding therefore a measure of template maps presence in each age group. This procedure also allows establishing how well a cluster map explains individual patterns of activity (GEV: Global Explained Variance), and provides information on map presence and duration. Analyses were performed using the Cartool software (Brunet, Murray & Michel, 2011). In order to analyze whether one map is more representative of one particular condition or whether it lasts longer in one condition, durational measures for each period of topographic stability in each subject are used for further statistical analysis.

Results

Behavioral results

Picture naming

Although both groups had high performance in the task, older adults named pictures less accurately than younger adults (94.6 and 97.0% respectively, z(3924) =2.217, p <.05).

Outliers (reaction times faster than 500 ms or slower than 1500 ms) were excluded from further analysis (3.8% of the data). Mean response latencies were 882 ms (SD = 60.2 ms) for older adults and 846 ms (SD = 81.7 ms) for younger adults. The 36 ms difference in response latencies did not reach significance (t(3672)=1.58, p=.11)

Picture-word verification

Match and no-match responses were analyzed as separate conditions. Older adults performed the task more accurately than younger adults (99.1% versus 97.4%, z(3447)=-2.123, p<.05) with no interaction between groups and match/no-match condition (z=1.05, p=.3). Outliers (reaction times falling outside the 300 and 1100 ms interval) were excluded from further analysis (6.1% of the data). An expected condition effect was observed (t(3153)=8.53, p<.001) with the match condition being faster than the no-match condition; no differences in response latencies were observed across groups (t(3153)=-1.15, p=.3), but an interaction was found between condition and group (t(3153)=-2.3, p<.05). In the no-match condition older adults were slower than younger adults (respectively 716 ms and 653 ms, t=-2.13, p<.05), whereas the difference was not significant in the match condition (respectively 650 ms and 612 ms, t=-1.18, p=.24).

ERP waveform analysis

Picture naming

Eleven subjects were excluded after pre-analyses of the EEG signal recorded during the picture naming task. Subjects with artifacts contaminated signal, or for which less than 50% of epochs were exploitable, were excluded from further analysis. The final groups included 17 younger adults (aged between 18 and 29, mean: 22.8) and 17 older adults (aged 60-80, mean: 68.1).

Results of the point-wise waveform analysis are shown in Figure 1A. In the response-aligned ERPs, significant amplitude divergences between age groups appeared on a large proportion of electrodes from several scalp regions in two different time windows: between 150 and 230 ms and after ~ 420 ms after picture onset. In the time window ranging from 150 to 200 ms, older adults displayed different polarity relative to the younger group, with more positive amplitudes on anterior sites (see Fpz in Figure 1), and more negative amplitudes on posterior sites (see POz in Figure 1). In the response-aligned ERPs significant inter-age differences were observed in a time-period ranging from - 300 to -100 ms before articulation.

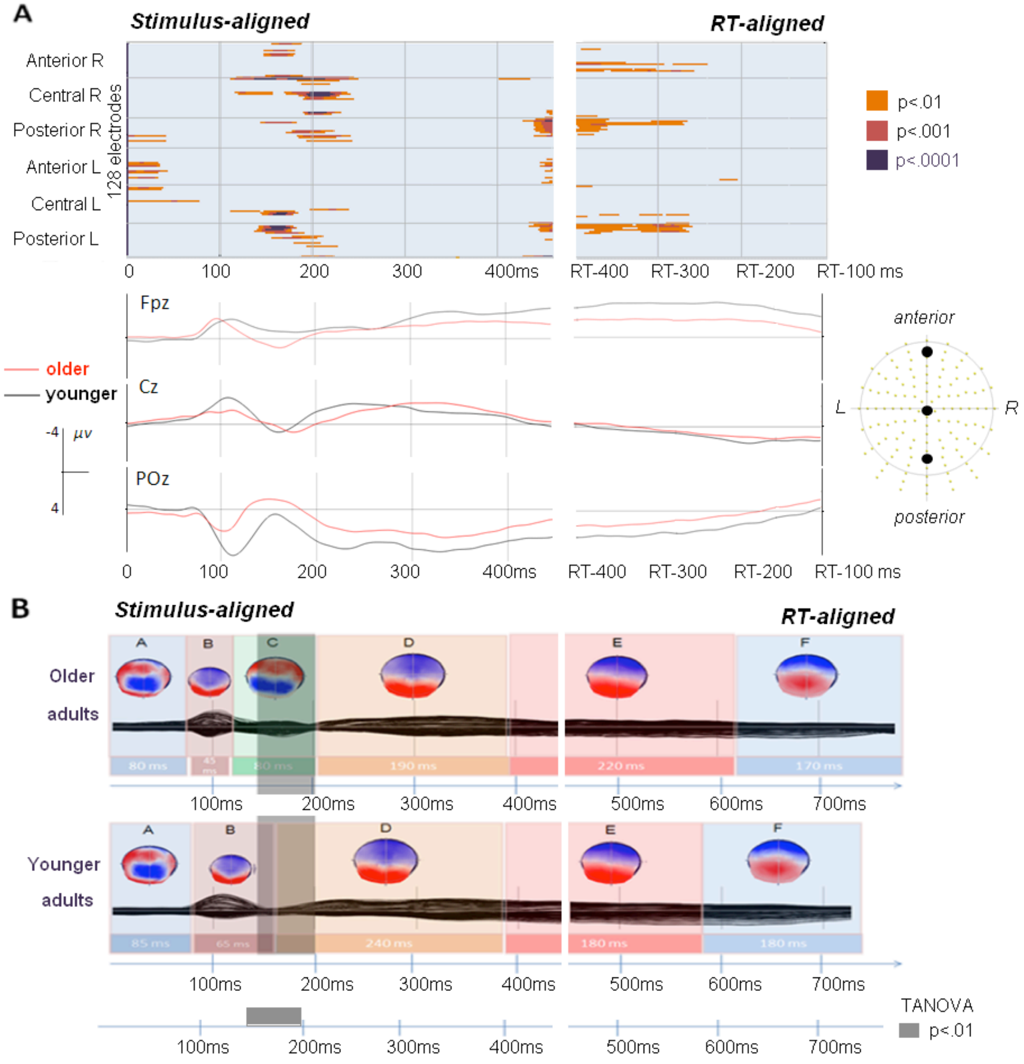


Figure 1. (A) Results of the point-wise and electrode-wise waveform comparison between age groups in the picture naming task (orange, pink and purple points represent significant p values at p<.01, p<.001 and p<.0001 respectively) and averaged ERP waveforms for younger and older adults with the arrangement and electrode position of the displayed waveforms (Fpz, Cz and POz). (B) Results of the spatio-temporal analysis displayed on the group-averaged ERPs. The duration of each period of topographic stability is displayed in the color bars with the corresponding topographies (positive values in red, negative values in blue). The superimposed grey rectangles represent the periods of topographic incongruity as revealed by the Tanova.

Results of the spatio-temporal segmentation, issued on the group-averaged ERPs extending from stimulus onset to response, are shown in Figure 1.B. The Tanova revealed a time window of topographic incongruity between age groups ranging from about 150 to 200 ms after picture onset (grey bar). The segmentation yielded a total of seven different topographic maps, accounting for the 94.23% of data variance. Globally, the same topographic maps were present in the two age groups from stimulus to response, but older adults displayed an additional period of topographic stability (map named “C” in Figure 1.B present from about 120 to 200 ms).

The fitting procedure carried out in the time window between 100 and 240 ms showed that template map “C” was significantly more present in older than in younger adults (Pearson Chi Square computed on map presence across individuals: χ^2= 10.08, *p* <.01). This result on map “C” is in line with the different polarities observed in the waveforms displayed in Figure 1 (posterior negativity and anterior positivity in the 150-200 ms in the older group and the reverse pattern in the younger group).

A systematic fitting was run to determine whether differences appeared across groups on map duration or GEV on other periods of topographic stability, namely between 60 to 160 ms, from 170 to 420 ms, from 340 to 640 ms and from 460 ms to -100 ms before articulation onset. No other stable topographic configuration presented differences in terms of duration between age groups, except for an earlier P100 component in the older group. A Mann-Whitney U test revealed that the maximum GFP of the P100 peak (map B in Figure 1.B) appeared significantly earlier in older adults (z=-2,256, *p* < .05).

In order to further investigate the potential relationship between the observed ERP and behavioral changes, correlations were computed between the duration of periods of topographic stability, appearing in the two time-windows where ERP divergences were observed, and naming accuracy. This analysis revealed the presence of a significant negative correlation between the duration of the topographic map “C” and naming accuracy (r=-.361, z(34)=-2.1, p=.036), indicating that this electrophysiological pattern was more present in case of lower naming accuracy. No significant correlations appeared between accuracy and the later periods of topographic stability (r<.1 for map “E” and r=-.149, z<1 for map “F”). Finally, to determine whether a relationship was present between ERP modifications in the early time-window and those observed after 400 ms, correlations were computed between the duration of map “C” and the duration of maps “”E” and “F”. None of these correlations was significant (r <.1 for both map “E” and “F”).

Picture-word verification

Fifteen participants had to be excluded after inspection of the EEG signal using the same criteria illustrated for the picture naming task. The final group comprised 15 younger adults (aged 18-28, mean: 23.2) and 15 older adults (aged 60-80, mean: 66.5). ERPs corresponding to the match and no-match conditions were first analyzed across the 30 subjects with the aim to index the time points at which the two conditions (match/no-match) differed, i.e. the time window in which semantic processing should be engaged. Paired t-tests computed electrode-wise and time-point wise indicated that waveforms started to diverge, between match and no-match conditions, from about 200 ms after picture onset onward. The Tanova revealed topographic differences arising in the same time window.

The following analyses were carried out on the match condition across age groups. Results of the waveform analysis are shown in Figure 2. Inter-age amplitude divergences were concentrated in the time period ranging from 0 to 100 ms after picture onset, and between about 150 to 230 ms, mainly on anterior, central and posterior right electrode sites.

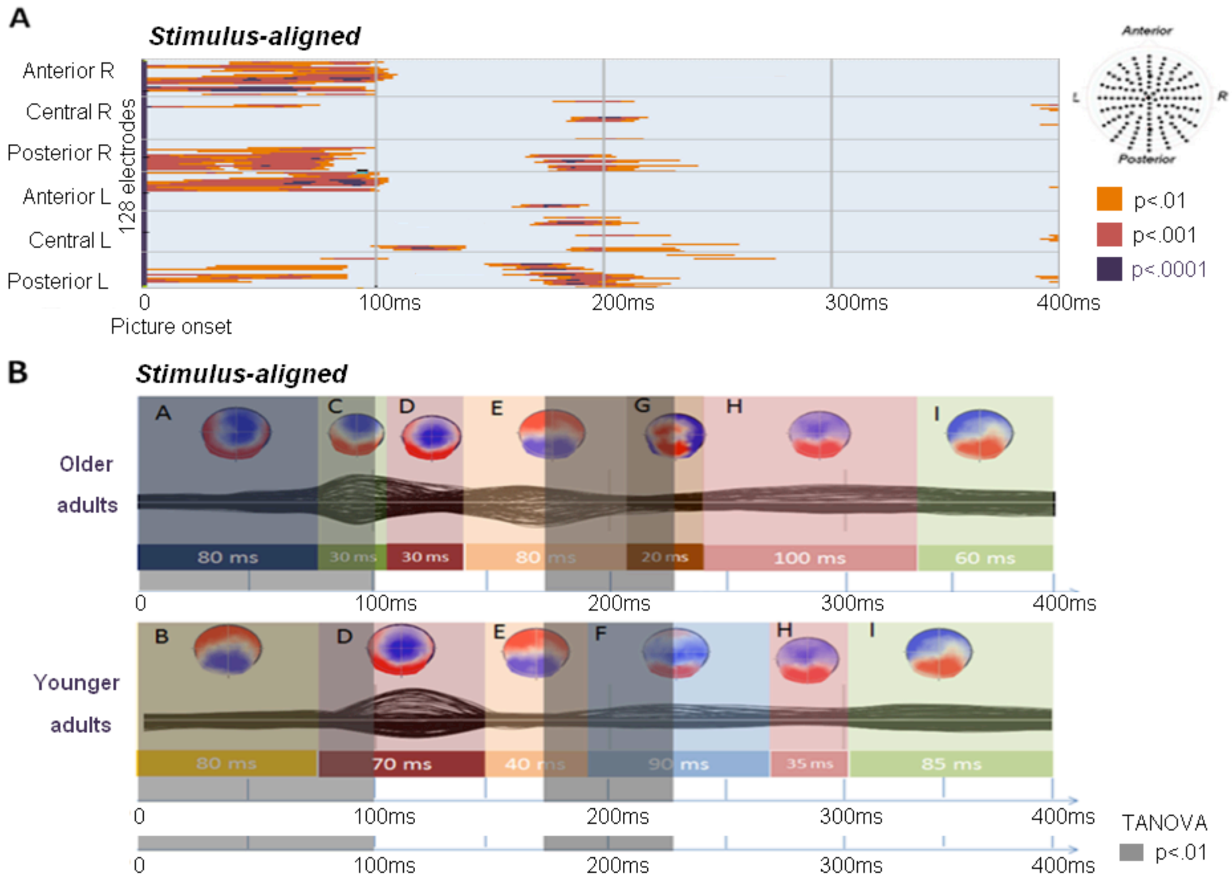


Figure 2. (A) Results of the point-wise and electrode-wise waveform comparison between age groups in the picture-word verification task (orange, pink and purple points represent significant p values at $p<.01$, $p<.001$ and $p<.0001$ respectively). (B) Results of the spatio-temporal analysis displayed on the group-averaged ERPs. The duration of each period of topographic stability is displayed in the color bars with the corresponding topographies (positive values in red, negative values in blue). The superimposed grey rectangles represent the periods of topographic incongruity as revealed by the Tanova.

The Tanova also indicated topographic differences in the time window ranging from 0 to 100 ms and from about 170 and 230 ms after picture onset (see gray bar in figure 2B), almost perfectly overlapping inter-age amplitude differences revealed by the t-test. The spatio-temporal segmentation yielded nine different template maps (Figure 2. B), accounting for 91.6% of the variance.

The fitting procedure carried out in the time window comprised between 170 and 230 ms (template maps E, F and G) showed that two different periods of stable configuration were predominantly present in such interval. More precisely, map named “E” was significantly more present in older adults ((χ^2= 5.40, *p* <.05), as well as map named “G” (χ^2= 6.13, *p* <.05), whereas map named “F” was more present in younger adults (χ^2= 10.99, *p* <.005). The analysis revealed the presence of a significant negative correlation between the duration of the topographic map “F” – significantly more present in younger adults - and accuracy (r=-.382, z(30)=-2.1, p=.037). No correlation was found between maps “E” or “G” – significantly more present in older adults - and accuracy (respectively r=.214, p=.25 and r=.299, p=.11).

As in the case of picture naming, older adults displayed an earlier P100 peak as revealed by a Mann-Whitney U test on the maximum GFP of the visual map (z=-3.285, *p*=.001).

Discussion

We will first summarize and discuss the results of the picture naming task, before integrating them with the results of the picture verification task.

Despite previous familiarization with all the pictures and the corresponding words, older adults displayed lower naming accuracy relative to younger adults in the picture naming task. This result replicates what widely reported in the literature concerning the decreased naming accuracy in ageing (Goral et al. 2007; Connor et al., 2004; Nicholas et al., 1998 but see Goulet et al., 1994). Older adults named pictures 36 ms slower than younger adults, but this difference did not reach significance differently from previous reports (Verhaegen & Poncelet, 2013; Morrison et al., 2003). However, an absence of significant ageing effects on response latencies in single object naming has already been reported in previous studies (Belke & Meier, 2007).

ERPs comparison between age groups revealed significant differences on amplitudes between 150 and 250 ms after picture onset and at a later time window, from about 430 ms to -100 ms before articulation. According to estimates on the time course of word production encoding stages (e.g. Indefrey & Levelt, 2004; Indefrey, 2010) the early time window (150-200 ms) is associated with visual and semantic processing and the later time-window (after 400 ms) with post-lexical processing, likely phonological and phonetic encoding (see also Laganaro et al., 2013).

In addition to amplitude differences observed in the time-window associated with semantic processing, the Tanova highlighted inter-age topographic differences comprised between 150 and 200 ms after picture onset. Moreover, the spatio-temporal segmentation issued on the group-averaged ERPs of younger and older adults revealed that a stable topographic configuration characterized by posterior negativity was significantly more present in the older adults group, in the time window ranging from about

150 to 200 ms. The duration of the age-specific additional period of topographic stability in this time-window presented a significant negative correlation with naming accuracy. Taken together these results indicate different underlying processing between older and younger speakers in the 150-200 ms time-window, whereas the differences observed in later time-windows are due to different strength of similar underlying electrophysiological patterns and to a shift of these patterns due to the additional map "C" in the older group.

According to the TD model's predictions reviewed in the introduction, ageing would selectively affect phonological encoding, which has been associated in previous studies to the time-period following 300 ms after picture presentation (Indefrey, 2011). The only ERP study so far aimed at examining the predictions of the TD model (Neuman et al., 2009) showed that older adults presented a later ERP component associated with phonological processing with respect to younger adults. However, other components and earlier time-windows were not examined in that study.

Thus, our results only partially confirm the TD model's predictions, since inter-age divergences were also observed in an early time-window, unlikely associated with lexical-phonological processes.

Crucially, inter-age divergences in the time window associated with semantic processes in picture naming (150-200 ms) are corroborated by the results of the picture-word interference task, where differences were also concentrated in a time-window presumably involving lexical-semantic processes. ERPs comparison between the match and no-match conditions in the picture-word verification task revealed amplitude and topographic divergences from about 200 ms after picture presentation. This result indicates that the mismatch between the word and the picture, which is presumably achieved through access and comparison of the semantic content of the two stimuli (Stadthagen-Gonzalez et al., 2009), should be completely detected within 200 ms after picture onset. This allowed us to determine that in the time window comprised between 0 and 200 ms after picture presentation, participants should implement the semantic processing necessary to accomplish the matching of picture and word. The observation of different periods of topographic stability across age groups in the time period ranging from 170 to 230 ms after picture presentation, suggests that modifications in semantic processing could account for inter-age differences in the picture-word verification task. Moreover, results showed that the duration of the period of topographic stability ranging from 170 to 230 in younger adults presented a significant negative correlation with accuracy.

Thus, converging results across both tasks indicate age-related ERP modifications in a time-window compatible with the implementation of semantic processing, both correlating negatively with accuracy.

Globally, the present results do not seem to support general slowing theories accounts, according to which ageing effects should reflect in an even and unspecific slowing of each encoding stage involved in the performance of the tasks, regardless of the type of information processed in such stages. They do not support the predictions of the TD model either, as according to its predictions ERP modifications in naming accuracy with ageing would be localized only at the level of lexical-phonological processing.

The modifications in the time window associated with semantic processes in both tasks might indicate a greater difficulty encountered by elderly adults in recognizing and accessing the semantic properties of the depicted objects. However, there is sufficient evidence to conclude that object recognition is not significantly affected along ageing (see Mortensen, Meyer & Humphreys, 2006 for a review). Even more conclusively, older adults performed better than younger adults in the picture-word verification task, which involves object recognition. Regarding visual processes, it should be noted that older adults displayed an earlier P100 component in both tasks. This finding will be further discussed below, but it allows us to exclude a slower perceptual processing in older adults in favor of a different interpretation.

There is broad agreement to date that elderly people have a more solidly connected and distributed semantic system (e.g. Taylor & Burke, 2002), leading for instance to greater semantic interference effects (see Laver & Burke, 1993 for a review). In the framework of an interactive-activation model of language production as the Node Structure Theory (MacKay, 1987), a richer and more interconnected semantic network might cause the priming of a higher rate of competitors at the lexical-semantic (lemma) level, reducing the probability for the target phonological form to reach sufficient priming in order to be successfully activated and selected. We suggest that inter-age ERP divergences observed in the picture naming task in the semantic time-window might descend from this larger, and possibly slower, propagation of priming within older adults' lexical-semantic network. This hypothesis is supported by the fact that the duration of the additional topographic map in the time-window associated with semantic processes correlated negatively with naming accuracy, hence for longer durations of this period of topographic stability, the accuracy in picture naming decreased.

Similarly to ERPs components, periods of topographic stability are assumed to represent specific functional states of the brain. More specifically and more straightforwardly than differences observed on ERP components, different periods of topographic stability are thought to reflect different underlying functional microstates (Lehman et al., 1998; Pascual-Marqui et al., 1995, see also Changeux & Michel, 2004). The presence of an additional stable configuration in a time-window likely to correspond to semantic processing, seems to suggest substantial differences in term of the implemented encoding processes.

According to the hypothesis illustrated above, the lower naming accuracy displayed by older adults would not reflect a selective disruption in the lemma-to-phonology pathway, but rather be the consequence of modifications originating at an early stage, namely the priming of more lexical competitors induced by a richer semantic system. Secondarily, in the picture naming task waveforms also differed between age groups after 400 ms. There seems not to be a direct connection between ERP modifications in the early semantic and the late phonological time-window, since no correlations were found between these early and late ERP components. In addition, the late difference was only observed on waveforms and the corresponding periods of topographic stability (those appearing after 400 ms) did not correlate with accuracy. The question of whether modifications observed in early semantic processes have an impact on later phonological processing, or if the two age-related differences are independent, remains an issue to be further investigated.

An alternative interpretation is proposed by the studies suggesting that the decreasing naming ability in older adults could be the consequence of an incipient semantic degradation (e.g. Barresi et al., 2000; Verhaegen & Poncelet, 2013). Accordingly, the early electrophysiological differences observed in the picture naming task may be due to impaired access to semantic information. However, this hypothesis is challenged by the fact that older adults performed significantly better than younger adults at the picture-word verification task, which is assumed to involve extensive semantic processing (e.g. Stadthagen-Gonzalez et al., 2009). The fact that here inter-age amplitude and topographic differences were mainly concentrated in a temporally bounded time-window associated with semantic processing, and that older adults had a better performance in terms of accuracy with respect to younger adults, seems to indicate that elderly adults could benefit from qualitatively intact, if not improved, semantic abilities.

The inter-age asymmetry on accuracy between picture naming and picture-word verification is puzzling and also deserve further investigation. The interpretation of the higher accuracy displayed by older adults in the picture-word verification task is not straightforward; in fact, a richer and more interconnected semantic network is likely to cause more semantic interference in older adults in a word production task. This was indeed the case in the picture naming task, whereas the opposite pattern was observed in the picture-word verification task. However, there is a basic difference in the way the semantic system is activated in the two tasks: whereas the picture naming task is completely conceptually driven, in the picture-word verification task the lexical concept is pre-activated by the presentation of the word preceding the picture. Thus, although both tasks are thought to involve semantic processes, the semantic nodes are in different activation states upon the presentation of the picture, leading to the observed opposite results. In the first task, richer semantic connections interfere with the conceptual driven activation of the target lexical nodes as described above; in the verification task the conceptual nodes are pre-activated by the written word and the decision only relates on a conceptual matching, which seems to be facilitated by a richer semantic network.

A further result of the current study also merits a brief comment. Interestingly, older adults displayed an earlier P100, corresponding to the visual evoked potentials (VEPs) elicited by picture presentation in both tasks. Studies on visual ageing utilizing pattern reversal visual stimuli or checkerboard patterns presentation usually reported slower P100 latencies in older adults (e.g. Tobimatsu, Kurita-Tashima, Nakayama-Hiromatsu, Akazawa & Kato, 1993; Allison, Wood & Goff, 1983). There is however general agreement on the fact that the visual function is far from being uniformly affected by the ageing process, preventing generalizations between studies involving different stimuli and methodologies. Except for Neumann et al. (2009), who also used pictorial stimuli representing concrete objects and did not find significant inter-age differences in terms of VEPs latencies after presentation of a picture, to our knowledge no study extensively addressed the question of the ageing effects on VEPs in picture naming so far, therefore interpretations on this finding can only remain speculative.

Conclusion

In the picture naming task, older adults named pictures less accurately and amplitude divergences were observed in an early time-window, likely associated with semantic processes and in a later time window compatible with phonological encoding. Since ERP differences in a time period corresponding to semantic processes were also observed in the picture-word verification matching task in which older adults showed preserved performance, we interpreted the decrease in naming accuracy occurring with age as the consequence of a slower and possibly more difficult semantic to lexical processing stemming from the richer and more distributed semantic network in elderly speakers, leading to a less effective activation of a target lemma due to the priming of a greater number of competitors. This hypothesis is further endorsed by the presence of a significant correlation between the duration of the supplementary period of topographic stability displayed by older adults in the early time-window and naming accuracy. Further research is needed to clarify the dynamics and the possible relationship between ERP age-related changes in the early and in the later time-windows.

Acknowledgements This research was supported by Swiss National Science Foundation grants no. PP001-118969 and PP00P1_140796 to Marina Laganaro.

References

Abrams, L., White, K. K., & Eitel, S. L. (2003). Isolating phonological components that increase tip-of-the-tongue resolution. *Memory and Cognition*, *31*, 1153-1162.

Alario, F.X., & Ferrand, L. (1999). A set of 400 pictures standardized for French: norms for name agreement, image agreement, familiarity, visual complexity, image variability, and age of acquisition. *Behavior Research Methods, Instruments, & Computers*, *31*, 531–552.

Alario, F.X., Ferrand, L., Laganaro, M., New, B., Frauenfelder, U.H., Segui, J. (2004). Predictors of picture naming speed. *Behavior Research Methods, Instruments, & Computers*, *36*, 140–155.

Allison, T., Wood. C.C., Goff, W.R. (1983). Brainstem auditory, pattern-reversal visual, and short-latency somatosensory evoked potentials: latencies in relation to age, sex, and brain and body size. *Electroencephalography and Clinical Neurophysiology*, *55*, 619-636.

Baayen, R. H. (2008). Analyzing Linguistic Data. A Practical Introduction to Statistics Using R. Cambridge University Press.

Barresi, B. A., Nicholas, M., Connor, L. T., Obler, L. K., & Albert, M. L. (2000). Semantic degradation and lexical access in age-related naming failures. *Aging, Neuropsychology, and Cognition*, *7(3)*, 169–178.

Bates D.M., & Sarkar D. (2007). lme4: Linear mixed-effects models using S4 classes. R package version 0.9975–12.

Beier, M. E., & Ackerman, P. L. (2001). Current-events knowledge in adults: An investigation of age, intelligence, and nonability determinants. *Psychology & Aging*, *16*, 615–628.

Bonin, P., Peerman, R., Malardier, N., Méot, A., & Chalard, M., (2003). A new set of 299 pictures for psycholinguistic studies: French norms for name agreement, image agreement, conceptual familiarity, visual complexity, image variability, age of acquisition, and naming latencies. *Behavior Research Methods, Instruments, & Computers*, *35*, 157–168.

Bortfeld, H., Leon, S. D., Bloom, J. E., Schober, M. F., & Brennan, S. E. (2001). Disfluency rates in conversation: Effects of age, relationship, topic, role, and gender. *Language and Speech*, *44(2)*, 123–147.

Brown, A. S., & Nix, L. A. (1996). Age-related changes in the tip-of-the-tongue experience. *American Journal of Psychology*, *109*, 79–91.

Brunet, D., Murray, M.M., & Michel, C. M. (2011). Spatiotemporal analysis of multichannel EEG: CARTOOL. *Computational Intelligence and Neuroscience*, 2011, Article ID 813870. doi:10.1155/2011/813870.

Burke, D. M., & Shafto, M. A. (2004). Aging and language production. *Current Directions in Psychological Science*, *13*, 21–24.

Burke, D. M., & Shafto, M. A. (2008). Language and aging. In F. I. M. Craik & T. A. Salthouse (Eds.), The handbook of aging and cognition (pp. 373–443). New York: Psychology Press.

Burke, D. M., MacKay, D. G., & James, L. E. (2000). Theoretical approaches to language and aging. In T. Perfect & E. Maylor (Eds.), Models of cognitive aging (pp. 204–237). Oxford: Oxford University Press.

Burke, D.M., MacKay, D.G., Worthley, J.S., & Wade, E. (1991). On the tip of the tongue: What causes word finding failures in young and older adults. *Journal of Memory and Language*, *30*, 542-579.

Cattell, R.B., (1963) Theory of fluid and crystallized intelligence: A critical experiment. *Journal of* Educational Psychology, 54, 1-22.

Changeux J-P., Michel C.M. Mechanisms of neural integration at the brain scale level: the neuronal workspace and microstate models. In: S. Grillner and A.M. Grabyel (Eds.) Microcircuits: The Interface between Neurons and Global Brain Function. Dahlem Workshop Report. Cambridge, MA: The MIT Press, 2004, pp. 347-370.

Connor, L.T., Spiro, A., Obler, L.K., &Albert, M.L. (2004). Change in object naming ability during adulthood. The Journals of Gerontology: Series B, 59(5), 203–209.

Cross, E. S., Burke, D. M. (2004). Do alternative names block young and older adults retrieval of proper names? Brain and Language, 89, 174–181.

Feyereisen, P. (1997). A meta-analytic procedure shows an age related decline in picture naming: Comments on Goulet, Ska, and Kahn (1994). Journal of Speech, Language, and Hearing Research, 40(6), 1328–1333.

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

Goral, M., Spiro, A.I., Albert, M.L., Obler, L.K., & Connor, L.T. (2007). Change in lexical skills in adulthood: Not a uniform decline. *Mental Lexicon*, *2*, 215–238.

Goulet, P., Ska, B., & Kahn, H.J. (1994). Is there a decline in picture naming with advancing age? *Journal of Speech and Hearing Research*, *37(3)*, 629–644.

Indefrey, P. (2011). The spatial and temporal signatures of word production components: A critical update. *Frontiers in Psychology*, *2*, 1–16.

Indefrey, P., & Levelt, W.J.M., (2004). The spatial and temporal signatures of word production components. *Cognition*, *92*, 101–144.

Jaeger T.F., (2008). Categorical data analysis: Away from ANOVAs (transformation or not) and towards logit mixed models. *Journal of Memory and Language*, *59*, 434–446

James, L. E. &, Burke, D. M. (2000). Phonological priming effects on word retrieval and tip-of-the-tongue experiences in young and older adults. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *26*, 1378–1391.

Jescheniak, J. D., & Levelt, W. J. M. (1994). Word frequency effects in speech production: Retrieval of syntactic information and of phonological form. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *20*, 824-843.

Kemper, S., Herman, R., & Lian, C. (2003). Age differences in sentence production. *Journal of Gerontology: Psychological Sciences*, *58B(5)*, 260–268.

Laganaro, M., & Perret, C. (2011). Comparing electrophysiological correlates of word production in immediate and delayed naming through the analysis of word age of acquisition effects. Brain Topography, 24, 19–29.

Laver, G. D., & Burke, D. M. (1993). Why do semantic priming effects increase in old age? A meta-analysis. Psychology and Aging, 8, 34–43.

Lehmann, D., Strik W.K., Henggeler B., Koenig T., Koukkou, M. (1998). Brain electric microstates and momentary conscious mind states as building blocks of spontaneous thinking: I. Visual imagery and abstract thoughts. Internat Journal of Psychophysioliology, 29, 1-11.

Lehmann, D., Skrandies, W. (1984). Spatial analysis of evoked potentials in man - A review. Progress in Neurobiology, 23, 227-250.

Levelt, W. J. M., Roelofs, A., & Meyer, A. S. (1999). A theory of lexical access in speech production. Behavioral and Brain Sciences, 22, 1–75.

MacKay, D. G. (1987). The organization of perception and action: A theory for language and other cognitive skills. New York: Springer-Verlag.

MacKay, D. G., & Burke, D. M. (1990). Cognition and aging: A theory of new learning and the use of old connections. In T. Hess (Ed.), Aging and cognition: Knowledge organization and utilization (pp. 213–263). Amsterdam: North-Holland.

Michel, C.M., Thut, G., Morand, S., Khateb, A., Pegna, A.J., Grave de Peralta, R. (2001). Electric source imaging of human brain functions. *Brain Research Reviews*, *36*, 108–118.

Morrison, C.M., Hirsh, K.W., & Duggan, G.B. (2003). Age of acquisition, ageing and verb production: Normative and experimental data. *The Quaterly Journal of Experimental Psychology*, *56(A)*, 2–26.

Mortensen, L., Meyer, A.S., Humphreys, G.W. (2006). Age-related effects on speech production: A review. *Language and Cognitive Processes*, *21(1)*, 238-290.

Murray, M.M., Brunet, D., & Michel, C., (2008). Topographic ERP analyses, a step-by step a tutorial review. *Brain Topography*, *20*, 249–269.

Myerson, J., Hale, S., Wagstaff, D., Poon, L. W., & Smith, G. A. (1990). The information-loss model: A mathematical theory of age-related cognitive slowing. *Psychological Review*, *97*, 475–487.

Neumann, Y., Obler, L. K., Gomes, H., & Shafer, V. (2009). Phonological vs. sensory contributions to age effects in naming: An electrophysiological study. *Aphasiology*, *23 (7)*, 1028-1039.

New, B., Pallier, C., Brysbaert, M., Ferrand, L., 2004. Lexique2: a new French lexical database. *Behavior Research Methods, Instruments, & Computers*, *36*, 516–524.

Nicholas, M., Connor, L.T., Obler, L.K., & Albert, M.L. (1998). Aging, language, and language disorders. In M.T. Sarno (Ed.), Acquired aphasia (pp. 413–449). San Diego, CA: Academic Press.

Nicholas, M., Obler, L. K., Albert, M. L., & Goodglass, H. (1985). Lexical retrieval in healthy aging. *Cortex*, *21*, 595–606.

Oldfield, R.C., (1971). The assessment and analysis of handedness: the Edinburgh inventory. *Neurospychologia*, 9, 97–113

Pascual-Marqui RD, Michel CM, & Lehmann D. (1995). Segmentation of brain electrical activity into microstates, model estimation and validation. *IEEE Transactions on Biomedical Engineering*, *42*, 658–65.

Protopapas, A. (2007). CheckVocal: a program to facilitate checking the accuracy and response time of vocal responses from DMDX. *Behavior research methods*, *39(4)*, 859-862.

Rabbitt, P., Maylor, E., McInnes, L., Bent, N., & Moore, B. (1995). What goods can self-assessment questionnaires deliver for cognitive gerontology? *Applied Cognitive Psychology*, *9*, 127–152

Rastle, K. G., & Burke, D. M. (1996). Priming the tip of the tongue: Effects of prior processing on word retrieval in young and older adults. *Journal of Memory and Language*, *35*, 586–605.

Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review*, *103*, 403–428.

Santiago, J., MacKay, D. G., Palma, A., & Rho, C. (2000). Sequential activation processes in producing words and syllables: Evidence from picture naming. *Language & Cognitive Processes, 15,* 1-44.

Schaie, K. W. (2005). Developmental influences on adult intelligence. Oxford: Oxford University Press.

Spinnler H., & Tognoni G. (1987). Standardizzazione e taratura italiana di test neuropsicologici. *The Italian Journal of Neurological Sciences*, *8*, 1-120.

Stadthagen-Gonzalez, H., Damian, M.F., Pérez, M.A., Bowers, J.S., & Marín, J. (2009). Name-picture Verification as a Control Measure for Object Naming: A Task Analysis and Norms for a Large Set of Pictures. *Quarterly Journal of Experimental Psychology*, *62*, 1581-1597.

Strijkers, K., Costa, A., & Thierry, G. (2010). Tracking lexical access in speech production: electrophysiological correlates of word frequency and cognate effects. *Cerebral Cortex*, *20*, 912–928.

Taylor, J.K. & Burke, D.M. (2002). Asymmetric aging effects on semantic and phonological processes: Naming in the picture-word interference task. *Psychology and Aging*, *17*, 662-676.

Thornton, R., & Light, L.L. (2006). Language comprehension and production in normal aging. In J.E. Birren & K.W. Schaie (Eds.) Handbook of the Psychology of Aging (6th ed.) (pp. 261 287). San Diego, CA: Elsevier.

Tobimatsu, S., Kurita-Tashima, S., Nakayama-Hiromatsu, M., Akazawa, K., Kato, M. (1993). Age-related changes in pattern visual evoked potentials: differential effects of luminance, contrast and check size. *Electroencephalography and Clinical Neurophysiology*, *88*, 12–19.

Tombaugh, T.N. (2004). Trail Making test A and B: Normative Data Stratified by Age and Education. *Archives of Clinical Neuropsychology : The Official Journal of the National Academy of Neuropsychologists*, *19(2)*, 203–214.

Ulatowska, H. K., Cannito, M. P., Hayashi, M. M., & Fleming, S. G. (1985). Language abilities in the elderly. In H. K. Ulatowska (Ed.), The aging brain: Communication in the elderly (pp. 125-139). San Diego, CA: College-Hill Press.

Verhaegen C. & Poncelet M. (2013). Changes in Naming and Semantic Abilities With Aging From 50 to 90 years. *Journal of the International Neuropsychological Society*, *19*, 119–126.

White, K. K., & Abrams, L. (2002). Does priming specific syllables during tip-of-the tongue states facilitate word retrieval in older adults? *Psychology and Aging*, *17(2)*, 226–235.

Zacks, R. T., & Hasher, L. (1997). Cognitive gerontology and attentional inhibition: A reply to Burke and McDowd. *Journal of Gerontology: Psychological Sciences*, *52*, 274–283.

Chapter 4: ageing and the lemma-to-word-form priming transmission: investigating the transmission deficit model with ERP topographic analysis

Introduction

As illustrated in Chapter 1, the ageing process does not uniformly affect the language system. A first, higher-level distinction is the one between comprehension abilities, which are usually preserved, and production abilities, which are subject to substantial age-related changes (Burke, MacKay & James, 2000).

In the domain of language production, ageing exerts selective effects on the process of word retrieval. The bulk of evidence in fact suggests that the most prominent characteristic of language ageing is the increasing difficulty in word finding, which manifests itself primarily with an increased rate of Tip-of-the-tongue (TOT) states in both experimental and everyday life circumstances (e.g. Burke, MacKay, Worthley, & Wade, 1991; Heine, Ober, & Shenaut, 1999). On the other hand, there is general agreement on the fact that other aspects of language production, such as semantic and syntactic processing, are maintained if not improved in elderly speakers (Schaie, 1994; Burke, 1997; Kemper, 1992; Wingfield & Stine-Morrow, 2000, Kemper, Herman & Lian, 2003).

To this day, the main theoretical account of age-related increasing failures in word finding is provided by the Transmission Deficit Model (from now on: TD Model; MacKay & Burke, 1990; Burke, MacKay, Worthley & Wade, 1991). The TD Model explains the increasing difficulty in word form retrieval basing its predictions on an interactive-activation model of language production, the Node Structure Theory (from now on: NST; MacKay, 1987). In such model (illustrated in Figure 1 of chapter 1), nodes represent the processing units and are hierarchically organized in two main systems: the semantic system - which contains concepts which underlie words, phrases and propositions but is devoid of phonological information -, and the phonological system, which is structured as a hierarchy of units containing information as syllables, consonant clusters, vowels and phonological features. The NST postulates two basic processes, activation and priming; activation corresponds to the conscious retrieval of information represented in a node, whereas priming corresponds to the preparation of such information for possible activation. The activation of a node leads to the priming of all nodes that are in connection with it.

In error-free speech production, thoughts are translated into speech through the serial activation of nodes, starting from concept nodes in the semantic system, subsequently retrieving the corresponding most activated lexical nodes which finally activate the phonological nodes and allow retrieval of the target word. In TOT states, semantic information about a target word is retrieved through the activation of a lexical node in the semantic system; nevertheless, there is at least a partial inability to retrieve the phonology of such target word (Burke et al., 1991). The reason why TOT states become more frequent as age increases is accounted by the TD model by postulating an age-related selective weakening in the lemma-to-word-form transmission of priming. Such decline would finally prevent the complete phonology of target words to be fully retrieved.

As illustrated in more detail in chapter 1, experimental verifications of the TD model's predictions have been gathered mainly with the use of behavioral paradigms implying experimentally induced TOT states (e.g. Cross & Burke, 2004; Abrams, White & Eitel, 2003; White & Abrams, 2002). However, in these studies the hypothesis of a priming transmission deficit from lexical to phonological nodes was investigated more indirectly by examining for instance the effect of different sizes of phonological priming - from a single letter to syllables - on TOTs resolution in older adults (e.g. Abrams et al., 2003; White & Abrams, 2002). The fact that priming at least the first syllable of a target word increased TOT states resolution comparatively more than priming only the first letter or phoneme, was interpreted as an evidence of the fact that priming a syllable allowed to effectively offset priming transmission deficits of the one-on-one lexical-to-phonological connections necessary to successfully retrieve the complete word form.

A more direct examination of the TD model's predictions has been conducted by Taylor & Burke (2002) by adopting a picture-word interference paradigm. The picture-word interference paradigm is particularly suitable to isolate the priming pathways hypothesized by the NST. The structure of the NST envisages three distinct priming pathways (see Fig. 1 in Chapter 1): priming transmission within semantic nodes, between lexical and phonological nodes (top-down priming) and inversely between phonological and the lexical nodes (bottom-up priming).

According to the TD model's, ageing selectively affects the top-down priming transmission pathway from lexical to phonological nodes; the reason why this specific priming pathway is particularly vulnerable, in conjunction with the sparing of the other pathways, is due to the very structure of the NST. Transmission of priming within the semantic system is resistant to decline in reason of its highly complex and distributed network; the disruption of information flow between two semantic nodes would be easily offset by alternative connections, capable of providing sufficient priming by indirect ways. Likewise, the bottom-up priming transmission from phonological to lexical nodes is characterized by a convergence of many nodes phonological nodes onto one lexical node, such that the transmission priming in one of these connections would not prevent the lexical node to reach sufficient priming. Conversely, the top-down priming pathway from lexical to phonological nodes is highly sensible to transmission priming declines in reason of the divergence from one single lexical nodes to many phonological nodes (one-on-one connections), such that the disruption of one single connection would prevent retrieval of the complete phonology of a target word.

The Authors examined each of the three priming pathways in two different experiments: priming within the semantic system has been investigated by means of a semantic interference paradigm. A picture is named slower when accompanied - typically preceded - by a semantically related competitor (e.g. the picture of a frog preceded by the distractor "turtle"), if compared to an unrelated distractor.

The semantic interference effect is accounted for by the hypothesis that when a semantically related distractor is presented before the target, some semantic nodes will receive a concomitant priming from both the semantic processing of picture and the perceptual processing of the distractor, preventing the target's priming level to overcome on the distractor by reaching the critical threshold for activation (e.g. Levelt, Roelofs & Meyer, 1999) and therefore slowing response latencies.

Considering the evidences showing that older adults present greater semantic priming effects (Pichora-Fuller, Schneider, & Daneman, 1995; Speranza, Daneman, & Schneider, 2000; Wingfield, Alexander, & Cavigelli, 1994), and considering such greater effect as the consequence of a more effective priming of lexical representations stemming from older adult's richer and more interrelated semantic system (e.g. Taylor & Burke, 2002), the TD model predicts that older adults would show a greater semantic interference effect in relation to younger adults.

The "bottom-up" priming pathway from phonological to lexical nodes has been investigated by means of a phonological priming task. A picture is named faster when accompanied - or followed - by a phonologically related distractor word (e.g. the picture of a "frog" followed by the word frost") if compared to an unrelated distractor. The underlying assumption is that the phonologically related distractor will prime the same phonemes primed by the picture, speeding up naming latencies (e.g. Schriefers, Meyer & Levelt, 1990). Considering the convergence of phonological nodes onto a single lexical node envisaged by the NST, no inter-age differences should be observed in phonological priming according to the TD model.

The "top-down" priming pathway from lexical to phonological nodes has been examined by resorting to a paradigm originally introduced by Cutting & Ferreira (1999) to address the theoretical issue of serial and cascaded processing in word production. In such condition, a word with an homophone name is accompanied by a distractor word which is related to its implicit meaning. Figure 1 below illustrates such paradigm.

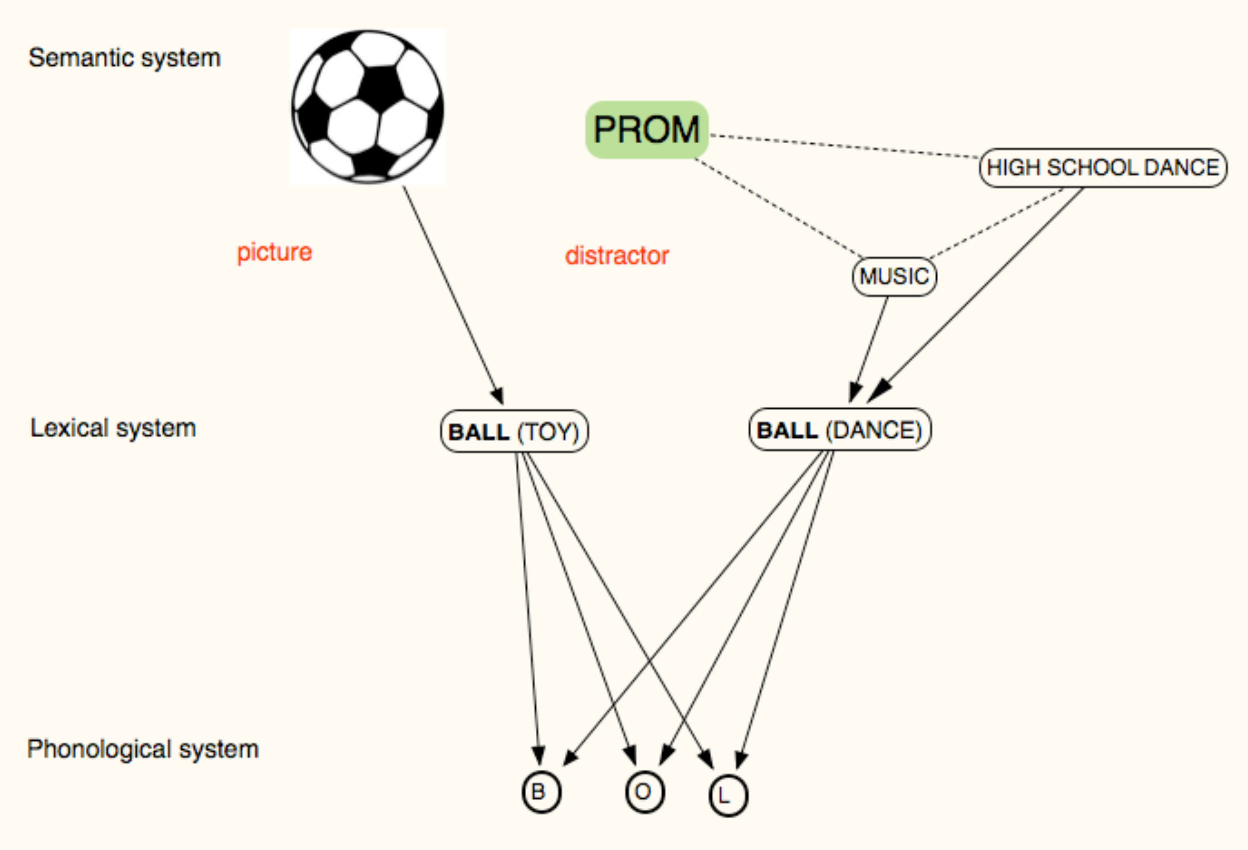


Fig 1. Illustration of the "top-down" priming condition introduced by Cutting & Ferreira (1999). The distractor activates a lexical node that shares the phonological form of the picture to be named.

For instance, the picture of a toy "ball" is preceded by a distractor word which is related to the non depicted meaning of the picture, for example “prom”, which is semantically related to the word dance “ball”, which is in turn phonologically related to the picture "toy ball", if compared to a condition in which an unrelated distractor is presented (e.g.: car). The authors explain this effect by assuming that the related distractor (in this case "prom") will activate semantic nodes that will transmit priming to semantically related lexical nodes, including dance “ball". Priming will then advance top-down from the lexical node to the phonological system in which the appropriate phonemes are primed. The presentation of the picture of a toy “ball” allows the activation of semantic nodes that will prime the lexical node (toy “ball”) and the corresponding phonemes, which are the same phonemes primed by the distractor. This convergent priming from lexical nodes to the same phonological nodes is expected to speed up naming latencies. However, as illustrated above, this specific priming pathway is thought to be more vulnerable to age-related declines in priming transmission in reason of the divergence from one lexical node to several phonological nodes. Hence, the TD model predicts that older adults would not benefit form the concurrent top-down priming to phonological nodes triggered by this particular condition.

Results of the study by Taylor & Burke (2002) substantially confirmed the TD model’s predictions. Older adults showed a greater semantic interference effect in comparison with younger adults, no significant differences were found in the “bottom-up” priming condition from phonological to lexical nodes, and older adults did not benefit, contrary to younger adults, of the “top-down” priming from lexical to phonological nodes.

The absence of a facilitatory effect on response latencies in the “top-down” priming condition in the older adults group, has been utilized by the authors to endorse the core hypothesis of an age-related deficit in the priming transmission from lexical to phonological nodes. By the way, results are yet open to different interpretations. The evidence of a greater semantic priming and interference effects in older adults has been explained as the outcome of a richer and more interconnected semantic system, deriving from an increase in connections between semantic nodes occurring during adulthood and confirmed by older adult's greater verbal competence and richness of vocabulary (e.g. Schaie, 1994).

In the case of semantic interference, older adult's richer semantic network would cause a comparatively more effective priming of the lexical competitors to the target word, slowing lexical selection and therefore causing a greater semantic interference effect in relation to younger adults. Following results of the study presented in Chapter 3 of the present thesis – in which older adults' lower accuracy in a picture naming task has been interpreted as the outcome of a less effective activation of a target lemma due to the priming of a greater number of competitors - an equally plausible hypothesis for the greater semantic interference effect in older adults is that older adults' richer and more distributed semantic network would lead not only to a more effective priming of the competitor lexical representation, but also to the priming of a greater number of lexical competitors. In the case of semantic interference, reaching of the activation threshold for the target word would be made more difficult by such priming of a greater number of competitors, further complicating lexical selection for older adults in reason of the greater number of activated candidates.

On the other hand, in the case of the top-down priming condition utilized by Taylor & Burke (2002), older adults' absence of a facilitatory effect on response latencies could stem from the activation – caused by presentation of the distractor related to the non depicted meaning of the picture (e.g. "prom" preceding the picture of a "ball") - of a comparatively greater number of alternates beyond the one sharing the phonological form with the picture to be named. This over-activation at the lemma level would in turn be transmitted to phonological nodes, therefore reducing the successful priming of the phonological nodes of the target item.

Greater semantic priming effects in older adults have been reported frequently in the literature (Taylor & Burke, 2002; Pichora-Fuller et al., 1995; Speranza et al., 2000; Wingfield et al., 1994; and see Laver & Burke, 1993 for a review). On the contrary, to our knowledge the absence of a top-down priming effect in older adults has been reported only by Taylor & Burke (2002).

Thus, in the present study we investigated the effects of healthy ageing on language production even more directly relative to the study presented in Chapter 3, by focusing more on the top-down priming paradigm. Here we examined the TD model's predictions by resorting to an interference paradigm similar to the one utilized by Taylor & Burke (2002). This was done by coupling behavioral measures (response latencies) with a neurophysiological measure capable of providing information on the time course of the top-down interference task described above.

In order to test the hypothesis that older adults did not benefit from the top-down priming in reason of the activation of more alternates at the lexical level, the negative SOA of -150 ms utilized in the previous studies of Cutting & Ferreira (1999) and Taylor & Burke (2002) was increased to -500 ms in three distinct picture-word interference conditions: phonological priming, top-down priming and an unrelated condition. The idea underlying the choice to increase the distractors' SOA is that an SOA of -150 ms could be too short to allow an effective priming transmission of a greater number of candidates - due to older adults' richer and more distributed semantic network - from the lexical to the phonological level. Increasing the SOA of the distractor related to the non depicted meaning of the picture to be named could in fact offset this over-activation of alternates at the lemma level, allowing the appropriate phonemes to reach the sufficient priming required for the facilitatory effect to emerge clearly also in older adults.

Material and methods

Participants

20 undergraduate students recruited at the University of Geneva, and 16 older adults recruited through an advertisement in a local trade journal participated in the research.

Younger adults were aged between 18 and 25 year-old (mean: 21; 2 men), older adults between 62 and 80 year-old (mean: 70; 6 men). All participants gave informed consent and were remunerated for their participation in the experiment. They were all native French speakers, right-handed according to the Edinburgh Handedness Scale (Oldfield, 1971), with no history of brain damage and a normal or corrected-to-normal vision. They all underwent short tests assessing attentional and executive functions, namely the Trail Making Test (Tombaugh, 2004) and a simple go/no go test, administered to verify that they were all comprised within the normal range according to their age and education.

Material

The stimuli were 42 imageable words with homophone names (ex. “verre” - /vER/ -glass- has several homophones, among them “ver” /vER/ -worm-) and their black-and-white line corresponding drawings.

The stimuli were selected from a larger set of 88 concrete homophone words following a pre-test carried out with 12 participants in a word association task. Participants were given the distractor words and were asked to provide an associated word that came to mind. Results of the pre-test were utilized to ensure that the distractor word effectively activated homophone words of the target words in at least half of the participants, which was the case only for the 42 finally selected stimuli.

Each item was associated with three different kinds of written distractor words to create the three priming conditions, namely "top-down", "phonological" and "unrelated":

- Words semantically associated to the non-depicted meaning corresponding to the name of the homophone picture (for instance the word "asticot" - maggot - associated with a picture of a "verre" - glass - which in French is an homophone of the word "ver" - worm),
- Words which were phonologically related to the name of the target word by sharing its first phoneme (e.g. the word "vélo" - bike - associated with the picture of a "verre" - glass)
- Words that had no relationship - either semantic or phonological - with the picture presented (e.g. the word "toit" - roof - associated with the picture of a "verre" - glass).

The pictures corresponding to the selected items were taken from two French databases (39, from Alario & Ferrand, 1999 or from Bonin, Peerman, Malardier, Méot & Chalard, 2003) and 3 black-and-white line drawings were created for the study.

The 42 pictures consisted in 280 x 280 pixels black-line drawings. The written words distractors were presented in Courier New 18-point font, in white on a gray background.

Each participant was presented 42 pictures in three consecutive blocks separated by short pauses. Each picture appeared in the three different conditions (top-down priming, phonological priming and unrelated condition), for a total of 126 trials. Each of the condition appeared only once in one of the three block. The stimuli appeared in a pseudo-randomized order, which differed across participants, and each condition had to appear an equal number of times in each of the three blocks across all participants. Two filler items were added at the beginning of each block.

Procedure

Each participant sat on a chair placed at about 60 cm from the computer screen. Experiments were conducted in a soundproof cabin. The presentation of stimuli was controlled with the E-Prime software (E-Studio). Before the experiment, participants were shown a list of the 42 pictures included in the study and the corresponding words in order to avoid doubts and non-recognitions of pictures during task performance.

Instructions for the task appeared on the screen before a short training session, which included six trials and was administered to be sure that instructions were clear.

Each trial consisted of a fixation cross presented for 500 ms, followed by the written word, which was presented for 400 ms at a negative SoA of - 500 ms with respect to picture onset. Pictures were then presented for 2000 ms on a gray screen. Participants were instructed to ignore the distractor and to name the pictures as quickly and accurately as possible. Vocal responses were recorded by means of a microphone and digitized for further accurate verification. Participants were given 2000 ms to name the picture; if responses were not entered in this time lapse the trials were classified as "no responses”. The inter-trial interval lasted 2000 ms, during which a blank screen was displayed before the next trial.

EEG acquisition and pre-analyses

EEG was recorded using the Active-Two Biosemi EEG system (Biosemi V.O.F. Amsterdam, Netherlands) with 128 channels covering the entire scalp. Signals were sampled at 512 Hz with band-pass filters set between 0.16 and 100 Hz.

Stimulus-aligned (forward) epochs of 450 ms and response-aligned (backward) epochs of 450 ms were averaged across subjects and age groups. In the younger adults group, response-aligned epochs were time-locked to 200 ms before the onset of articulation of each individual trial in order to avoid artifacts due to response preparation and articulation; stimulus- aligned epochs were locked to the time the picture appeared on screen. In the older adults group, response-aligned epochs were time-locked to 300 ms, in reason of the higher rate of articulation artifacts that was found during pre-analyses.

In the spatio-temporal topographic analysis, stimulus- and response-aligned data of each subject were combined according to each individual subject's response latency by removing the overlapping signal, in order to end up with an ERP covering the entire word encoding interval picture onset to 200 ms before articulation in the younger adults group, and 300 ms before articulation in the older adults group (Laganaro & Perret, 2011).

During the process of pre-analysis an automated selection criterion rejecting epochs with amplitudes reaching +-100 µV was utilized. Moreover, each trial was inspected individually so to exclude epochs which were contaminated by artifacts due to eye blinking, movements or other sources of noise from the averaged data. ERPs were bandpass-filtered to 0.2–30 Hz and recalculated against the average reference. A minimum of 61 trials was averaged for each subject.

Behavioral analyses

Response latencies (RTs) that separated stimulus onset from onset of articulation were identified with a speech analysis software (Check Vocal, Protopapas 2007) that allows visualizing both waveforms and spectrograms of each response. RTs were analyzed with two repeated measures ANOVAs, one by participants and one by items, with the distractor condition as a within-participants and within-items factor and age group as a between-participants and within-items factor.

ERP analyses

Local waveform analyses

A waveform analysis was conducted on ERPs to identify the time windows of amplitude differences between conditions and age group. Electrode-wise and sampling point-wise (every ~2 ms) ANOVAS were computed on amplitudes of the evoked potentials at each electrode and time point with priming condition as within subject factor and age groups as between- subjects factor for each data set, that is on stimulus-and response-aligned ERPs (aligned 300 ms before articulation for all participants).

As a criterion, only differences occurring over at least 5 (out of 128) electrodes, and with duration of more than 20 ms were retained with an alpha criterion of .01. For the analysis of within group priming effects, electrode-wise and sampling point-wise paired t-tests were run over the entire analyzed time periods.

Amplitude modulations of ERP traces can be due to disparate reasons: the modulation in the strength of the electric field, a global topographic difference of the electric fields (revealing distinguishable brain generators) or latency shifts of similar brain processes. For this reason, the group-averaged ERPs were subjected to a TANOVA and to spatio-temporal segmentation to determine topographic differences across different conditions in each age group, and statistically validate them in the responses of single subjects. This methodology allows reducing the complete EEG dataset into a limited series of template maps explaining at best total data variability, with additional information on the duration of stable periods in different tasks and conditions. Each modification at the level of the spatial configuration of the electric field recorded on the scalp can be interpreted as a changing in the activation of the intracranial generators and therefore of the information processing stage involved (Pascual-Marqui, Michel & Lehmann, 1995).

Spatio-temporal segmentation of ERPs (global topographic pattern analysis)

A Topographic Anova (from now on: Tanova) was previously issued on each sampling point to identify periods of significant topographic modulation between different conditions in each of the two age groups separately. The Topographic Anova is a non-parametric randomization test, which analyzes global dissimilarity measures between conditions (Murray, Brunet & Michel, 2008). The same time-period criterion of 30 consecutive ms was applied.

A spatio-temporal segmentation analysis of the ERPs over periods of electrophysiological stability (i.e. topographic maps or EEG microstates) was subsequently run using a modified hierarchical clustering analysis (Michel, Thut, Morand, Khateb, Pegna & Grave de Peralta, 2001; Pascual-Marqui et al., 1995) - the agglomerative hierarchical clustering (Murray et al., 2008).

The spatio-temporal segmentation algorithm compresses the variability of ERPs in a series of template maps which summarize the data and serve to determine was used to determine the dominant spatial configurations of the electric field at the scalp (topographic maps). Periods of stable configuration are assumed to reflect different encoding substages of information processing (e.g. Pascual-Marqui et al., 1995). A temporal post-processing was added to the process of segmentation: segments lasting less than 15 time frames (about 30 ms) were excluded and reassigned to neighbor clusters sharing the higher spatial configuration. Moreover, maps that shared a spatial correlation of more than .95 were merged together. Each spatio-temporal segmentation yields a set of quality measures useful to pick the best segmentation among alternatives. A combination of cross-validation and Krzanovski-Lai criteria was used to choose the optimal number of template maps explaining at best the group-averaged datasets across conditions.

A spatio-temporal segmentation was issued on the three different conditions (unrelated, phonological and top-down priming) separately in each age group (younger and older subjects). Afterwards, the sequence of template maps observed in the group-averaged data was statistically tested by comparing each of these maps with the moment-by moment scalp topography of individual subject-averaged ERPs in each group or condition. This procedure, known as “fitting”, allows to establish how well a cluster map explains individual patterns of activity (GEV: Global Explained Variance) and its duration, by producing a labeling of each time point for each of the individual subjects’ ERP according to the Grand Average’s template map with which it best correlates spatially, yielding therefore a measure of the presence of template maps in each condition for each age group.

Results

Behavioral results

One stimulus had to be excluded from further analysis because almost all participants gave a wrong response. On the remaining 41 stimuli, both younger and older adults had a very high accuracy (respectively 92% and 89% of correct responses). Reaction times for each group (younger and older adults) and condition (top-down, phonological and unrelated) are reported in Figure 2.

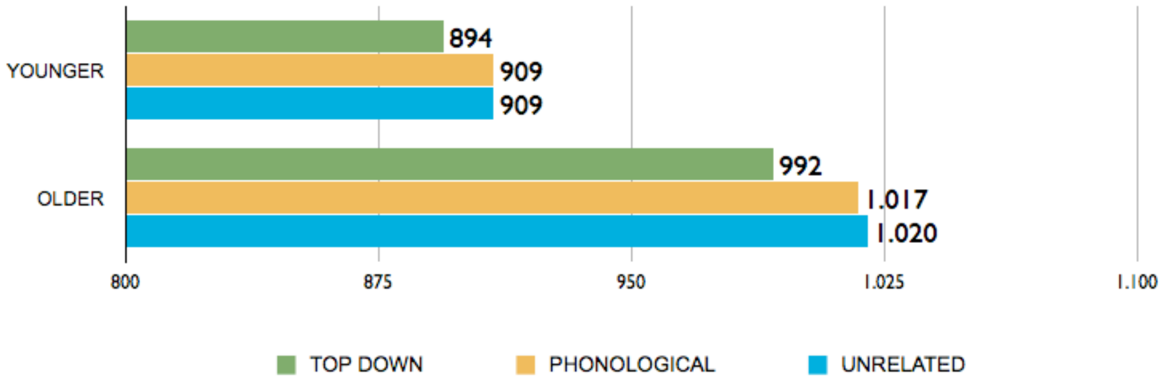


Fig. 2 Reaction times (in ms) for each age group and priming condition.

Older adults were slower in naming pictures with respect to younger adults (F1(1, 34)=13.535, p=.001, F2(1, 80)=132.592, p<.001) and the distractor type significantly affected response latencies (F1(2, 68)=7.832, p=.001, F2(2, 80)=6.246, p=.003).

No interaction between group and condition was found (F1(1, 34)=1.53, p=.225, F2(2, 80)=1.092, p=.340).

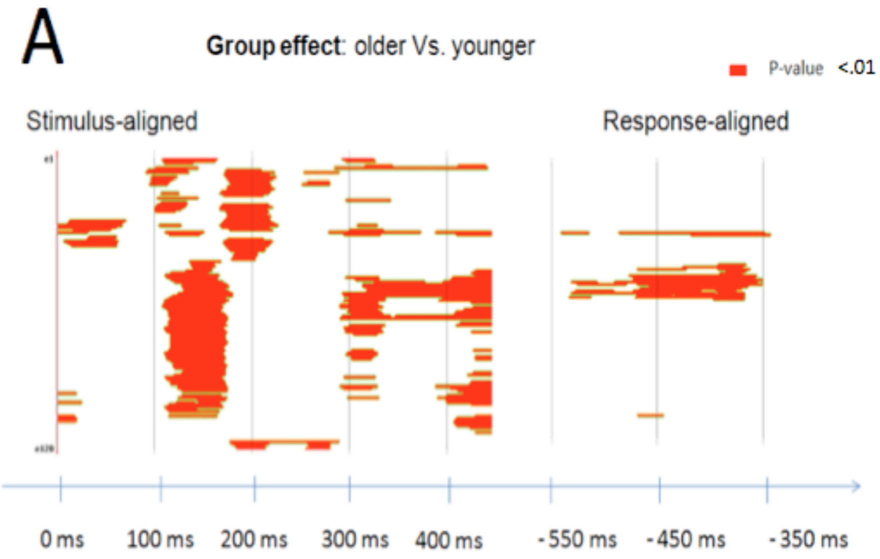
Paired t-tests revealed that younger adults were faster to name pictures in the top-down priming condition when compared to the unrelated condition, but this effect was significant only in the subject analysis (t1(19)=2.272, p=.035, t2(40)=1.54, p=.13). No effect of the phonological distractors was observed in relation to the unrelated condition (t1, t2 <1).

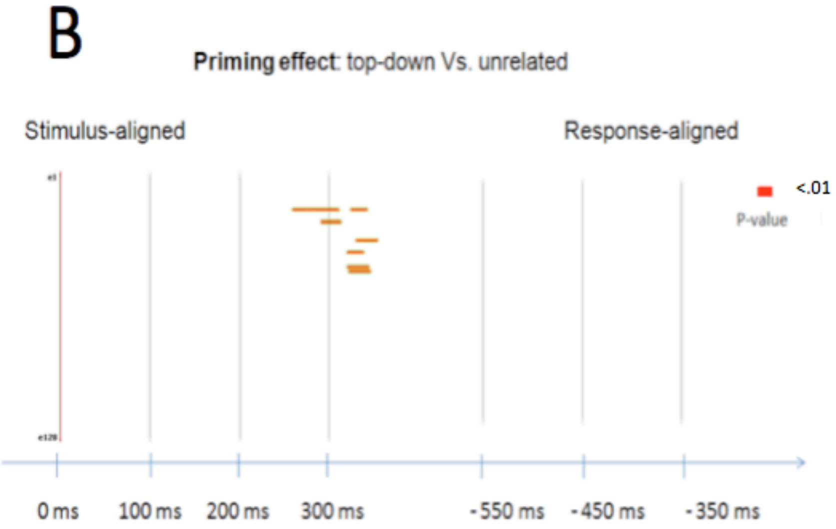
In the older adults group, participants were faster in naming pictures in the top-down condition (t1(15)=3.495, p=.003, t2(40)=2.663, p=.011) and no effect of the phonological distractors was found (t1, t2<1).

ERP waveform analysis

A total of 4 subjects were excluded after pre-analysis of the EEG signal (3 younger adults and 1 older adult). Subjects which had a signal contaminated by blinking or movement artifacts, or for which less than 50% of epochs were exploitable, were excluded from further analysis. The final groups included 17 younger adults (aged between 18 and 25, mean: 21) and 15 older adults (aged 62-81, mean: 71).

Results of the ANOVA on the response-aligned ERPs are shown in Figure 2. Considering the absence of effects in the phonological priming condition, only the top-down priming and unrelated conditions were compared. Between age groups, amplitudes differed significantly across a large proportion of electrode sites from about 150 to 200 ms and from 300 to about 450 ms after picture onset and between - 450 and – 350 ms before response articulation (Fig. 2A). Between priming conditions, amplitudes differed in the time window comprised from about 300 to 350 ms (Fig. 2B). An interaction between age group and priming condition was concentrated at about 150 ms after picture onset (Fig. 2C).


A
Group effect: older Vs. younger
🟥 P-value <.01
Stimulus-aligned
Response-aligned
e1
e128
0 ms
100 ms
200 ms
300 ms
400 ms
-550 ms
-450 ms
-350 ms


B
Priming effect: top-down Vs. unrelated
Stimulus-aligned
Response-aligned
🟥 <.01
P-value
e1
e128
0 ms
100 ms
200 ms
300 ms
-550 ms
-450 ms
-350 ms

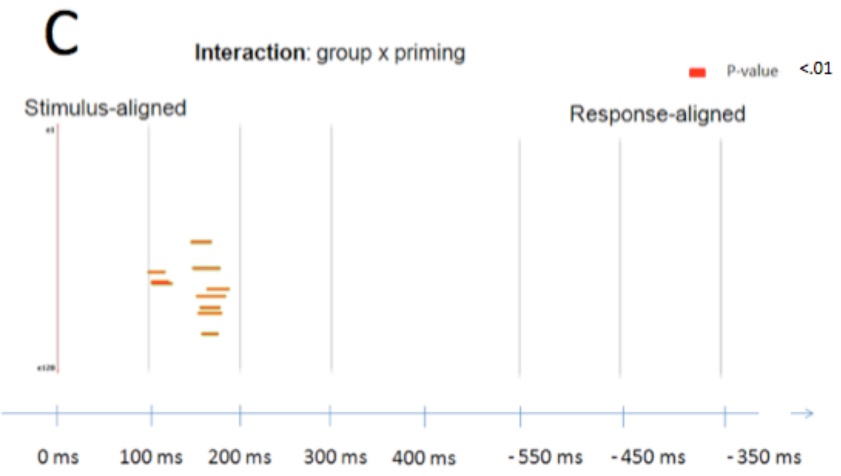
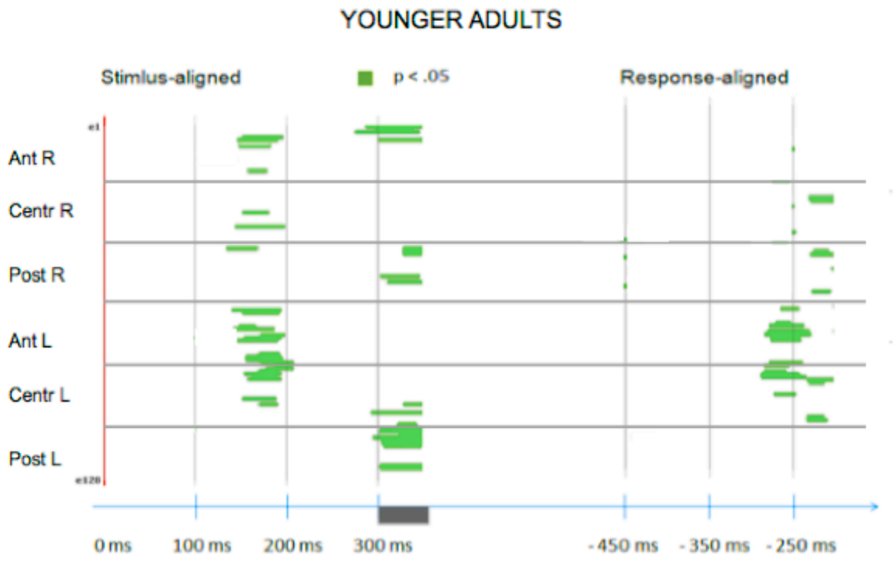


Fig 2 Significant differences (ANOVA's p values) on ERP waveform amplitude on each electrode and time point A. Between age groups, B. Between top-down and unrelated conditions, C. In the interaction between age group and priming condition.

Paired t-tests and TANOVAS were then issued between the top-down priming and the unrelated condition in both age groups separately. Results of the point-wise waveform analysis are shown in Figure 3.



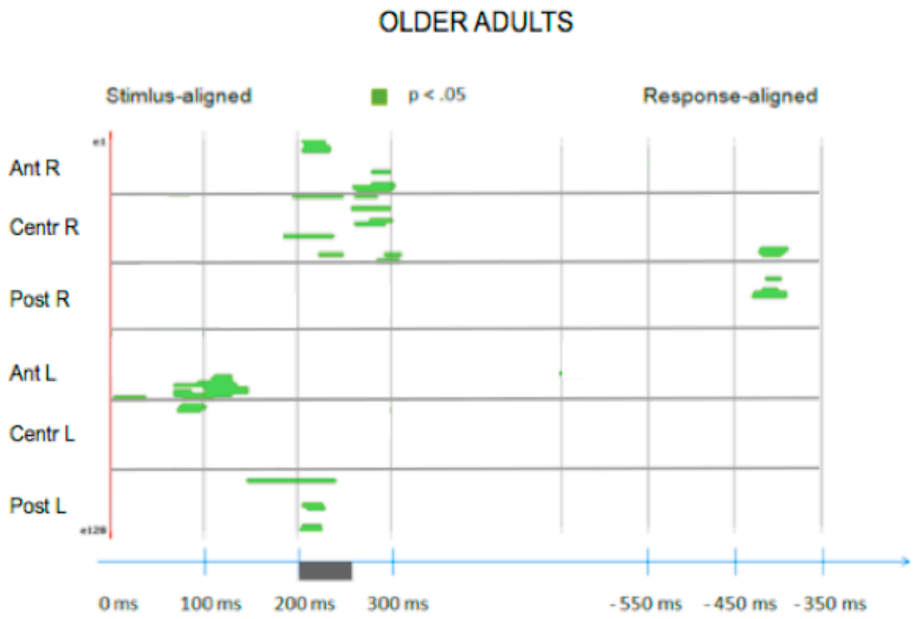


Fig. 3 Significant amplitude differences (p values) on ERP waveforms on each electrode and time point between top-down and unrelated conditions in younger and older adults.

In younger adults group, significant amplitude divergences were mainly concentrated in a time window comprised between about 150 and 200 ms after picture onset, between about 300 ms and 350 ms after picture onset and at about 250 ms before response articulation. In the older adults group, significant amplitude differences were concentrated at about 100 ms and between about 200 ms and 300 ms after picture onset, and at about 400 ms before the onset of articulation.

In the younger adults group, the Tanova (gray bar on the time line) highlighted a time window of topographic incongruity between the top-down priming condition and the unrelated distractor condition in a time window ranging from about 300 to 350 ms after picture onset (gray bar), i.e. in the time-window corresponding to the main effect of priming on amplitudes. In the older adults group, an earlier period of topographic incongruity was present at about 200 ms after picture onset.

Then, a spatio-temporal segmentation was issued on the group-averaged ERPs of each priming condition in the two age groups separately. Results are shown in Fig. 4. Each colored segment represents a specific template map with additional information on its time course. The red arrows indicate the periods of topographic stability that presented significant differences in terms of duration and/or onset between the top-down priming and the unrelated condition.

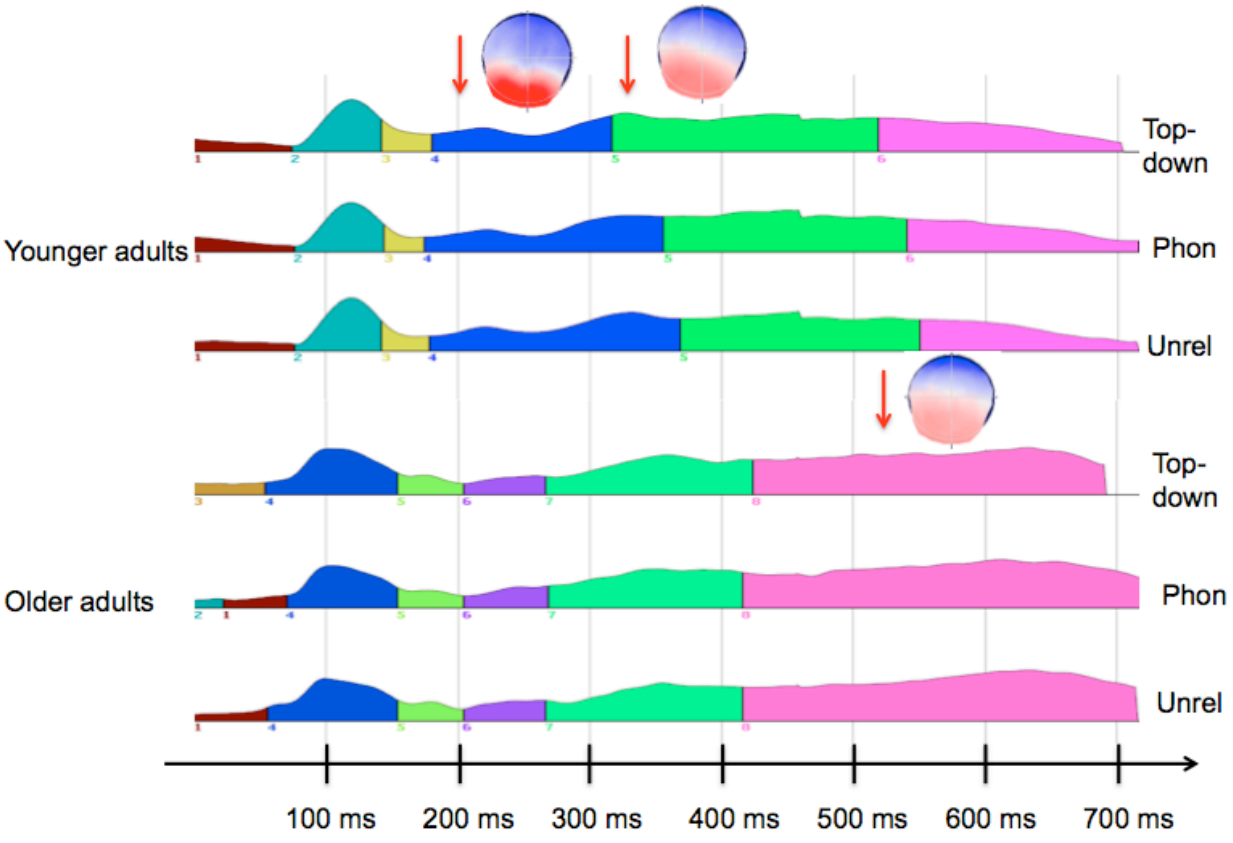


Fig. 3 Results of the spatio-temporal segmentation issued on the three group-averaged ERPs for each priming condition in each age group separately.

The spatio-temporal segmentation of the three priming conditions in the younger adults group yielded a total of 6 different topographic maps accounting for the 96.7% of data variance. The same topographic maps were present in the three conditions, in the time period from stimulus presentation to 200 ms before response articulation. Results of the fitting procedure carried out in five different time windows comprised between 100-260 ms, 160-400 ms, 160-400 ms, 260-460 ms and from 460 ms to response articulation, revealed that template map 4 – ranging from about 180 ms to 350 ms after picture onset - presented an earlier onset in the top-down priming condition in relation to the unrelated condition. A Wilcoxon Signed Rank test issued on map onset between conditions revealed that such difference was significant (Z=-2,023, p<.05). Template map 4 was also significantly shorter in the top-down priming condition in relation to the unrelated condition (Z=-1,959, p=.05).

Finally, onset of the topographic map ranging from about 350 to 550 ms (template map 5) occurred earlier in the top-down priming condition if compared to the unrelated condition. This difference revealed to be tendentially significant (Z=-1,820, p=.069).

In older adults, the segmentation yielded a total of 8 template maps, accounting for the 96% of data variance. The same topographic maps were globally present from about 100 ms after picture onset to 300 ms before response articulation. The fitting procedure was carried out in five different time windows, comprised between 100-240 ms, 180-320 ms, 240-460 ms and from 460 ms to response articulation, and revealed that only the late template map (map 8 in figure X) , ranging from about 400 to 700 ms, was shorter in the top-down condition if compared to the unrelated condition. A Wilcoxon Signed Rank test issued on map durations revealed that such difference was significant (Z=-2,472, p<.05).

Discussion

Contrary to what found by Taylor & Burke (2002), behavioral results showed that at distractor negative SOA of - 500 ms, facilitation in response latencies in the top-down condition emerged clearly also in the older adults group. Such facilitatory effect wasn’t modulated by age. No effects of the phonological primes were found in both age groups. The absence of phonological priming effects with distractors presented at negative SOAs has been also reported for instance by Meyer & Schriefers (1991). This result is presumably explained by the fact that when a phonologically distractor is presented too early in relation to the target, the activation of distractors' segments will decay before processing of the target, resulting in an absence of facilitation.

Results of the ANOVA issued on grand-averaged ERPs with age as between-factor and priming condition (top-down vs. unrelated) as within-factor, revealed age effects on a large proportion of electrodes in different time windows: from 150 to 200 ms and from 300 to about 450 ms after picture onset, and between - 450 and – 350 ms before response articulation. The manipulated priming condition modulated ERPs on sparse electrodes only between about 300 and 350 ms after picture presentation, and the interaction between age groups and priming conditions were localized on sparse electrodes in a time window ranging approximately between 150 and 200 ms after picture onset.

Taken together, these results indicate that age-related differences in terms of encoding processes are quite widespread. The effects of priming, and the interaction between priming and age occurred in relatively early time windows, compatible with semantic processing (from 150 to 200 ms after picture onset) and presumably lemma selection (between about 300 and 350 ms after picture onset). This finding is consistent with the hypothesis of age-related modifications in early encoding stages. Contrary to what postulated by the TD model, no salient differences in the effect of the priming condition were observed in later time windows in which phonological retrieval should be engaged. This seems to suggest that, at increased distractor negative SOA, facilitatory effects on phonological processing remain constant across age groups, consistently with the hypothesis that raising negative SOA to – 500 ms could allow compensation for older adults' higher activation at the phonological level. However, results are at odds with the TD model's hypothesis of a selective lexical-to-phonological priming transmission deficit, which would predict transmission deficits independently of distractor SOA.

The paired t-test and TANOVA conducted separately within age groups between the top-down and priming conditions, revealed that younger adults displayed significant amplitude differences in three distinct time periods: from 150 to 200 ms and from 300 to 350 ms after picture onset, and at about -250 ms before response articulation. The TANOVA identified a period of topographic incongruity ranging from about 300 to 350 ms after picture onset. Older adults displayed amplitude differences localized on more sparse electrodes, mainly at about 100 ms and between about 250 ms and 300 ms after picture onset, and at about 400 ms before the onset of articulation. The TANOVA identified topographic inconsistencies between 200 and 250 ms after picture presentation.

Amplitude differences between priming conditions in both age groups seem to be evenly distributed in time-windows in which different stages of encoding involved in retrieving the name of a picture are assumed to be engaged, namely semantic processing, lexical selection and finally phonological encoding (e.g Levelt et al., 1999).

According to Cutting & Ferreira (1999), who introduced the paradigm, the top-down priming condition should lead to a facilitation in response latencies due to the early priming of the same phonological nodes that will be subsequently activated by presentation of the picture. Considering that in the top-down priming condition, the only relationship between distractor and target should be at the phonological level, amplitude differences between the top-down and unrelated condition should be distributed in a late time window compatible with retrieval of phonological information. On the other hand, the TD model predicts no phonological facilitation in older adults, because of the priming transmission between the lexical and phonological level.

In the light of these premises, results of the amplitude comparisons in both age groups are not easily interpretable, since differences appear to be distributed in several time periods, with relatively early amplitude differences corroborated also by the TANOVA. With respect to the TD model's prediction, results showed differences in a late time window compatible with phonological processing also in older adults group. This result is consistent with the hypothesis that at negative distractor SOA of -500 ms, the facilitation in retrieval of phonological information is likely to occur also in older adults.

A spatio-temporal segmentation was run on each of the grand-averaged ERPs for the three priming conditions in each age group separately, with the aim of assessing the effect exerted by the top-down priming condition with respect to the unrelated condition on periods of topographic stability.

Results showed that in younger adults differences were concentrated on both the onset and duration of the period of topographic stability ranging from about 180 to 350 ms. This period of topographic stability was significantly earlier and shorter in the top-down condition if compared to the unrelated condition, a result which is corroborated by results of the TANOVA, indicating topographic incongruities in younger adults in a time window comprised between about 300 and 350 ms after picture onset. Likewise, the onset of the subsequent period of topographic stability, ranging from about 350 to 550 ms, occurred earlier in the top-down condition. No differences were found in later periods of topographic stability, compatible with phonological processing.

Discordantly, older adults showed differences between the top-down and unrelated condition, in the duration of the last period of topographic stability, ranging from about 400 to 700 ms after picture onset, in a time window compatible with phonological encoding, a finding which seems to be in accordance with our hypothesis of phonological facilitation at distractor negative SOA of

– 500 ms. The fact that younger adults did not manifest topographic differences in the time window compatible with phonological processing is more difficult to explain. One hypothesis is that a smaller activation of candidates at the lemma level (due to a less rich and distributed semantic network) could have allowed a more effective and earlier priming of phonological nodes in respect to older adults; the increased distractor's SOA could have subsequently induced a priming decay at the phonological level and partially reduced phonological facilitation effects with respect to the unrelated condition. This could perhaps also explain younger adults' differences in terms of periods of topographic stability in an earlier encoding stage, suggesting that they could have benefited from priming at the level of lemma selection.

Chapter 5: General discussion

General discussion

The main purpose of this doctoral thesis was to investigate age-related modifications in language production processes. This aim has been pursued by associating behavioral and neurophysiological measures (ERP topographic analysis) capable of providing information on the exact time course of the encoding processes involved in the performance of theoretically relevant tasks.

In the following section we will resume the contributions of each chapter and discuss future openings.

After an introduction on theoretical aspects of healthy language ageing, we presented a novel methodological approach to topographic analysis (chapter 2), suitable to establish connections between periods of stable topographic configuration and the encoding stages postulated by current models of word production (e.g. Levelt et al., 1999). This methodological approach has been applied to determine the influence of specific psycholinguistic factors on the duration of periods of topographic stability in a classic picture naming paradigm. However, an open future possibility is to apply such methodology to the study of language ageing, with the aim of better pinpointing which stages of information processing are subject to age-related modifications, and therefore to examine more deeply the validity of current theories on healthy language ageing.

In chapters 3 and 4 we presented two studies more directly aimed at investigating age-related modifications in language production processes. Globally, results of these studies question the core assumption of the TD model, according to which the increasing word finding difficulties in elderly speakers are attributable to a selective deficit in the top-down pathway for production between lexical and phonological nodes (e.g. Neumann, Obler, Gomes & Shafer, 2009; Taylor & Burke, 2002).

In chapter 3 we presented a study aimed at investigating age-related modifications in word production processes. A picture naming and a picture-word verification task were utilized. Behavioral measures were associated with a functional brain imaging technique (topographic analysis) useful to provide more detailed information on the precise time course of the encoding stages involved in word production, and to better index the precise temporal locus of inter-age differences.

Results confirmed the decrease in naming accuracy occurring along the ageing process (e.g. Goral et al. 2007; Connor et al., 2004; Nicholas et al., 1998 but see Goulet et al., 1994); in fact, older adults named pictures less accurately in relation to younger adults in a classic picture naming paradigm. In ERPs analysis, the main inter-age differences at the level of both local waveforms and global topographies were concentrated in both an early (150-200 ms after picture onset) and late time window (from 430 to -100 ms before articulation). Previous estimates on the time course of the encoding stages involved in word production associated the early time window with visuo-semantic encoding and the later time window with phonological encoding (Indefrey & Levelt, 2004; Indefrey, 2010). Older adults displayed an additional period of topographic stability - which according to the theory underlies a specific step of information processing (e.g. Pascual-Marqui et al., 1995) - in a time period in which visuo-semantic processing is engaged. This period of stability significantly correlated with naming accuracy, suggesting that the lower naming accuracy displayed by older adults could stem from age-related changes in semantic processing. No significant correlation was found between early ERP differences in the semantic range, and late amplitude divergences concentrated in a more phonological time-window of encoding. Therefore, the impact of age-related modifications on later phonological processing remains an issue to be further investigated.

The hypothesis that the early semantic modifications could arise from an incipient semantic degradation in older adults, as proposed in some studies (e.g. Barresi et al., 2000; Verhaegen & Poncelet, 2013), is challenged by results of the picture-word verification task. Results of this task, which is assumed to imply extensive semantic processing in order to be accomplished (e.g. Stadthagen-Gonzalez et al., 2009), showed that older adults were more accurate, although slower, with respect to younger adults. Moreover, ERP divergences between age groups were again concentrated in a time window compatible with semantic processing. In fact, the period of topographical stability ranging from 170 to 230 ms correlated significantly with accuracy, reinforcing the hypothesis that differences in performance could depend on stage-specific modifications during semantic processing.

The TD model predicts that the priming transmission disruption between lexical and phonological nodes would result in a selective deficit in accessing phonological information (Neumann et al., 2009). Evidences in support of these predictions are based on the fact that, when in TOT states, older adults provide comparatively less partial phonological information and less alternate words (Brown & Nix, 1996). Moreover, Neumann et al. (2009) found that older adults displayed a later ERP component associated with phonological retrieval in a metalinguistic go/no go task. This data alone do not necessary support the hypothesis of a selective deficit in accessing phonological information, since other encoding time windows of interest were not examined.

It is suggested here that lower naming accuracy in older adults is primarily the consequence of age-related modifications occurring during semantic processing, and only secondarily to changes in accessing phonological information. To date there is broad agreement that older adults show greater semantic priming and semantic interference effects (Taylor & Burke, 2002; Pichora-Fuller, Schneider, & Daneman, 1995; Speranza, Daneman, & Schneider, 2000; Wingfield, Alexander, & Cavigelli, 1994). This has been interpreted as an increase in the number of connections within the semantic network, such that conceptually related words are more strongly connected by sharing a higher number of features (see Laver & Burke, 1993 for a review). This would in turn yield a greater priming summation at the level of lexical representations and more effective activation of competitors.

Given the interactive-activation nature of the language production model on which the TD model is based (the Node Structure Theory; MacKay, 1982), it is reasonable to posit that an increase in the number of connections between semantic nodes - due to the higher experience with word meaning acquired by elderly speakers - would similarly lead to the priming of a higher number of candidates at the lexical level, some of which will be primed by semantic nodes which are shared within more numerous lexical representations, finally leading to difficulties in activating the target lexical representation.

Inter-age asymmetries in performance between picture naming and picture-word verification can be explained according to the specific way in which the semantic system receives activation in the two tasks. In the case of picture naming, retrieval of the word form is entirely conceptually driven, whereas in picture-word verification lexical concepts are previously activated by presentation of the word. Hence, in the former case richer semantic connections will interfere with activation of the target lexical nodes, whereas in the verification task the preactivation of conceptual nodes would facilitate conceptual matching, which is likely to be more easily accomplished in a richer semantic network.

In Chapter 4 we presented a study aimed at examining even more directly the TD model's predictions, by adopting a picture-word interference task similar to the one utilized by Taylor & Burke (2002). This paradigm is suitable to isolate the priming pathways envisaged by the interactive activation model of language production on which the TD model is built (the Node Structure Theory; see Fig. 1 of Chapter 1 for an illustration). Behavioral measures were associated with ERP methodology, useful to index the time course of the encoding processes involved in the performance of this task.

Considering the general consensus around the greater semantic priming and interference effect in older adults (e.g. Pichora et al., 1995; Speranza et al., 2000; Wingfield et al., 1994), we focused more on the top-down priming condition, which according to the TD model is particularly vulnerable to age-related transmission deficits. Results of the study by Taylor & Burke (2002) were apparently consistent with the TD model's predictions: inter-age differences in the picture-word interference task were limited to the top-down priming condition and absent in the phonological and unrelated condition. More specifically, older adults did not benefit, contrary to younger adults, from the concurrent priming of phonological nodes triggered by distractors which were semantically associated to the non-depicted meaning of the picture to be named.

Generalizing the interpretations of the study presented in Chapter 3, we hypothesized that the absence of a facilitatory effect in phonological retrieval could again originate - rather than from a selective lemma-to-word-form priming transmission weakening - from age-related modifications originating at an earlier encoding stage. In particular, a richer and more interconnected semantic network, causing the priming of a higher number of competitors at the lemma level, and consequently spreading to a comparatively higher amount of phonological nodes, could have reduced the facilitatory effect in older adults by slowing down spreading of activation across phonological nodes after presentation of the stimuli. To test this hypothesis, we decided to increase the negative distractor SOA from -150 ms (Taylor & Burke, 2002; Cutting & Ferreira, 1999) to - 500 ms in three different priming paradigms: top-down, phonological and the unrelated condition. The rationale for this choice is that a distractor SOA of - 150 ms could be too short to compensate for older adults' comparatively higher phonological activation, which might delay facilitation effects in phonological retrieval.

Behavioral results showed that at negative distractor SOA of – 500 ms, the facilitatory effect in the top-down priming condition with respect to the unrelated condition emerged clearly also in older adults.

Results of the ANOVA conducted on grand-averaged ERPs with age as between-factor and priming condition (top-down vs. unrelated) as within-factor, revealed widespread age effects in several time windows: from 150 to 200 ms and from 300 to about 450 ms after picture onset, and between - 450 and – 350 ms before response articulation. Interestingly, priming effects and the interaction between age and priming conditions were concentrated in relatively early time periods, compatible with semantic processing and possibly lexical selection (Indefrey & Levelt, 2004; Indefrey, 2010). This observation seems to be in accordance with our hypothesis that when the negative SOA of the distractor is increased, facilitatory effects on phonological processing remain constant across age groups, consistently with the prediction that an increased SOA could compensate for older adults' larger activation of phonological nodes. Results are however difficult to explain in the framework of TD model, which would rather predict a timing-independent lemma-to-word-form priming transmission deficit.

The amplitudes comparison conducted between the priming conditions in both younger and older adults, revealed that for both age groups ERP divergences were quite evenly distributed across distinct time-windows, in which the different encoding stages implied in retrieving the name of a picture are assumed to be unfold, namely semantic processing, lexical selection and finally phonological encoding (e.g. Levelt et al., 1999). Topographic incongruities revealed by the TANOVA test were concentrated in an early time window, from 200 to 250 ms after picture onset in younger adults, and from 300 to 350 ms after picture onset in older adults. According to Cutting & Ferreira's (1999) account of the processing stages involved in the top-down priming condition, ERP divergences between the top-down and unrelated condition should be more concentrated in a late time window compatible with phonological encoding. This is due to the fact that in the top-down priming condition, the only relation between distractor and target is at the level of phonological form. The TD model nevertheless predicts no differences in older adults between the two priming conditions, since phonological facilitation would be obscured by the priming transmission deficit.

These premises are less easily interpretable in the light of the results obtained. ERPs divergences were rather evenly distributed across the entire encoding period from picture presentation to response, and – as predicted and confirmed by the top-down priming effect on response latencies - older adults did show amplitude differences in a late time period compatible with phonological encoding.

These ERPs divergences in a late time window were also confirmed by the spatio-temporal segmentation of group-averaged ERPs. In older adults, topographic differences were concentrated in the very last period of topographic stable configuration – compatible with retrieval of phonological information – that displayed a significantly lower duration in the top-down condition if compared to the unrelated condition. This finding further endorses the suggestion that older adults' top-down priming facilitation in response latencies could be accounted for by differences at the level of word form retrieval.

Conversely, in younger adults topographic divergences were localized in earlier periods of topographic stability. More specifically, the topographic map ranging from about 180 to 350 ms were significantly shorter and earlier in the top-down condition, a result confirmed by the TANOVA test. Likewise, the subsequent period of topographic stability, ranging from about 350 to 550 ms, presented a tendential earlier onset in the top-down condition.

Taken together, results of the spatio-temporal segmentation and TANOVA indicate that younger adults might have benefited of facilitation at the level of lexical selection rather than phonological encoding. One possible explanation for the absence of ERPs differences in the phonological encoding time window has to take into account the increased distractor's negative SOA introduced in the interference paradigm. We hypothesize that younger adults' comparatively lower activation of lexical competitors, due to a less rich and interconnected semantic network, might have caused a more effective priming of phonological nodes compared to older adults; however, the relatively high time interval between distractor and picture might have induced some degree of priming decay of phonological information, partially obscuring the facilitatory effect. ERPs divergences in the time window more likely to involve lexical selection, however, deserve further investigation.

Another point which is worth to be noted here, is that a fundamental issue exists when one has to apply interpretations on the temporal dynamics of word production processes deriving from serial models (e.g. Indefrey & Levelt, 2004) – which currently represent the most advanced integration of behavioral and neuroimaging data – to theoretical accounts of language ageing, which are built on interactive activation models (as the Node Structure Theory; MacKay, 1982) assuming some degree of processing in cascade between encoding stages. The issue of how to exhaustively interpret ERPs data collected in the framework of cascaded processing models remains open to future investigation. This is even more true when utilizing topographic ERP analysis, a methodology that yields a strictly serial sequence of topographic maps underlying different stages of information processing (e.g. Pascual-Marqui et al., 1995). Addressing the theoretical issue of how to reconcile the seriality of topographic maps with the parallel information processing envisaged by cascaded processing is the object of future research, and will offer further insight on results of the study presented in this thesis.

General References

Abrams, L., White, K. K., & Eitel, S. L. (2003). Isolating phonological components that increase tip-of-the-tongue resolution. Memory and Cognition, 31, 1153-1162.

Alario, F.X., & Ferrand, L. (1999). A set of 400 pictures standardized for French: norms for name agreement, image agreement, familiarity, visual complexity, image variability, and age of acquisition. Behavior Research Methods, Instruments, & Computers, 31, 531–552.

Alario, F.X., Costa, A., & Caramazza, A. (2002). Hedging one's bets too much? A reply to Levelt (2002). Language & Cognitive Processes, 17(6), 673-682.

Alario, F.X., Ferrand, L., Laganaro, M., New, B., Frauenfelder, U.H., & Segui, J. (2004). Predictors of picture naming speed. Behavior Research Methods, Instruments & Computers, 36, 140-155.

Allison, T., Wood. C.C., Goff, W.R. (1983). Brainstem auditory, pattern-reversal visual, and short-latency somatosensory evoked potentials: latencies in relation to age, sex, and brain and body size. Electroencephalography and Clinical Neurophysiology, 55, 619-636.

Arbuckle, T. Y., Nohara-LeClair, M., & Pushkar, D. (2000). Effect of off-target verbosity on communication efficiency in a referential communication task. Psychology and Aging, 15, 65–77.

Aristei, S., Melinger, A., & Abdel Rahman, R. (2011). Electrophysiological chronometry of semantic context effects in language production. Journal of Cognitive Neuroscience, 23, 1567-1586.

Attneave, F. (1957). Physical determinants of the judged complexity of shapes. Journal of Experimental Psychology, 53, 221-227.

Baayen, R. H. (2008). Analyzing Linguistic Data. A Practical Introduction to Statistics Using R. Cambridge University Press.

Baayen, R.H. (2010). A real experiment is a factorial experiment? The Mental Lexicon, 5 (1), 149-157.

Baayen, R.H., & Milin, P (2010). Analyzing reaction times. International Journal of Psychological Research, 3 (2), 12-28

Baayen, R.H., Davidson, D.J., & Bates, D.M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. Journal of Memory and Language, 59, 390-412.

Bachoud-Lévi, A.C., Dupoux, E., Cohen, L. & Mehler, J. (1998). Where is the length effect? A cross-linguistic study of speech production. Journal of Memory and Language, 39(3), 331-346.

Balling, L.W. (2008). A brief introduction to regression designs and mixed-effects modelling by a recent convert. Copenhagen Studies in Language 36, pp. 175-192.

Barr D., Levy R., Scheepers C., & Tily H.J. (in press). Random effects structure for confirmatory hypothesis testing: Keep it maximal. Journal of Memory and Language.

Barresi, B. A., Nicholas, M., Connor, L. T., Obler, L. K., & Albert, M. L. (2000). Semantic degradation and lexical access in age-related naming failures. Aging, Neuropsychology, and Cognition, 7(3), 169–178.

Barry, C., Hirsh, K.W., Johnston, R.A., & Williams, C.L. (2001). Age of acquisition, word frequency, and the locus of repetition priming of picture naming. Journal of Memory and Language, 44, 350-375.

Barry, C., Morrison, C. M., & Ellis, A.W. (1997). Naming the Snodgrass and Vanderwart pictures: Effects of age of acquisition, frequency, and name agreement. Quarterly Journal of Experimental Psychology, 50A, 560-585.

Bates D.M., & Sarkar D. (2007). lme4: Linear mixed-effects models using S4 classes. R package version 0.9975–12.

Beier, M. E., & Ackerman, P. L. (2001). Current-events knowledge in adults: An investigation of age, intelligence, and nonability determinants. Psychology & Aging, 16, 615–628.

Belke, E., Brysbaert, M., Meyer, A. S., & Ghyselinck, M. (2005). Age of acquisition effects in picture naming: Evidence for a lexical-semantic competition hypothesis. Cognition, 96, B45-B54. doi:10.1016/j.cognition.2004.11.006

Blackford T., Holcomb P., Grainger J., & Kuperberg G.R. (2012). A funny thing happened on the way to articulation: N400 attenuation despite behavioral interference in picture naming. Cognition, 123(1), 84-99.

Bock, K. (1996). Language production: methods and methodologies. Psychonomic Bulletin & Review, 3, 395-421.

Bonin, P ., Chalard, M., Méot, A., & Fayol, M. (2002). The determinants of spoken and written picture naming latencies. British Journal of Psychology, 93, 89-114.

Bonin, P., Peereman, R., Malardier, N., Mot, A., & Chalard, M. (2003). A new set of 299 pictures for psycholinguistic studies: French norms for name agreement, image agreement, conceptual familiarity, visual complexity, image variability, age of acquisition, and naming latencies. Behavior Research Methods, Instruments, & Computers, 35, 158-167.

Bortfeld, H., Leon, S. D., Bloom, J. E., Schober, M. F., & Brennan, S. E. (2001). Disfluency rates in conversation: Effects of age, relationship, topic, role, and gender. Language and Speech, 44(2), 123–147.

Box, G. E. P., & Cox, D. R. (1964). An analysis of transformations. Journal of the Royal Statistical Society, Series B, 26, 211-252.

Brown, A. S., & Nix, L. A. (1996). Age-related changes in the tip-of-the-tongue experience. American Journal of Psychology, 109, 79–91.

Brunet, D., Murray, M.M., & Michel, C. M. (2011). Spatiotemporal analysis of multichannel EEG: CARTOOL. Computational Intelligence and Neuroscience, 2011, Article ID 813870. doi:10.1155/2011/813870.

Burke, D. M. (1997). Language, aging and inhibitory deficits: Evaluation of a theory. Journal of Gerontology: Psychological Sciences, 52B, P254–P264.

Burke, D. M., & Shafto, M. A. (2004). Aging and language production. Current Directions in Psychological Science, 13, 21–24.

Burke, D. M., & Shafto, M. A. (2008). Language and aging. In F. I. M. Craik & T. A. Salthouse (Eds.), The handbook of aging and cognition (pp. 373–443). New York: Psychology Press.

Burke, D. M., MacKay, D. G., & James, L. E. (2000). Theoretical approaches to language and aging. In T. Perfect & E. Maylor (Eds.), Models of cognitive aging (pp. 204–237). Oxford: Oxford University Press.

Burke, D.M., MacKay, D.G., Worthley, J.S., & Wade, E. (1991). On the tip of the tongue: What causes word finding failures in young and older adults. Journal of Memory and Language, 30, 542-579.

Carroll, J. B., & White, M. N. (1973). Age-of-acquisition norms for 220 picturable nouns. Journal of Verbal Learning & Verbal Behavior, 12, 563-576.

Cattell, R.B., (1963) Theory of fluid and crystallized intelligence: A critical experiment. Journal of Educational Psychology, 54, 1-22.

Chalard, M., & Bonin, P. (2006). Age-of-acquisition effects in picture naming: Are they structural and/or semantic in nature? Visual Cognition, 137(8), 864-883.

Chalard, M., Bonin, P., Méot, A., & Boyer B., & Fayol M. (2003). Objective age-of-acquisition (AoA) norms for a set of 230 object names in French: Relationships with other variables used in psycholinguistic experiments, the English data from Morrison et al. (1997) and naming latencies. European Journal of Cognitive Psychology, 15, 209-245

Changeux J-P., Michel C.M. Mechanisms of neural integration at the brain scale level: the neuronal workspace and microstate models. In: S. Grillner and A.M. Grabyel (Eds.) Microcircuits: The Interface between Neurons and Global Brain Function. Dahlem Workshop Report. Cambridge, MA: The MIT Press, 2004, pp. 347-370.

Cheng X., Schafer G., & Akyürek E. G., (2010). Name agreement in picture naming: An ERP study. International Journal of Psychophysiology, 76(3), 130-141.

Connor, L.T., Spiro, A., Obler, L.K., &Albert, M.L. (2004). Change in object naming ability during adulthood. The Journals of Gerontology: Series B, 59(5), 203–209.

Cornelissen, K., Laine, M., Renvall, K., Saarinen,T., Martin, N., & Salmelin, R. (2004). Learning new names for new objects: cortical effects as measured by magnetoencephalography. Brain and Language, 89, 617–622.

Costa, A., Strijkers, K., Martin, C., & Thierry, G. (2009). The time course of word retrieval revealed by event-related brain potentials during overt speech. Proceedings of the National Academy of Science,, 106, 21442–21446.

Cross, E. S., Burke, D. M. (2004). Do alternative names block young and older adults retrieval of proper names? Brain and Language, 89, 174–181.

Cuetos, F., Ellis, A.W., & Alvarez, B. (1999). Naming times for the Snodgrass and Vanderwart pictures in Spanish. Behavior Research Methods, Instruments, & Computers, 31, 650-658.

Cutting, J. C., & Ferreira, V. S. (1999). Semantic and phonological information flow in the production lexicon. Journal of Experimental Psychology: Learning, Memory, and Cognition, 25, 318–344.

Damian, M. F., Bowers, J. S., Stadthagen-Gonzalez, H., & Spalek, K. (2010). Does word length affect speech onset latencies in single word production? Journal of Experimental Psychology: Learning, Memory & Cognition, 36, 892-905.

Dell, G. S. (1986). A spreading-activation theory of retrieval in sentence production. Psychological Review 93, 283–321.

Dell, G. S. (1988). The retrieval of phonological forms in production: Tests of predictions from a connectionist model. Journal of Memory and Language, 27, 124–42.

Dell, G. S. (1990) Effects of frequency and vocabulary type on phonological speech errors. Language and Cognitive Processes, 5, 313–49.

Dell'Acqua, R., Lotto, L., & Job, R. (2000). Naming times and standardized norms for the Italian PD/DPSS set of 266 pictures: direct comparisons with American, English, French, and

Spanish published databases. Behavior Research Methods, Instruments, and Computers, 32, 588–615.

De Lucia, M., Michel, C.M., Clarke, S., Murray, M.M. (2007). Single-subject EEG analysis based on topographic information. Internal Journal of Bioelectromagnetism, 9, 168–71.

Ellis, A. W., & Morrison, C. M. (1998). Real age-of-acquisition effects in lexical retrieval. Journal of Experimental Psychology: Learning, Memory, & Cognition, 24, 515-523.

Feyereisen, P. (1997). A meta-analytic procedure shows an age related decline in picture naming: Comments on Goulet, Ska, and Kahn (1994). Journal of Speech, Language, and Hearing Research, 40(6), 1328–1333.

Fromkin, V. A. (1971). The Non-Anomalous Nature of Anomalous Utterances. Language, 47(1), 27-52.

Ganushchak, L. Y., Christoffels, I., & Schiller, N. (2011). The use of electroencephalography (EEG) in language production research: A review. Frontiers in Language Sciences, 2, 208.

Garrett, M. F. (1980). Levels of processing in sentence production. In B. Butterworth (Ed.), Language production: Vol. 1. Speech and talk (pp. 177–220). San Diego, CA: Academic Press.

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

Glaser, W. R., & Düngelhoff, F.J. (1984). The time course of picture-word interference. Journal of Experimental Psychology: Human Perception and Performance, 10(5), 640-654.

Goldstein, H. (1987). Multilevel models in educational and social research. London, Griffin.

Goldstein, H. (1995). Multilevel Statistical Models , Halstead Press, New York.

Goral, M., Spiro, A.I., Albert, M.L., Obler, L.K., & Connor, L.T. (2007). Change in lexical skills in adulthood: Not a uniform decline. Mental Lexicon, 2, 215–238.

Goulet, P., Ska, B., & Kahn, H.J. (1994). Is there a decline in picture naming with advancing age? Journal of Speech and Hearing Research, 37(3), 629–644.

Griffin, Z.M., & Bock, K. (1998). Constraint, word frequency, and levels of processing in spoken word production. Journal of Memory and Language, 38, 313-338.

Hasher, L., & Zacks, R. T. (1979). Automatic and effortful processes in memory. Journal of Experimental Psychology: General, 108, 356–388.

Hasher, L., & Zacks, R.T. (1988). Working memory, comprehension, and aging: A review and a new view. In G.H. Bower (Ed.), The psychology of learning and motivation Vol. 22 (pp. 193-225). San Diego, CA: Academic Press.

Hauk, O., Davis, M.H., Ford, M., Pulvermüller, F. & Marslen-Wilson, W.D. (2006). The time course of visual word recognition as revealed by linear regression analysis of ERP data. Neuroimage, 30, 1383-400.

Heine, M. K., Ober, B. A., & Shenaut, G. K. (1999). Naturally occurring and experimentally induced tip-of-the-tongue experiences in three adult age groups. Psychology and Aging, 14, 445–457.

Hirsh, K.W., & Funnell, E. (1995). Those old, familiar things: Age of acquisition, familiarity and lexical access in progressive aphasia. Journal of Neurolinguistics, 9, 23-32.

Horn, J.L., & Cattell, R.B. (1967). Age differences in fluid and crystallized intelligence. Acta psychologica, 26, 107-129.

Indefrey, P. (2011). The spatial and temporal signatures of word production components: A critical update. Frontiers in Psychology, 2, 1–16.

Indefrey, P., & Levelt, W., (2004). The spatial and temporal signatures of word production components. Cognition, 92, 101–144.

Jaeger T.F., (2008). Categorical data analysis: Away from ANOVAs (transformation or not) and towards logit mixed models. Journal of Memory and Language, 59, 434–446

James, L. E. &, Burke, D. M. (2000). Phonological priming effects on word retrieval and tip-of-the-tongue experiences in young and older adults. Journal of Experimental Psychology: Learning, Memory and Cognition, 26, 1378–1391.

Janssen, N., Pajtas, P., & Caramazza, A. (2011). A set of 150 pictures with morphologically complex English compound names. Norms for name agreement, familiarity, image agreement and visual complexity. Behavior Research Methods, 43, 478-490.

Jescheniak, J. D., & Levelt, W. J. M. (1994). Word frequency effects in speech production: Retrieval of syntactic information and of phonological form. Journal of Experimental Psychology: Learning, Memory, and Cognition, 20, 824-843.

Jescheniak, J. D., Schriefers, H., & Hantsch, A. (2003). Utterance format affects phonological priming in the picture-word task: Implications for models of phonological encoding in speech production. Journal of Experimental Psychology: Human Perception and Performance, 29, 441-454.

Jescheniak, J. D., Schriefers, H., Garrett, M. F., & Friederici, A. D. (2002). Exploring the activation of semantic and phonological codes during speech planning with event-related brain potentials. Journal of Cognitive Neuroscience, 14, 951-964.

Johnson, C., Paivio, A., & Clark, J. M. (1996). Cognitive components of picture naming. Psychological Bulletin, 120(1), 113-139.

Johnston, R.A., & Barry, C. (2005). Age of acquisition effects in the semantic processing of pictures. Memory and Cognition, 33, 905-912.

Kan, I.P., & Thompson-Schill, S. L. (2004). Selection from perceptual and conceptual representations. Cognitive, Affective, & Behavioral Neuroscience, 4, 466-482.

Kemper, S. (1992). Language and aging. In F. I. M. Craik & T. A. Salthouse (Eds.), The handbook of aging and cognition (pp. 213–270). Hillsdale, NJ: Erlbaum.

Kemper, S., Herman, R., & Lian, C. (2003). Age differences in sentence production. Journal of Gerontology: Psychological Sciences, 58B(5), 260–268.

Kittredge, A.K., Dell, G.S., Verkuilen, J., & Schwartz, M.F. (2008). Where is the effect of frequency in word production? Insights from aphasic picture-naming errors. Cognitive Neuropsychology, 25, 463-492.

Knobel, M., Finkbeiner, M., & Caramazza, A. (2008). The many places of frequency: Evidence for a novel locus of the lexical frequency effect in word production. Cognitive Neuropsychology, 25(2), 256-286.

Koenig, T., & Melie-García, L. (2010). A method to determine the presence of averaged event-related fields using randomization tests. Brain Topography, 3, 233–242.

Lachman, R., Shaffer, J.P., & Hennrikus, D. (1974). Language and cognition: Effects of stimulus codability, name-word frequency, and age of acquisition on lexical reaction time. Journal of Verbal Learning & Verbal Behavior, 13, 613-625.

Laganaro, M., & Perret, C. (2011). Comparing electrophysiological correlates of word production in immediate and delayed naming through the analysis of word age of acquisition effects. Brain Topography, 24, 19–29.

Laganaro, M., Morand, S., & Schnider, A. (2009). Time course of evoked-potential changes in different forms of anomia in aphasia. Journal of Cognitive Neuroscience, 21(8), 1499-1510.

Laganaro, M., Valente, A., & Perret, C. (2012). Time course of word production in fast and slow speakers: a high density ERP topographic study. Neuroimage, 59, 3881-3888.

Laver, G. D., & Burke, D. M. (1993). Why do semantic priming effects increase in old age? A meta-analysis. Psychology and Aging, 8, 34–43.

Lehmann, D., Strik W.K., Henggeler B., Koenig T., Koukkou, M. (1998). Brain electric microstates and momentary conscious mind states as building blocks of spontaneous thinking: I. Visual imagery and abstract thoughts. Internat Journal of Psychophysioliology, 29, 1-11.

Lehmann, D., Skrandies, W. (1984). Spatial analysis of evoked potentials in man - A review. Progress in Neurobiology, 23, 227-250.

Levelt, W. J. M., Praamstra, P., Meyer, A. S., Helenius, P., & Salmelin, R. (1998). An MEG study of picture naming. Journal of Cognitive Neuroscience, 10, 553–567.

Levelt, W. J. M., Roelofs, A., & Meyer, A. S. (1999). A theory of lexical access in speech production. Behavioral and Brain Sciences, 22, 1–75.

Levelt, W.J.M., Praamstra, P., Meyer, A. S., Helenius,P., & Salmelin, R. (1998). An MEG study of picture naming. Journal of Cognitive Neuroscience, 10, 553–567.

MacKay, D.G. (1982). The problems of flexibility, fluency, and speed-accuracy tradeoff in skilled behavior. Psychological Review, 89, 483-506.

MacKay, D. G. (1987). The organization of perception and action: A theory for language and other cognitive skills. New York: Springer-Verlag.

MacKay, D. G., & Burke, D. M. (1990). Cognition and aging: A theory of new learning and the use of old connections. In T. Hess (Ed.), Aging and cognition: Knowledge organization and utilization (pp. 213–263). Amsterdam: North-Holland.

Martinovic, J., Gruber, T., & Müller, M.M. (2008). Coding of Visual Object Features and Feature Conjunctions in the Human Brain. PLoS ONE 3(11): e3781. doi:10.1371/journal.pone.0003781

Meyer, A. S., & Schriefers, H. (1991). Phonological facilitation in picture-word interference experiments: Effects of stimulus onset asynchrony and types of interfering stimuli. Journal of Experimental Psychology: Learning, Memory, and Cognition, 17, 1146-1160. doi:10.1037/0278-7393.17.6.1146.

Michel, C.M., Koenig, T., Brandeis, D., & Gianotti L.R.R. (2009). Electric neuroimaging. Cambridge: Cambridge University Press.

Michel, C.M., Murray, M.M., Lantz, G., Gonzalez, S., Spinelli, L., & Grave de Peralta, R., (2004). EEG source imaging. Clinical Neurophysiology, 115, 2195–2222.

Michel, C.M., Thut, G., Morand, S., Khateb, A., Pegna, A.J., Grave de Peralta, R. (2001). Electric source imaging of human brain functions. Brain Research Reviews, 36, 108–118.

Miller, G.A. (1956). The magical number seven, plus or minus two: some limits in our capacity for processing information. The psychological review, 63, 81-97.

Morrison, C. M., Chappell, T. D., & Ellis, A. W. (1997). Age of acquisition norms for a large set of object names and their relation to adult estimates and other variables. Quarterly Journal of Experimental Psychology, 50A, 528-559.

Morrison, C.M., & Ellis, A. W. (1995). The roles of word frequency and age of acquisition in word naming and lexical decision. Journal of Experimental Psychology: Learning, Memory, and Cognition, 21, 116-133.

Morrison, C.M., Ellis, A. W., & Quinlan, P. T. (1992). Age of acquisition, not word frequency, affects object naming, not object recognition. Memory and Cognition, 20, 705-714.

Morrison, C.M., Hirsh, K.W., & Duggan, G.B. (2003). Age of acquisition, ageing and verb production: Normative and experimental data. The Quaterly Journal of Experimental Psychology, 56(A), 2–26.

Mortensen, L., Meyer, A.S., Humphreys, G.W. (2006). Age-related effects on speech production: A review. Language and Cognitive Processes, 21(1), 238-290.

Murphy, D. R., Craik, F. I. M., Li, K. Z. H., & Schneider, B. A. (2000). Comparing the effects of aging and background noise on short-term memory performance. Psychology and Aging, 15, 323–334.

Murray, M.M., Brunet, D., & Michel C. (2008). Topographic ERP analyses, a step-by-step tutorial review. Brain Topography, 20, 249-269.

Myerson, J., Hale, S., Wagstaff, D., Poon, L. W., & Smith, G. A. (1990). The information-loss model: A mathematical theory of age-related cognitive slowing. Psychological Review, 97, 475–487.

Navarrete, E., Basagni, B., Alario, F.X., & Costa, A. (2006). Does word frequency affect lexical selection is speech production? Quarterly Journal of Experimental Psychology, 59, 1681-1690.

Neumann, Y., Obler, L. K., Gomes, H., & Shafer, V. (2009). Phonological vs. sensory contributions to age effects in naming: An electrophysiological study. Aphasiology, 23 (7), 1028-1039.

New, B., Brysbaert, M., Veronis, J., & Pallier, C. (2007). The use of film subtitles to estimate word frequencies. Applied Psycholinguistics, 28, 661-677.

New, B., Pallier, C., Brysbaert, M., Ferrand, L. (2004) Lexique 2: A New French Lexical Database. Behavior Research Methods, Instruments, & Computers, 36 (3), 516-524.

Nicholas, M., Connor, L.T., Obler, L.K., & Albert, M.L. (1998). Aging, language, and language disorders. In M.T. Sarno (Ed.), Acquired aphasia (pp. 413–449). San Diego, CA: Academic Press.

Nicholas, M., Obler, L. K., Albert, M. L., & Goodglass, H. (1985). Lexical retrieval in healthy aging. Cortex, 21, 595–606.

Oldfield, R.C., (1971). The assessment and analysis of handedness: the Edinburgh inventory. Neurospychologia, 9, 97–113.

Paivio, A., Clark, J. M., Digdon, N., & Bons, T. (1989). Referential processing: Reciprocity and correlates of naming and imaging. Memory and Cognition, 17, 163-174.

Pascual-Marqui R.D., Michel C.M., & Lehmann D. (1995). Segmentation of brain electrical activity into microstates, model estimation and validation. IEEE Transactions on Biomedical Engineering, 42, 658–65.

Pichora-Fuller, M. K., Schneider, B. A., & Daneman, M. (1995). How young and old adults listen to and remember speech in noise. Journal of the Acoustical Society of America, 97, 593–608.

Protopapas, A. (2007). CheckVocal: a program to facilitate checking the accuracy and response time of vocal responses from DMDX. Behavior research methods, 39(4), 859-862.

Rabbitt, P., Maylor, E., McInnes, L., Bent, N., & Moore, B. (1995). What goods can self-assessment questionnaires deliver for cognitive gerontology? Applied Cognitive Psychology, 9, 127–152

Rastle, K. G., & Burke, D. M. (1996). Priming the tip of the tongue: Effects of prior processing on word retrieval in young and older adults. Journal of Memory and Language, 35, 586–605.

Rodriguez-Fornells, A., Schmitt, B. M., Kutas, M., & Münte, T. (2002). Electrophysiological estimates of the time course of semantic and phonological encoding during listening and naming. Neuropsychologia, 40, 778–787.

Roelofs, A. (2002). Syllable structure effects turn out to be word length effects: Comment on Santiago et al. (2000). Language and Cognitive Processes, 17, 1-13.

Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. Psychological Review, 103, 403–428.

Salthouse, T.A. (1985). A theory of cognitive aging. Amsterdam: North-Holland.

Santiago, J., MacKay, D. G., Palma, A., & Rho, C. (2000). Sequential activation processes in producing words and syllables: Evidence from picture naming. Language & Cognitive Processes, 15, 1-44.

Schaie, K. W. (2005). Developmental influences on adult intelligence. Oxford: Oxford University Press.

Schaie, W. K. (1994). The course of adult intellectual development. American Psychologist, 49, 304–313.

Schmitt, B.M., Münte, T.F., & Kutas, M. (2000). Electrophysiological estimates of the time course of semantic and phonological encoding during implicit picture naming. Psychophysiology, 37, 473–484.

Schriefers, H., Meyer, A. S. & Levelt, W.J. M. (1990). Exploring the time course of lexical access in language production: Picture-word interference studies. Journal of Memory and Language, 29(1), 86-102.

Snodgrass, J. G., & Yuditsky, T. (1996). Naming times for the Snodgrass and Vanderwart pictures. Behavior Research Methods, Instruments, & Computers, 28, 516-536.

Snodgrass, J.G., & Vanderwart, M. (1980). A standardized set of 260 pictures: Norms for name agreement, image agreement, familiarity, and visual complexity. Journal of Experimental Psychology: Human Learning & Memory, 6, 174-215.

Speranza, F., Daneman, M., & Schneider, B. A. (2000). How aging affects the reading of words in noisy backgrounds. Psychology and Aging, 15, 253–258.

Spinnler H., & Tognoni G. (1987). Standardizzazione e taratura italiana di test neuropsicologici. The Italian Journal of Neurological Sciences, 8, 1-120.

Stadthagen-Gonzalez, H., Damian, M.F., Pérez, M.A., Bowers, J.S., & Marín, J. (2009). Name-picture Verification as a Control Measure for Object Naming: A Task Analysis and Norms for a Large Set of Pictures. Quarterly Journal of Experimental Psychology, 62, 1581-1597.

Strijkers, K., & Costa, A. (2011). Riding the lexical speedway: a critical review on the time course of lexical access in speech production. Frontiers in Psychology, 2, 356.

Strijkers, K., Costa, A., & Thierry, G. (2010). Tracking lexical access in speech production: electrophysiological correlates of word frequency and cognate effects. Cerebral Cortex, 20, 912–928.

Szekely, A., D'Amico, S., Devescovi, A., Federmeier, K., Herron, D., Iyer, G., Jacobsen, T., Arévalo, A. L., Vargha, A., & Bates, E. (2005). Timed action and object naming. Cortex, 41(1), 7-26.

Taylor, J.K. & Burke, D.M. (2002). Asymmetric aging effects on semantic and phonological processes: Naming in the picture-word interference task. Psychology and Aging, 17, 662-676.

Thornton, R., & Light, L.L. (2006). Language comprehension and production in normal aging. In J.E. Birren & K.W. Schaie (Eds.) Handbook of the Psychology of Aging (6th ed.) (pp. 261 287). San Diego, CA: Elsevier.

Thorpe, S., Fize, D., & Marlot, C. (1996). Speed of processing in the human visual system. Nature, 381, 520–522.

Tobimatsu, S., Kurita-Tashima, S., Nakayama-Hiromatsu, M., Akazawa, K., Kato, M. (1993). Age-related changes in pattern visual evoked potentials: differential effects of luminance, contrast and check size. Electroencephalography and Clinical Neurophysiology, 88, 12–19.

Tombaugh, T.N. (2004). Trail Making test A and B: Normative Data Stratified by Age and Education. Archives of Clinical Neuropsychology : The Official Journal of the National Academy of Neuropsychologists, 19(2), 203–214.

Tzovara, A., Murray, M.M., Plomp, G., Herzog, M.H., Michel, C.M., & De Lucia, M., (2012). Decoding stimulus-related information from single-trial EEG responses based on voltage topographies. Pattern Recognition, 45 (6), 2109–2122.

Ulatowska, H. K., Cannito, M. P., Hayashi, M. M., & Fleming, S. G. (1985). Language abilities in the elderly. In H. K. Ulatowska (Ed.), The aging brain: Communication in the elderly (pp. 125-139). San Diego, CA: College-Hill Press.

Van Turennout, M., Hagoort, P., & Brown, C. M. (1998). Brain activitity during speaking: From syntax to phonology in 40 milliseconds. Science, 280, 572-574.

Verhaegen C. & Poncelet M. (2013). Changes in Naming and Semantic Abilities With Aging From 50 to 90 years. Journal of the International Neuropsychological Society, 19, 119–126.

Vihla, M., Laine, M., & Salmelin, R. (2006). Cortical dynamics of visual/semantic vs. phonological analysis in picture confrontation. Neuroimage, 33, 732–738.

Vitevitch, M. S. (2002). The influence of phonological similarity neighborhoods on speech production. Journal of Experimental Psychology: Learning, Memory, & Cognition, 28, 735-747.

Vitevitch, M.S. & Armbruster, J. & Chu, S. (2004). Sublexical and lexical representations in speech production: Effects of phonotactic probability and onset density. Journal of Experimental Psychology: Learning, Memory and Cognition, 30, 514-529.

Vitevitch, M.S. & Sommers, M.S. (2003). The facilitative influence of phonological similarity and neighborhood frequency in speech production in younger and older adults. Memory & Cognition, 31, 491-504.

Vitkovitch, M., & Tyrrell, L. (1995). Sources of disagreement in object naming. Quarterly Journal of Experimental Psychology, 48A, 822-848.

White, K. K., & Abrams, L. (2002). Does priming specific syllables during tip-of-the tongue states facilitate word retrieval in older adults? Psychology and Aging, 17(2), 226–235.

Wingfield, A., & Stine-Morrow, E. A. L. (2000). Language and speech. In F. I. M. Craik & T. Salthouse (Eds.), The handbook of aging and cognition (2nd ed., pp. 359-416). Mahwah, NJ: Lawrence Erlbaum Associates.

Wingfield, A., Alexander, A. H., & Cavigelli, S. (1994). Does memory constrain utilization of top-down information in spoken word recognition? Evidence from normal aging. Language and Speech, 37, 221–235.

Yarkoni, T, Balota, D.A., & Yap, M.J. (2008). Moving Beyond Coltheart's N: A New Measure of Orthographic Similarity. Psychonomic Bulletin & Review, 15, 971-979.

Zacks, R. T., & Hasher, L. (1997). Cognitive gerontology and attentional inhibition: A reply to Burke and McDowd. Journal of Gerontology: Psychological Sciences, 52, 274–283.

Zacks, R.T., & Hasher, L. (1994). Directed ignoring: Inhibitory regulation of working memory. In D. Dagenbach & T.H. Carr (Eds.) Inhibitory processes in attention, memory, and language (pp. 241-264). San Diego, CA: Academic Press.

Zhang, Q. & Damian M.F. (2009). The time course of segment and tone encoding in Chinese spoken production: an event-related potential study. Neuroscience 163 (1), 252-65.