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Research report

Electrophysiology of cross-language interference and facilitation in picture naming

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ABSTRACT

Disagreement exists about how bilingual speakers select words, in particular, whether words in another language compete, or competition is restricted to a target language, or no competition occurs. Evidence that competition occurs but is restricted to a target language comes from response time (RT) effects obtained when speakers name pictures in one language while trying to ignore distractor words in another language. Compared to unrelated distractor words, RT is longer when the picture name and distractor are semantically related, but RT is shorter when the distractor is the translation of the name of the picture in the other language. These effects suggest that distractor words from another language do not compete themselves but activate their counterparts in the target language, thereby yielding the semantic interference and translation facilitation effects. Here, we report an event-related brain potential (ERP) study testing the prediction that priming underlies both of these effects. The RTs showed semantic interference and translation facilitation effects. Moreover, the picture-word stimuli yielded an N400 response, whose amplitude was smaller on semantic and translation trials than on unrelated trials, providing evidence that interference and facilitation priming underlie the RT effects. We present the results of computer simulations showing the utility of a within-language competition account of our findings.

1. Introduction

A central issue in bilingual language performance concerns how bilingual speakers manage to select words in a target language while ignoring words in another language. In particular, how are bilingually non-balanced speakers able to select words in a weaker language (e.g., their non-dominant second language) while ignoring words in a stronger language (i.e., their dominant first language)? Bilingual speakers appear to be very good at this. For instance, Poulisse and

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Bongaerts (1994) observed that in second-language (English) picture naming, story retelling, and free conversation by Dutch-English bilingual speakers, only .5 percent of all words produced were first-language (Dutch) intrusions (i.e., 771 out of about 140,000 words). In the literature, three main views have been proposed about how bilingual speakers accomplish this feat (see Hall, 2011, for an extensive review). According to the between-language competition view, words in both languages are activated and compete for selection, but speakers select the words in the target language by selectively boosting their activation (De Bot, 2004) or by inhibiting words in the other language (e.g., Green, 1998; Kroll, Bobb, Misra, & Guo, 2008; Kroll, Bobb, & Wodniecka, 2006). According to the within-language competition view, words in both languages are activated but only words in the target language compete for selection (Costa, 2005; Costa & Caramazza, 1999; Roelofs, 1998, 2003, 2010; Roelofs, Dijkstra, & Gerakaki, 2013). Finally, according to the no-competition view, words in both languages are activated, but the activation of words in the target language is boosted and therefore they exceed a selection threshold first and will be selected (Finkbeiner, Gollan, & Caramazza, 2006).

In testing between these theoretical views, a major tool has been the picture-word interference paradigm, in which speakers name pictures while trying to ignore superimposed distractor words. In a bilingual version of this paradigm, pictures have to be named in one language and the distractor words are from the other language. All three views assume that pictures activate words in both languages, but they differ in whether words in another language compete, or competition is restricted to a target language, or no competition occurs. In Sections 1.1 and 1.2, we briefly describe the key behavioral results from monolingual and bilingual picture-word interference studies and we argue that the available response time (RT) evidence is most compatible with the within-language competition view (but see Hall, 2011). Whereas RT studies measure the time elapsing between picture and articulation onset, event-related brain potential (ERP) studies provide electrophysiological information about processing events happening during this time interval. Previous studies have reported characteristic ERP modulations in monolingual picture-word interference, but there is a lack of evidence on bilingual versions of the paradigm. The aim of the research reported in the present article is to fill this gap. In Section 1.3, we briefly describe the ERP evidence on monolingual picture-word interference and outline predictions for bilingual performance. In Sections 2 and 3, we report on a new ERP experiment testing these predictions. In Section 4, we evaluate the three theoretical views on bilingual lexical selection (i.e., between-language competition, within-language competition, and no competition) with respect to their ability to account for our findings, and we present the results of computer simulations showing the utility of a within-language competition account.

1.1. *Monolingual picture-word interference*

In the widely used monolingual version of the picture-word interference paradigm, speakers name pictures in their native language while trying to ignore spoken or written distractor words in the same language. For example, speakers of English say "horse" to a pictured horse combined with the written word *duck* (i.e., a word from the same semantic category, here animals; the semantic condition), the word *chair* (the unrelated condition), the word *horse* (the identity condition), or a row of Xs (the non-linguistic control condition). RT is typically longer on semantically related than on unrelated trials, called *semantic interference* (e.g., Damian & Martin, 1999; Glaser & Düngelhoff, 1984; Glaser & Glaser, 1989; Rayner & Springer, 1986). Moreover, RTs are longer on unrelated than on control trials, an effect of *lexicality* (e.g., Glaser & Düngelhoff, 1984; Glaser & Glaser, 1989; Roelofs, 2006, 2007). Finally, RTs are shorter on identity than on unrelated trials, an *identity facilitation* effect (e.g., Glaser & Düngelhoff, 1984; Glaser & Glaser, 1989; Roelofs, 2006, 2007).

According to a competition account of lexical selection (e.g., Roelofs, 1992), a semantically related distractor word receives activation from the target picture and is therefore a more potent competitor to the picture name than an unrelated distractor word, which is not activated by the picture. Neumann (1986) and La Heij, Dirkx, and Kramer (1990) referred to this mechanism underlying semantic interference as *reverse priming*. Although a semantically related distractor word will also prime the picture name, this target priming is assumed to be less than the reverse priming of the distractor because of functional distance, as we further explain below. As a consequence, the net effect is semantic interference in RTs. Moreover, when the distractor corresponds to the name of the picture, the target word is primed at all planning levels, yielding the identity facilitation effect. This account of semantic interference and identity facilitation has been computationally implemented in a number of models of word production, including the model of Starreveld and La Heij (1996) and WEAVER++ (Levelt, Roelofs, & Meyer, 1999; Roelofs, 1992, 1993, 1997, 2003, 2006, 2007, 2008a, 2008b, 2008c, 2014).

The WEAVER++ model assumes that information about words is stored in a large declarative associative network. This network is accessed by spreading activation while procedural condition-action rules determine what is done with the activated lexical information depending on the goal (cf. Anderson et al., 2004; Eliasmith, 2013). In picture-word interference experiments, the goal is to name a picture and ignore a superimposed word. A fragment of the lexical network of WEAVER++ is illustrated in Fig. 1 for the words *duck* and *horse*. According to the model, the naming of pictures involves the activation of nodes for lexical concepts, lemmas, morphemes, phonemes, and articulatory programs. For example, naming a pictured horse involves the activation and selection of the representation of the concept HORSE(X), the lemma of *horse* specifying that the word is a noun (for languages such as Dutch, lemmas also specify grammatical gender), the morpheme <horse>, the phonemes /h/, /ɔː/, and /s/, and the articulatory program [hɔːs] for British English. The model assumes that perceived pictures have direct access to concepts [e.g., HORSE(X)] and only indirect access to lemmas (e.g., *horse*) and word forms (e.g., <horse> and /h/, /ɔː/, and /s/), whereas perceived words have direct access to lemmas (e.g., *duck*) and word forms (e.g., <duck> and /d/, /ʌ/, and /k/) and only indirect access to concepts [e.g., DUCK(X)].

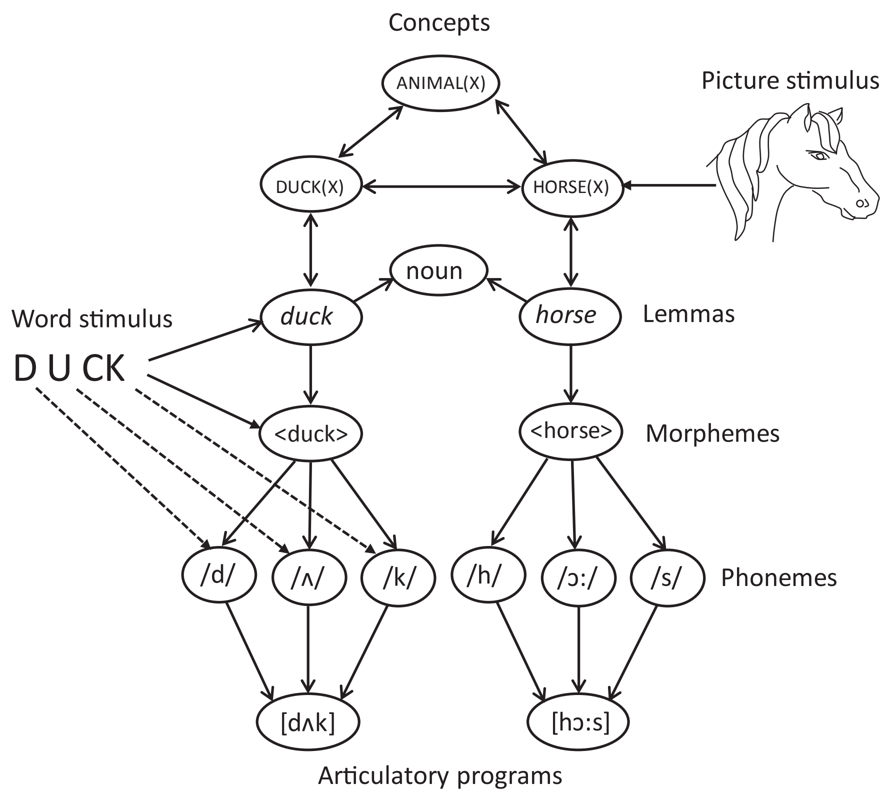

Fig. 1 – Illustration of the lexical network of WEAVER++. Perceived pictures (e.g., of a horse) directly activate concept nodes and perceived words (e.g., DUCK) directly activate lemma, morpheme, and phoneme nodes, after which other nodes become activated through spreading activation. The dashed lines indicate grapheme-to-phoneme correspondences.

In the semantic condition (e.g., the word *duck* superimposed on a pictured horse), the target picture will prime the lemma of a semantically related distractor word (*duck*) via the conceptual connections (i.e., reverse priming) and the distractor word will prime the lemma of the picture name (*horse*). The picture will prime the distractor lemma more than the distractor will prime the lemma of the picture name, because of different network distances (two *vs* three links, see Fig. 1). Unrelated distractor words and pictures do not activate each other. As a consequence, a semantically related distractor word is a stronger competitor to the picture name than an unrelated distractor word, prolonging the lemma retrieval latency and yielding semantic interference in the RTs. In the identity condition (e.g., the word *horse* combined with a picture of a horse), the distractor activates the target at all levels, yielding the identity facilitation in the RTs.

The finding that the semantic effect is one of interference rather than facilitation suggests that words compete for selection. However, a no-competition explanation of the semantic interference effect has also been advanced (e.g., Finkbeiner & Caramazza, 2006; Janssen, Schirm, Mahon, & Caramazza, 2008; Mahon, Costa, Peterson, Vargas, & Caramazza, 2007), called the *response-exclusion* account. According to this account, a word is selected if its activation exceeds some threshold, but selection is assumed to be independent of the activation state of other words. Semantically related distractors help targets to exceed the selection threshold quicker, but this facilitation is counteracted by interference that arises after word planning, reflecting the exclusion of an articulatory response to the distractor word from an output buffer. This exclusion process is assumed to take longer when the distractor is semantically related to the picture than when it is unrelated, yielding the semantic interference effect in the naming RTs. According to Finkbeiner and Caramazza, an articulatory response to the distractor word may be prevented by masking the distractor, which should yield semantic facilitation in the RTs, as they observed (but see Piai, Roelofs, & Schriefers, 2012).

1.2. *Bilingual picture-word interference*

In a bilingual version of the picture-word interference paradigm, speakers name pictures in one language while trying to ignore spoken or written distractor words in another language. For example, Dutch-English bilingual speakers produce the English word "horse" in response to a pictured horse combined with the written Dutch word *eend* (*duck*, the semantic condition), the word *stoel* (*chair*, the unrelated condition), the word *paard* (*horse*, the translation condition), or a row of Xs (the non-linguistic control condition). RT is typically longer on semantically related than on unrelated trials, the semantic interference effect (e.g., Costa & Caramazza, 1999; Costa, Colomé, Gómez, & Sebastián-Gallés, 2003; Costa, Miozzo, & Caramazza, 1999; Hermans, Bongaerts, De Bot, & Schreuder, 1998). The magnitude of the semantic interference effect is the same within and between languages (e.g., Costa & Caramazza, 1999; Costa et al., 2003, 1999). Moreover, RTs are longer on unrelated than on non-linguistic control trials (Roelofs, Piai, & Garrido Rodriguez, 2011), the lexicality effect. Finally, RTs are shorter when the distractor is the translation of the name of the picture in the other language than on unrelated trials, a *translation facilitation* effect (e.g., Costa & Caramazza, 1999; Costa et al., 2003, 1999; Hermans, 2004; Roelofs et al., 2011). The magnitude of the between-language translation facilitation effect is smaller than the within-language identity facilitation effect (e.g., Costa & Caramazza, 1999; Costa et al., 1999). The translation facilitation effect is also obtained in the color-word Stroop task (Costa, Albareda, & Santesteban, 2008; Roelofs, 2010).

The between-language competition view readily accounts for the between-language semantic interference but it is challenged by the translation facilitation effect. Under this view, distractors that are the translation equivalents of the picture names in the other language should be the strongest competitors. Whereas semantically related distractors only partly match the pictures in conceptual respects, there is a full match in case of distractors that are translations of the picture name. Consequently, the interference should be larger for the translation than for the semantically related condition. But in contrast to this prediction, translation distractors facilitate the naming response relative to unrelated distractors.

In defense of the between-language competition view, Hermans (2004) argued that because of the full conceptual match with the picture, translation distractors will yield a large amount of priming of the target picture name. This large amount of priming may offset the fierce competition in lexical selection, yielding the translation facilitation effect. However, this account of the translation facilitation effect is incompatible with the account of between-language semantic interference. According to the reverse priming account of semantic interference, semantic interference is the net effect of semantic priming of the target name by the distractor word and reverse semantic priming of the distractor word by the picture. The overall effect is one of interference rather than facilitation because target priming is smaller than reverse priming of the distractor due to network distances. However, the same applies to translation distractors. Although these distractors will prime the target picture name more than semantically related distractors because of their greater conceptual match with the picture, for the very same reason reverse priming will also be stronger for the translation distractors than for the semantically related distractors. Priming will be less than reverse priming because of network distances. Thus, on balance, interference rather than facilitation is predicted for the translation distractors, contrary to what is empirically observed. Thus, the translation facilitation effect challenges the between-language competition account.

Whereas the between-language competition view has difficulty explaining the translation facilitation, the within-language competition view readily explains both the translation facilitation and the between-language semantic interference effects. Under this view, distractor words from another language do not compete themselves but activate their counterparts in the target language. As a consequence, semantically related distractors from the other language activate semantic competitors of the picture name in the target language, which yields semantic interference. The effect is mediated rather than direct. However, the magnitude will be the same for the between-language and within-language effects, because semantic interference is calculated with respect to an unrelated word in the same language, which factors out any baseline difference (Hall, 2011; Roelofs, 1992). Moreover, translation distractors activate the target name but will not compete, which will yield the translation facilitation effect. The magnitude of the translation facilitation effect will be smaller than the within-language identity facilitation effect because identity distractors (e.g., the word *horse* in naming a picture of a horse, say "horse") will prime the target picture name at all processing levels (i.e., conceptual, lemma, and form) whereas translation distractors (e.g., the word *paard* in naming a picture of a horse, say "horse") prime the target at conceptual and lemma levels but not at the form level. Consequently, the facilitation will be less for translation than identity distractors, as empirically observed.[1]

Finally, the no-competition view can account for either the between-language semantic interference or the translation facilitation, but not both, depending on the presumed role of conceptual similarity and language membership in the exclusion process. Under one view (Finkbeiner et al., 2006), semantically related distractors help targets to exceed the selection threshold quicker, but this effect is counteracted by a prolongation of the response-exclusion process because of the conceptually similarity between target and semantically related distractor, yielding semantic interference. However, for the same reason, although translation distractors may help targets to exceed the selection threshold quicker, this effect should also be countered by the response-exclusion process because of conceptual similarity, yielding translation interference. Under another view (discussed by Hall, 2011), distractors from another language can be excluded so quickly that response exclusion no longer offsets target priming and the net effect is facilitation. However, this would predict facilitation for both the semantically related and the translation distractors, contrary to the empirical findings.

[1] Hermans et al. (1998) observed that distractor words that are phonologically related to the translation of the picture name (e.g., the word *pass*, which shares part of its form with *paard*, in naming a picture of a horse, say "horse") yield cross-language interference compared to unrelated words. This finding has been taken to support the between-language competition view and to challenge the within-language competition view (see also Hall, 2011). The argument is that an English word like *pass* activates the word *paard*, which competes for selection with the picture name *horse*, yielding the interference. However, the phonological interference from *pass* does not need to arise in lemma selection but may also occur during form encoding. In the WEAVER++ model, competition occurs during lemma retrieval and phonetic encoding (i.e., in selecting syllable motor programs). Distractor words that are phonologically related to the translation of the picture name will increase the activation of phonologically related syllable motor programs, making them stronger competitors during phonetic encoding. This may explain the phonological interference (cf. Roelofs, 2008a).

1.3. Electrophysiological evidence

Previous research has shown that both pictures and words evoke an N400 response, which is a broad negative-going wave that usually starts around 200–300 msec after stimulus onset and peaks at approximately 400 msec. The amplitude of the N400 response to both pictures and words reflects lexical-semantic processing demand (for reviews, see Kutas & Federmeier, 2011; Lau, Phillips, & Poeppel, 2008). For example, the N400 amplitude to perceived words is smaller for high-frequency words (low demand) compared with low-frequency words (higher demand). Also, the N400 amplitude is smaller for pictures with high-frequency than with low-frequency names (Piai, Roelofs, & Van der Meij, 2012). Moreover, the N400 amplitude to pictures and words is smaller when they are preceded by semantically related compared with unrelated pictures and words (e.g., Barrett & Rugg, 1990; Jescheniak, Hahne, & Schriefers, 2003; Jescheniak, Schriefers, Garrett, & Friederici, 2002; Lau, Almeida, Hines, & Poeppel, 2009; McPherson & Holcomb, 1999).

In a monolingual picture-word interference study, Blackford, Holcomb, Grainger, and Kuperberg (2012) had participants say, for example, "horse" to a pictured horse preceded by masked words such as *duck* (the semantic condition), *chair* (the unrelated condition), *horse* (the identity condition), or *home* (the phonological condition). The onset of the word was 80 msec before picture onset, whereby the word was presented for 60 msec followed by a 20-msec backward mask. Blackford et al. used masking, although picture-word interference experiments typically do not (e.g., Damian & Martin, 1999; Glaser & Düngelhoff, 1984; Glaser & Glaser, 1989; Rayner & Springer, 1986). Nevertheless, the standard RT effects were replicated. According to Blackford et al., "the 20 msec backward mask did not eliminate awareness of the word or reduce its availability as a response alternative during selection, distinguishing our parameters from those used by Finkbeiner and Caramazza (2006)" (p. 90). RTs showed semantic interference, identity facilitation, and phonological facilitation (i.e., RTs were shorter on phonologically related than unrelated trials; e.g., Damian & Martin, 1999; Starreveld & La Heij, 1996). The amplitude of the N400 in the experiment of Blackford et al. was modulated by distractor condition between 350 and 550 msec after picture onset (see also Hirschfeld, Jansma, Bölte, & Zwitserlood, 2008, without masking). In particular, the amplitude was smaller in the semantically related and identity conditions than in the unrelated condition, whereas the phonological and unrelated conditions did not differ. Thus, relative to unrelated distractors, semantically related distractors increased RTs but decreased N400 amplitude (see also Dell'Acqua et al., 2010, without masking).

According to Blackford et al. (2012), the N400 amplitude attenuation despite behavioral interference on semantic trials challenges the competition view implemented in WEAVER++ and agrees with the response-exclusion account. However, in WEAVER++, a picture primes a semantically related distractor word and vice versa, whereas a picture and unrelated word do not prime each other. If priming reduces processing demand and thus the N400 response to picture-word stimuli, semantically related distractor words will evoke a smaller N400 response than unrelated distractor words. However, because pictures prime the distractor words more than vice versa, semantic interference will be obtained in the RTs. Moreover, identity distractors and pictures activate the same word, which reduces the N400 amplitude and the RT compared to unrelated distractors. In a monolingual magnetoencephalography study (without masking), Piai, Roelofs, Jensen, Schoffelen, and Bonnefond (2014) replicated the RT and electrophysiological findings of Blackford et al. using semantically related, unrelated, and identity distractors, and they reported the results of WEAVER++ simulations showing that the model accounts for both the RT and the electrophysiological results.

Only a few bilingual ERP studies on picture-word interference have been reported in the literature. Chauncey, Holcomb, and Grainger (2009) examined the effect of identity (within-language) and translation (between-language) word distractors in a masked priming study of picture naming. Relative to unrelated words, they observed identity and translation facilitation effects in the RTs and a reduction of the N400.

Chauncey et al. (2009) used masked distractors (i.e., 500 msec forward mask, 70 msec word, and 50 msec backward mask). According to Finkbeiner and Caramazza (2006), such masking prevents any competition at the level of the articulatory buffer. Under the response exclusion account, this may explain why Chauncey et al. obtained translation facilitation in the RTs and an attenuated N400. If response exclusion no longer counteracts the conceptual facilitation for translation distractors, facilitation in RTs may be obtained. Thus, it is important to assess whether the RT and N400 effects for translation distractors of Chauncey et al. are replicated without masking of the distractor words. If the results are replicated without masking, this would be problematic for the response exclusion account because translation distractors should now be excluded from the articulatory buffer and thus yield translation interference in the RTs, as argued earlier.

1.4. The present study

Above, we argued that the cross-language semantic interference and translation facilitation effects in RTs support the within-language competition view and challenge the between-language competition and no-competition views. In monolingual picture-word interference studies, semantic interference and identity facilitation effects in RTs are associated with reductions of the N400 (e.g., Blackford et al., 2012; Dell'Acqua et al., 2010; Piai et al., 2014), providing evidence for interference and facilitation priming underlying the RT effects (Piai et al., 2014). In bilingual picture-word interference, a translation facilitation effect in RTs is also associated with a reduction of the N400 (Chauncey et al., 2009) but ERP evidence on semantic interference is lacking. Moreover, it is unclear whether the reduced N400 for translation distractors is also obtained without masking. The aim of the present study was to examine whether the RT effects in bilingual performance are associated with reductions of the N400 using clearly visible distractor words.

To examine this, we had Dutch-English bilingual participants name pictures in their second language English, while trying to ignore written distractor words in their first language Dutch. The distractors were not masked. For example, participants said "horse" to a pictured horse combined with the written Dutch word *eend* (*duck*, the semantic condition), the word *stoel* (*chair*, the unrelated condition), the word *paard* (*horse*, the translation condition), or a row of Xs (the control condition). Based on the monolingual literature, we expected to find semantic interference and translation facilitation effects in the RTs and a corresponding reduction of the N400 response for semantically related and translation distractors relative to unrelated distractors. Finding this pattern of RT and ERP effects would support within-language competition and challenge the between-language competition and no-competition views.

2. Material and methods

2.1. *Participants*

The experiment was carried out with a group of 17 participants (10 women) who were students at Radboud University, Nijmegen, The Netherlands. All participants were right-handed young adults, native speakers of Dutch with normal or corrected-to-normal vision. They had learned English as a second language at a mean age of 10.29 years ($SD = 1.64$). The participants indicated their proficiency in English on a five point scale, in which 1 represents that English skills were just as good as Dutch skills and 5 represents that English skills were worse than Dutch skills. On average, participants rated their proficiency in English compared with Dutch as 2.67 ($SD = 1.01$). Thus, the participants were bilingually non-balanced. Participants provided informed consent and none had any neurological or psychological impairment, or had previously used psychoactive medication. The experiment was conducted in agreement with the declaration of Helsinki (World Medical Association).

2.2. *Materials and design*

From the picture gallery of the Max Planck Institute for Psycholinguistics (Nijmegen, The Netherlands), 32 pictured objects from eight different semantic categories (i.e., clothing, animals, transportation, buildings, weapons, kitchenware, furniture, and body parts) were selected together with their basic-level names in Dutch (the Appendix lists the materials). There were four pictures per semantic category. The pictures were white line drawings on a black background and they were digitized and scaled to fit into a virtual frame of 10 cm $\times$ 10 cm. The printed words were presented in white color in 36-point lowercase Arial font.

Each picture was combined with a printed word from the same semantic category (the semantic condition), with a word from another semantic category (the unrelated condition), with a word that was the Dutch translation equivalent of the English picture name (the translation condition), or a string of Xs (the control condition). The unrelated condition was created by recombining the pictures with words from one of the seven other semantic categories. The distractors were presented in the middle of the pictures. All target pictures and words occurred equally often in each condition and they were repeated three times, yielding 384 different trials in total. The order of presenting the stimuli across trials was randomized for each participant.

2.3. *Procedure and apparatus*

The participants were tested individually. They were seated in front of a computer monitor and a microphone connected to an electronic voice key. The distance between participant and screen was approximately 70 cm, and the distance between participant and microphone was approximately 18 cm. Before the experiment began, participants were given a booklet that contained the set of experimental pictures. They were asked to go through it in order to be familiarized with the pictures and their appropriate English names. After a participant had read the instructions, a block of 32 practice trials was administered in which the participant named the experimental pictures in English combined with a row of Xs just once. After this, testing began. A trial started with the presentation of a picture combined with a distractor word in Dutch for 250 msec, followed by a black screen that lasted 1500 msec plus a randomized latency jitter of either 250 msec, 500 msec, or 750 msec. The presentation of stimuli and the recording of vocal responses were controlled by Presentation Software (Neurobehavioral Systems, Albany, CA).

2.4. *EEG acquisition*

EEG activity was recorded from the scalp with 61 tin electrodes mounted in an elastic electrode cap. The electrodes were arranged according to the extended International 10–20 System. All electrodes were initially referenced to the left mastoid and later off-line re-referenced to the mean of the left and right mastoids. The electro-oculogram (EOG) was recorded bipolarly: horizontal EOG was measured by placing electrodes on the outer canthus of each eye and vertical EOG by placing electrodes on the infra-orbital and the supra-orbital of the left eye. Electrode impedance was kept below 3 kΩ. All signals were sampled at 250 Hz and filtered on-line using a .02–70 Hz band-pass filter with an 8-sec time constant.

2.5. *Data analyses*

Naming RTs and ERPs were calculated for each participant for correct trials only. Trials that were discarded from the analyses included (1) a wrong pronunciation of the word, (2) a wrong response word (e.g., the response word was given in Dutch instead of English), (3) a disfluency, (4) a voice key triggering by a non-speech sound, or (5) recording failures and time-outs (RTs shorter than 100 msec or longer than the trial duration).

The RTs of correct trials were submitted to by-subject (F_1) and by-item (F_2) repeated measure analyses of variance (ANOVA) and dependent *t*-tests (t_1, t_2), with distractor condition (semantic, unrelated, translation, control) as independent variable. In addition, responses were coded as either correct or incorrect and were submitted to a binomial logistic regression analysis. This analysis models the log odds that the dependent variable takes on a value of 1 (i.e., a correct response is made). The independent variable was distractor condition, which is a categorical variable with four levels. This variable was included in the model by means of dummy coding taking the unrelated condition as a reference category. An alpha level of .05 was adopted for all statistical tests.

The ERP data were analyzed using Brain Vision Analyzer. The EEG signal was re-referenced to the mean of both mastoids, low-pass filtered at 30 Hz (Butterworth filter, default settings of Brain Vision Analyzer) and segmented into stimulus-locked −200 msec to 700 msec epochs. Single waveforms were baseline corrected using the average EEG activity from the 200 msec prior to stimulus presentation. To avoid contamination of the EEG signal by movement-related artifacts caused by the naming response, only trials with RTs longer than 600 msec were included in the analyses (cf. Blackford et al., 2012; Verhoef, Roelofs, & Chwilla, 2009, 2010). Using this RT criterion, 3.6% of all trials were excluded from further analysis. A semiautomatic artifact rejection procedure was run based on the following criteria: the gradient criterion was set such that voltage steps of maximally 30 μV were allowed per sampling point; the absolute voltage per segment did not exceed 100 μV; the lowest allowed activity was .5 μV (max-min) per 100 msec; and amplitudes were between −75 and 75 μV. Using these exclusion criteria, about 20% of all trials were rejected from further analysis. Also considering exclusion of error trials, the percentages of trials that were discarded from each condition were as follows: semantic 22.7%, unrelated 23.4%, translation 22.5%, and control 23.1%. These percentages were similar for the different distractor conditions, and they correspond to earlier studies (e.g., Blackford et al., 2012; Hirschfeld et al., 2008; Verhoef et al., 2009, 2010).

To permit a fine-grained analysis of distractor condition effects, the ERPs were analyzed in the following way: For each participant, the mean amplitude within 50-msec epochs for the distractor conditions was computed beginning with stimulus onset until 600 msec post-stimulus. No early distractor condition effect was present for the epochs spanning the 0–300 msec latency window (all *ps* > .05). Significant distractor condition effects were obtained in three consecutive time windows from 300 to 450 msec after stimulus onset, falling into the standard time window of the N400 (i.e., 300–500 msec). No effects of distractor condition were found for the later time windows spanning the 450–600 msec latency epoch (all *ps* > .05). Given the timing, the waveshape, and the scalp distribution of the distractor condition effects in the 300–450 msec window (discussed later), we take these to reflect modulations in the N400 amplitude (e.g., Kutas & Federmeier, 2011). The mean amplitudes for the four conditions (semantic, unrelated, translation, control) for the 300–450 msec window were entered into repeated measures ANOVAs. Average waveforms were computed per participant for each distractor condition in a quadrant analysis with two factors, namely AP distribution (anterior, posterior) and hemisphere (left, right). The quadrant analysis (left anterior, left posterior, right anterior, right posterior) was determined by grouping 11 channels in each of the four quadrants.

We performed the quadrant analysis following related studies from our lab and in the literature (e.g., Blackford et al., 2012; Chauncey et al., 2009; Verhoef et al., 2009, 2010) to assess the distribution of the effects across the scalp. As outlined earlier (Section 1.3), we expected the N400 effects to be broadly distributed, and the quadrant analysis was performed to verify whether this was indeed the case. The N400 modulations are sometimes reported in the literature to be stronger for one hemisphere than another or stronger at anterior than posterior electrode sites or vice versa (e.g., Blackford et al., 2012; Chauncey et al., 2009). For completeness, we tested for such possible effects in our data. Documenting this seemed useful given that our study is the first to test for both semantic and translation effects in bilingual picture-word interference without masking of the distractor words.

All ANOVAs included the following variables: distractor condition (semantic, unrelated, translation, and control), AP distribution (anterior, posterior), and hemisphere (right, left). All *p*-values reported reflect the application of the Greenhouse-Geisser correction for violations of the sphericity assumption with the original degrees of freedom.

3. Results

3.1. Behavioral findings

Mean RTs and percentages of errors are presented in Fig. 2. Naming RTs were longer in the semantically related than in the unrelated condition, longer in the unrelated than in the control condition, and shorter in the translation than in the unrelated condition. More errors were made in the semantically related condition than in any of the other distractor conditions. Error rate was lowest in the translation condition.

The statistical analysis of the naming RTs yielded a significant main effect of distractor condition in both the by-subject and by-item analyses, $F_1(3, 48) = 112.91$, $p < .001$, $F_2(3, 93) = 50.03$, $p < .001$. Planned comparisons showed that there was a semantic interference effect, $t_1(16) = 8.20$, $p < .001$, $t_2(31) = 4.79$, $p < .001$, a lexicality effect, $t_1(16) = 7.25$, $p < .001$, $t_2(31) = 5.35$, $p < .001$, and a translation facilitation effect, $t_1(16) = 8.53$, $p < .001$, $t_2(31) = 7.28$, $p < .001$. Descriptively, compared with the unrelated condition, the odds of giving a

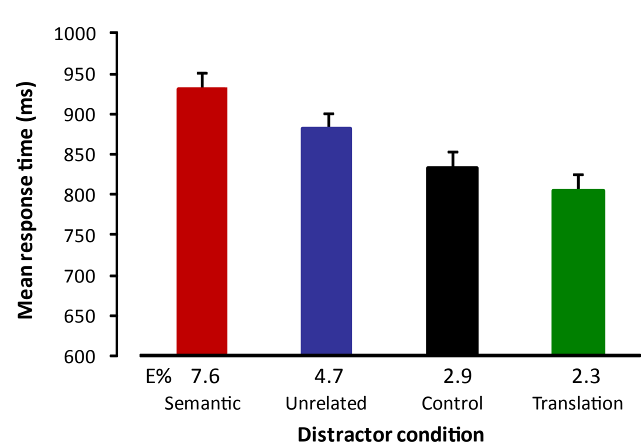

Fig. 2 – Mean naming response times and error percentages (E%) for the different distractor conditions. The error bars represent one standard error.

correct response were .60 times lower in the semantic condition and 2.07 times higher in the translation condition. The odds of giving a correct response in the control condition were 1.63 times higher than in the unrelated condition. Equivalent results were obtained when confining the analyses to trials with RTs longer than 600 msec, which were used for the ERP analyses.

3.2. *Electrophysiological findings*

In Fig. 3, grand average ERP waveforms for the different distractor conditions are displayed. Waveforms are time-locked to stimulus onset and are presented for a representative set of electrodes.

Visual inspection of the data suggests that the waveform around 400 msec after stimulus onset was more negative-going in the distractor word conditions (i.e., unrelated, semantic, translation) than in the non-linguistic control condition, in line with the observation of Greenham, Stelmack, and Campbell (2000) that picture-word combinations elicit a larger N400 response than pictures without superimposed words. Statistical analysis of the time window capturing N400 activity (i.e., 300–450 msec) confirmed that mean N400 amplitude was more negative-going for the unrelated, semantic, and translation conditions than for the non-linguistic control condition, all *ps* $< .05$. Fig. 4 gives the scalp distributions for the lexicality, semantic, and translation effects between 300 and 450 msec after stimulus onset. The topographic maps show that the lexicality, semantic, and translation effects are all broadly distributed across the scalp, as is typically observed for the N400 (see Kutas & Federmeier, 2011; Lau et al., 2008).

The statistical analysis revealed a main effect of distractor condition, $F(3, 48) = 16.58$, $p = .001$. There were no significant interactions of distractor condition and AP distribution, $F(3, 48) = 1.41$, $p = .25$, distractor condition and hemisphere, $F(3, 48) < 1$, $p = .97$, or distractor condition, AP distribution, and hemisphere, $F(3,48) = 1.82$, $p = .16$. Planned comparisons revealed that the N400 amplitude was larger for the unrelated than for the control condition, $t(16) = 6.97$, $p = .001$, smaller for the semantically related than for unrelated condition, $t(16) = 2.88$, $p = .01$, and smaller for the translation than for the unrelated condition, $t(16) = 4.85$, $p = .001$.

To summarize, we obtained an N400 response to picture-word interference stimuli, which was modulated by distractor condition between 300 and 450 msec after stimulus onset. The waveforms were more negative-going for the distractor word conditions (i.e., unrelated, semantic, translation) than for the non-linguistic control condition. The N400 amplitude was smaller for the semantic and translation conditions than for the unrelated condition.

4. Discussion

We argued that the behavioral pattern of cross-language semantic interference and translation facilitation effects

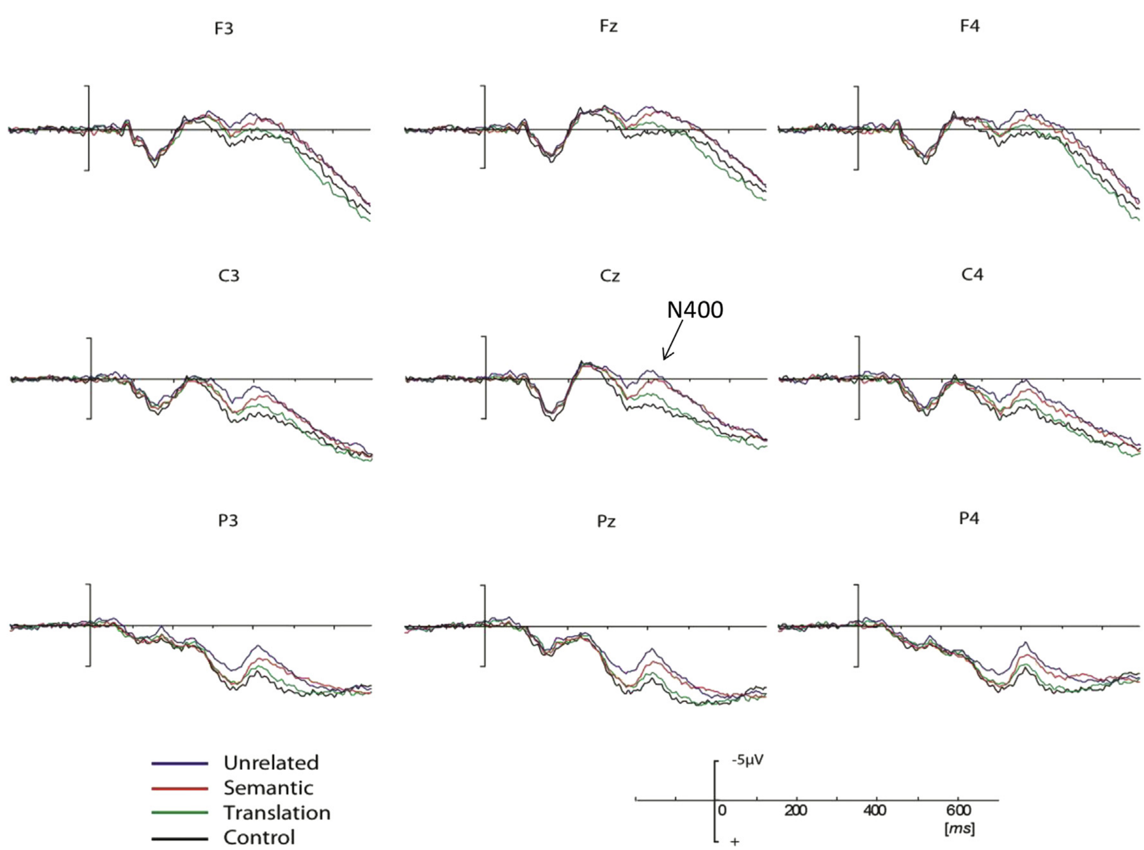

Fig. 3 – Grand average ERP waveforms in the different distractor conditions, shown for electrodes Fz, Cz, Pz (midline), F3, C3, P3 (left hemisphere), and F4, C4, P4 (right hemisphere).

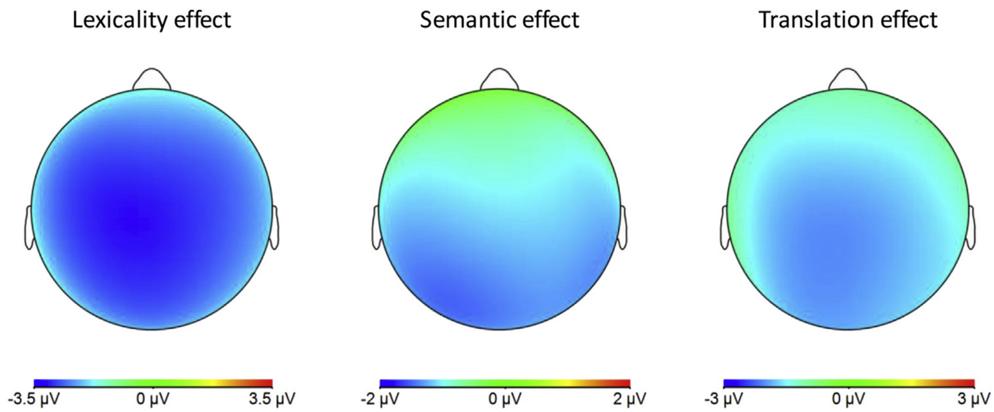

Fig. 4 – Topographic maps for the lexicality, semantic, and translation effects in the 300–450 msec time window after stimulus onset.

supports the within-language competition view and challenges the between-language competition and no-competition views. In monolingual picture-word interference studies, semantic interference and identity facilitation effects in RTs have been associated with reductions of the N400 (e.g., Blackford et al., 2012), providing evidence that interference and facilitation priming underlie the RT effects. In bilingual picture-word interference, the translation facilitation effect in RTs has also been associated with a reduction of the N400 (Chauncey et al., 2009) but corresponding electrophysiological evidence on semantic interference is lacking. Moreover, it has remained unclear whether the reduced N400 for translation distractors is also obtained without masking. The aim of the present study was to obtain evidence on RT effects and corresponding ERP modulations in bilingual picture-word interference with clearly visible distractors.

In our study, Dutch-English bilingual participants named pictures in their second language English, while trying to ignore written distractor words in their first language Dutch. Target and distractor words were semantically related, unrelated, or translations. In addition, we used a series of Xs as non-linguistic control condition. We expected to find semantic interference and translation facilitation effects in the naming RTs and corresponding reductions of the N400 response, providing evidence for interference and facilitation priming. This pattern of RT and ERP effects would support the within-language competition view and challenge the between-language competition and no-competition views.

We obtained semantic interference and translation facilitation effects in the RTs. Compared with the unrelated condition, the error rates were higher in the semantic condition and lower in the translation condition. Thus, semantic trials were hardest to perform and translation trials were easiest. Moreover, we obtained an N400 response to our picture-word stimuli, which was modulated by distractor condition between 300 and 450 msec after stimulus onset, but not earlier or later. The N400 amplitude was smaller for the semantic and translation conditions than for the unrelated condition, providing evidence for priming. This pattern of effects supports the view that interference and facilitation priming underlie the behavioral semantic interference and translation effects. These RT and ERP results support the within-language competition view and challenge the between-language competition and no-competition views.

It should be noted, however, that our findings were obtained under specific conditions (see Kroll et al., 2006, for an extensive discussion). Our Dutch-English bilingual participants used English for responding to the pictures throughout the experiment. They did not have to switch between languages and the other language Dutch was not used earlier in the experiment to name the pictures. In contrast, evidence that bilingual speakers inhibit words in the other language comes from language switching experiments (e.g., De Bruin, Roelofs, Dijkstra, & FitzPatrick, 2014; Jackson, Swainson, Cunnington, & Jackson, 2001; Meuter & Allport, 1999; Verhoef et al., 2009) and studies in which participants used the other language earlier in the experiment to name the pictures (e.g., Guo, Liu, Misra, & Kroll, 2011). It is plausible to assume that when speakers have to switch regularly between languages or have already named the pictures in the other language, competition for selection often can no longer be restricted to the target language or competition occurs at the level of the language task sets (e.g., Verhoef et al., 2009, 2010). Furthermore, Costa and Santesteban (2004) and Costa, Santesteban, and Ivanova (2006) argued that whether competition is within or between languages depends on language proficiency. Whereas words in both languages compete for selection in low-proficient bilingual speakers, high-proficient bilinguals have learned to restrict competition to the target language (but see Verhoef et al., 2009).

Poulisse and Bongaerts (1994) also argued for a role of proficiency based on language intrusions. They observed that the number of first-language (Dutch) intrusions in second-language (English) word production varied with second-language proficiency levels of Dutch-English bilingual speakers. The tasks were picture naming, story retelling, and free conversation. For relatively high-proficient bilingual speakers (having learned English for eight years), content word intrusions happened in only .02 percent of all words produced (i.e., 11 out of about 50,000 words), whereas this was .2 percent (i.e., 74 out of about 40,000 words) for low-proficient speakers (with three years experience). Still, the number of first-language intrusions was low, even for low-proficient bilingual speakers. The low number of intrusions fits well with the idea that competition for selection is restricted to the target language.

In the remainder, we first compare our ERP and RT data with prior observations in the literature. Next, we discuss the implications of our findings for the three views on how bilingual speakers select words (i.e., between-language competition, within-language competition, and no competition). Finally, we present the results of WEAVER++ simulations showing the utility of a within-language competition account of the findings.

4.1. Comparisons with earlier findings

Our behavioral data replicate earlier findings in the literature. Cross-language semantic interference and translation facilitation effects in RTs have earlier been obtained by Costa and colleagues (Costa & Caramazza, 1999; Costa et al., 2003, 1999), Hermans et al. (1998), and Roelofs et al. (2011), among others.

Our ERP data also replicate several earlier findings in the literature. The observation of a larger N400 response in the unrelated than in the non-linguistic control condition (i.e., the lexicality effect) replicates Hirschfeld et al. (2008). Our data show that this effect is also obtained across languages. The lexicality effect in the present experiment also corresponds to the results of Greenham et al. (2000), who observed that pictures combined with words yield a larger N400 amplitude than the same pictures presented in isolation. In the study of Hirschfeld et al. (2008) and the present experiment, the Xs of the control condition were repeated more often than the words, which may have reduced the electrophysiological response in the control condition. However, the correspondence between the results of Hirschfeld et al. (2008) and the present experiment, on the one hand, and the results of Greenham et al. (2000), on the other hand, suggests that the difference between the word and control conditions reflects an effect of lexicality rather than differential repetition. This conclusion is further corroborated by evidence that illegal letter strings, like a row of Xs, do not modulate the N400 and yield no repetition effect when task-irrelevant (cf. Laszlo & Federmeier, 2009; Laszlo, Stites, & Federmeier, 2012).

Our observation of a smaller N400 amplitude for semantically related than for unrelated distractor words replicates the findings of Blackford et al. (2012) and Dell'Acqua et al. (2010), although the smaller negativity for semantic than for unrelated distractors in the N400 time window was not identified as an N400 effect by Dell'Acqua et al. Our data show that the attenuation of the N400 by semantic relatedness is also obtained across languages. Moreover, our observation of a smaller N400 amplitude for translation distractors than for unrelated distractor words replicates the findings of Chauncey et al. (2009), who used masked distractor words. Importantly, our findings indicate that the N400 attenuation for translation distractors is obtained even when the words are clearly visible.

Several earlier studies did not obtain a semantic attenuation of the N400 response while still obtaining semantic interference in the RTs in the picture-word interference paradigm. Hirschfeld et al. (2008) conducted a picture-word interference experiment in which pictures (e.g., a horse) were named in semantically related (e.g., word *duck*), unrelated (e.g., *chair*), surface feature (e.g., *tail*), and non-linguistic control conditions (i.e., a row of Xs). The naming RTs revealed a 25-msec lexicality effect, a 24-msec facilitation effect from surface-feature relatedness, and a 14-msec semantic interference effect. Moreover, in the N400 time window, the word distractors (i.e., semantic, unrelated, surface feature) yielded a larger negativity than the non-linguistic control condition (which was replicated in the present experiment), but there were no differences among the distractor word conditions (different from the results of the present experiment). Similarly, Aristei, Melinger, and Abdel Rahman (2011) observed a semantic interference effect of 8 msec in the naming RTs, but no corresponding semantic effect in the waveforms. In an ERP study in our own lab (Piai et al., 2012), participants named pictures in Dutch (e.g., a horse) while trying to ignore Dutch distractor words in semantic, unrelated, and identity conditions (there was no non-linguistic control condition, different from the present experiment). Semantic interference was obtained in the naming RTs. In the N400 time window, the waveforms were more negative-going for the unrelated than identity condition, in line with the results of Blackford et al. (2012) and the present experiment. However, the waveforms did not show a difference between the semantic and unrelated conditions, unlike what Blackford et al. and the present experiment revealed. Thus, whereas semantic interference in the naming RTs is consistently obtained, the corresponding N400 effect is somewhat more variable (i.e., it was absent in several studies).

The variability of the semantic modulation of the N400 effect in picture-word interference may reflect differences in the impact of the distractor words. This would explain why Aristei et al. (2011) and Hirschfeld et al. (2008) obtained no N400 modulation and only small semantic interference effects in the RTs of 8 and 14 msec, respectively. In contrast, in the Dell'Acqua et al. (2010) and the present study, N400 effects were found alongside large semantic interference effects in the naming RTs (39 and 41 msec, respectively). Blackford et al. (2012) also obtained an N400 effect, but the exact magnitude of the semantic interference in the RTs is somewhat difficult to derive from their graphs. To conclude, picture-word interference studies seem to differ in the impact of the distractor words, as reflected by the N400 response and RTs.

Finally, our findings generally agree with the main findings from related naming paradigms, such as color-word Stroop and semantic blocking. In the Stroop task, participants name the ink color of incongruent or congruent color words (e.g., the word *green* in red or green ink, respectively), and in the semantic blocking paradigm, participants name pictures in semantically homogeneous and heterogeneous blocks of trials (e.g., all animal pictures *vs* pictures from different semantic categories, such as animals, buildings, furniture, etc.). Naming RT is typically longer on incongruent than on congruent Stroop trials, and longer in semantically homogeneous than in heterogeneous blocks of trials (e.g., Shao, Roelofs, Martin, & Meyer, 2015). In these other naming paradigms, effects are also associated with ERP modulations in the N400 time window (e.g., Liotti, Woldorff, Perez III, & Mayberg, 2000, for Stroop; Aristei et al., 2011, for semantic blocking). The onset of the ERP effects in our study (i.e., between 300 and 450 msec after stimulus onset) is in line with the onset of the effects reported in the literature. For example, in picture-word interference, Blackford et al. (2012) obtained effects between 350 and 550 msec after picture onset, which is only slightly later than in our study. Chauncey et al. (2009) obtained effects between 300 and 500 msec, thus with the same onset as in our study. Hirschfeld et al. (2008) obtained effects between 250 and 450 msec, which is somewhat earlier than in our study, but they presented the distractor words 150 msec before picture onset whereas we did not. In the color-word Stroop task, Liotti et al. observed N400 modulations between 350 and 500 msec, which is similar to our present findings. Finally, Aristei et al. combined semantic blocking and picture-word interference with auditory distractors, and they obtained semantic blocking effects between 250 and 400 msec and distractor effects between 200 and 550 msec. However, as in the study of Hirschfeld et al., the onset of the distractor was 150 msec before picture presentation onset, giving distractor processing a head-start, which may have led to an earlier onset of the distractor effect in the study of Aristei et al. than in our study. To conclude, the 300–450 msec time window of our distractor effect is well in line with the time window of the effects in color-word Stroop and semantic blocking paradigms.

4.2. *Theoretical consequences*

According to the between-language competition view, words in both languages compete for selection, but speakers manage to select the words in the target language by selectively boosting their activation (De Bot, 2004) or by inhibiting words in the other language (e.g., Green, 1998; Kroll et al., 2006, 2008). This view readily accounts for the between-language semantic interference but it is challenged by the translation facilitation effect. Under this view, distractors that are the translation equivalents of the picture names in the other language should be the strongest competitors. Consequently, the interference should be largest for the translation condition. Empirically, however, translation distractors help rather than hinder the naming response relative to unrelated distractors. Compared to unrelated trials, RT is shorter and error rate is lower on translation trials. These behavioral effects support the idea that translation trials are easiest rather than hardest to perform, contrary to the between-language competition view.

We argued that the between-language competition view is not compatible with the behavioral translation facilitation effect, because translation equivalents should be particularly strong competitors if competition between languages is assumed. However, other authors (i.e., Hall, 2011; Hermans, 2004) have come to different conclusions by arguing that competitive interference of translation distractors is not observed due to particularly strong semantic priming effects (because of perfect conceptual overlap of translation equivalents). However, we dismissed this argument by stating that higher priming necessarily implies even higher reverse priming (i.e., increased competition) and therefore translation interference needs to be expected by a between-language competition account. It should be noted that whereas this is true within the constraints of the framework of the WEAVER++ model, it remains possible that there are other factors in play that are not covered by this model. For example, it has been argued that semantically related and identity distractors may yield facilitation in conceptual encoding, that is, in selecting the appropriate concept for verbal expression. The facilitation in conceptual encoding may offset the interference due to competition at the lemma level (e.g., Abdel Rahman & Melinger, 2009; Hermans, 2004; Kuipers & La Heij, 2008). Based on the time window of conceptual encoding estimated by Indefrey and Levelt (2004; Indefrey, 2011), such a facilitation effect is expected to occur within 200–250 msec after picture-word onset. However, in the present study, a distractor effect was obtained starting no earlier than 300 msec after stimulus onset. Thus, the present ERP findings do not support the assumption that related distractors yield facilitation in conceptual encoding. This suggests that maintaining the idea of between-language competition requires still other additional assumptions to account for the behavioral pattern discussed here. Future research may perhaps discover these additional assumptions.

According to the no-competition view, words in both languages are activated, but the activation of words in the target language exceeds a selection threshold first and will be selected (Finkbeiner et al., 2006). Earlier, we argued that this view can account for either the between-language semantic interference or the translation facilitation, but not both, depending on the presumed role of conceptual similarity and language membership in the exclusion process. For example, although translation distractors may help targets to exceed the selection threshold quicker, this effect should also be countered by the response-exclusion process because of conceptual similarity, yielding translation interference. Chauncey et al. (2009) obtained translation facilitation in RTs and an attenuated N400, contradicting this prediction. However, Chauncey at al. used masked distractors. According to Finkbeiner and Caramazza (2006), masking prevents competition at the level of the articulatory buffer. Under the response exclusion account, this may explain why Chauncey et al. obtained translation facilitation in the RTs and an attenuated N400. If response exclusion no longer counteracts the conceptual facilitation for translation distractors, facilitation in RTs may be obtained, as empirically observed. However, in the present study, the distractors were not masked but clearly visible. Thus, the distractors should now be excluded from the articulatory buffer and yield translation interference in the RTs, as argued earlier. Given that we observed semantic interference and translation facilitation, the no-competition view is also not supported by our findings.

Finally, according to the within-language competition view, words in both languages are activated but only words in the target language compete for selection (Costa, 2005; Costa & Caramazza, 1999; Roelofs, 1998, 2003, 2010; Roelofs et al., 2013). This view readily explains both the translation facilitation and the between-language semantic interference effects. Under this view, distractor words from another language do not compete themselves but activate their counterparts in the target language. As a consequence, semantically related distractors from the other language activate semantic competitors of the picture name in the target language, which yields semantic interference. Moreover, translation distractors activate the target name but will not compete, which will yield the translation facilitation effect. According to this view, the same priming and reverse priming processes underlie monolingual and bilingual picture-word interference effects. Consequently, the corresponding electrophysiological signature of these processes should be the same for monolingual and bilingual performance. Previous monolingual ERP studies reported that the N400 response is smaller on semantic and identity than on unrelated trials, providing evidence for interference and facilitation priming. The present study indicates that this ERP signature is also obtained for bilingual picture-word interference, thereby corroborating the within-language competition view.

It is important to emphasize that we take the combination of cross-language RT and ERP effects (and not only the ERP effects) to support the within-language competition account and to challenge the between-language competition and no-competition accounts. In monolingual picture-word interference studies using first-language targets and distractors, behavioral semantic interference and identity facilitation effects are both associated with an N400 attenuation. Whereas Blackford et al. (2012) argued that the N400 attenuation in the presence of semantic interference in RTs challenges the idea of lexical selection by competition, we argued elsewhere (Piai et al., 2014) that the N400 attenuation reflects both priming and reverse priming, with the reverse priming being larger than the priming, causing the behavioral semantic interference. In the present article, we argued that a within-language competition account would predict a similar pattern of RT and ERP effects in bilingual picture-word interference with second-language targets and first-language distractors (i.e., N400 attenuation in the presence of behavioral semantic interference and translation facilitation), whereas the other two accounts would only be compatible with other patterns of ERP effects in the presence of behavioral semantic interference and translation facilitation. Given that previous bilingual research had examined translation facilitation effects for masked distractors only (Chauncey et al., 2009) and did not have examined semantic interference effects, it remained possible that different ERP findings would be obtained for bilingual than for monolingual picture-word interference. By replicating the monolingual pattern (i.e., N400 attenuation in the presence of behavioral semantic interference and identity facilitation) in bilingual picture-word interference, the within-language competition account is supported whereas the between-language competition and no-competition accounts are challenged.

Blackford et al. (2012) assumed that the N400 attenuation only reflects priming of the picture name by the distractor word. However, the literature suggests that both pictures and words evoke an N400 response, thus it seems difficult to maintain that the N400 evoked by picture-word combinations only reflects picture name processing. Instead, it is much more plausible to assume that the N400 response to a picture-word combination reflects both picture name and distractor word processing. According to WEAVER++, picture-word stimuli evoke both priming of the picture name and reverse priming of the distractor word, and it is plausible to assume that the N400 response to picture-word stimuli reflects both priming and reverse priming. Consequently, the behavioral semantic interference in the presence of an attenuated N400 is fully compatible with the model, as demonstrated through computer simulations by Piai et al. (2014). To conclude, we believe that the N400 attenuation is not providing direct evidence for reverse priming. However, given the evidence in the literature that both pictures and words evoke an N400 response, the N400 attenuation observed for picture-word stimuli better agrees with the idea that the attenuation reflects both picture and word processing (as Piai et al. maintained) than with the idea that it reflects picture processing only (as Blackford et al. maintained).

4.3. *Assessing the within-language competition account by computer simulations*

To assess the utility of the within-language competition view in accounting for the present findings, we conducted computer simulations using WEAVER++. The simulation protocol was similar to earlier simulations of lexical selection with this model (i.e., Levelt et al., 1999; Roelofs, 1992, 1993, 2003, 2007, 2008a, 2008b, 2008c, 2014). We refer the reader to these publications for details on the model and the simulation protocol. Two semantic domains were used in the present simulations, namely animals (i.e., animal, horse, duck) and furniture (i.e., furniture, chair, table). The structure of a semantic domain is illustrated in Fig. 1. To be able to simulate picture naming in English in the presence of Dutch distractor words, each concept node was connected to two lemma nodes, one for each language. For example, the concept node HORSE(X) was connected to the lemmas of the words *horse* (English) and *paard* (Dutch). The connections were set to be weaker (i.e., .5) for the English than the Dutch lemmas, representing the fact the participants in our experiment were bilingually non-balanced (cf. Roelofs et al., 2013). In the simulations, a picture activated the corresponding concept node and a printed word activated the corresponding lemma node. Whereas the target picture provided input activation to the network until the selection of a lemma node, the distractor provided activation input to its lemma for a limited period of time, the distractor duration. Processing in the model proceeded through time in discrete time steps. On each time step, activation spread through the network following a linear activation function with a decay factor. Activation of nodes in the network triggered the application of condition-action rules. A lemma node was selected as response when its level of activation exceeded that of the other nodes of the target language (English) by some critical amount, the selection threshold. The distractor duration was set to 100 msec and the selection threshold to 1.6. All other parameter values were fixed and identical to those of Roelofs (1992, 2003, 2008a, 2008b).

The simulations revealed that lemma retrieval latencies were longer in the semantic than in the unrelated condition and shorter in the translation than in the unrelated condition, as shown in Fig. 5. Thus, the model yields semantic interference and translation facilitation effects, as empirically observed. These effects on lemma retrieval latencies will surface as corresponding interference and facilitation effects on the naming RTs.

Following Blackford et al. (2012), we assume that the N400 effect reflects activation processes at the lemma level. Fig. 6 illustrates the activation curves for the lemmas of the relevant Dutch and English words. A constant of 200 msec was added for perceptual processes preceding lexical network activation. To associate the lemma activations in the model with the electrophysiological brain responses in the real experiment, a linking hypothesis is needed. Following earlier suggestions in the literature concerning the N400 effect (e.g., Kutas & Federmeier, 2011; Lau et al., 2008), we assume that the amplitude of the N400 response in picture-word interference reflects the ease of lexical processing of target picture and distractor word (not denying that the N400 effect in other task situations and normal reading also reflects contextual integration processes, e.g., Chwilla, Hagoort, & Brown, 1998; Chwilla, Kolk, & Vissers, 2007).

Fig. 6 shows that the lemmas of the Dutch distractors are activated more in the translation condition (*paard*) than the semantic condition (*eend*), and more in the semantic than in the unrelated condition (*stoel*), whereas activation of the English target lemma (*horse*) does not differ much among conditions. Under the ease-of-processing linking assumption, the N400 response should be larger for the lemmas of the Dutch words in the unrelated than in the semantic and translation conditions, because unrelated words are not primed by the picture (hence the low activation level), whereas words in the semantic and translation conditions are primed by the picture (hence their higher activation levels). This corresponds to the empirical results. Although the lemmas of the Dutch words do not directly compete for selection with the English target lemma, competing English lemmas (i.e., translation equivalents of the Dutch words) are indirectly activated via the shared concept nodes. For example, although the lemma of the Dutch word *eend* does not compete with the English target *horse* for selection, the lemma of the English translation equivalent *duck* does compete. Similarly, the unrelated Dutch distractor word *stoel* activates the lemma of the English competitor *chair*, but these lemmas are not primed by the picture. As a consequence, a semantic interference effect on lemma retrieval latencies is obtained, as shown in Fig. 6. In the translation condition, the lemma of the Dutch distractor *paard* will be primed by the picture and the distractor will activate the lemma of its English translation equivalent, the target *horse*. The activation of *paard* by the picture will be reflected in a reduced N400 amplitude, and the activation of the English target *horse* will reduce lemma retrieval latency. To conclude, the results of the computer simulations using WEAVER++ demonstrate the utility of the within-language competition view.

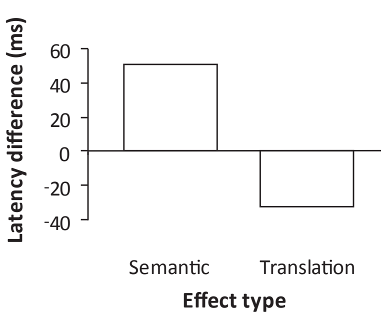

Fig. 5 – Semantic and translation effects on the latency of lemma retrieval in WEAVER++.

5. Conclusions

Picture naming RT and N400 amplitude were modulated in bilingual picture-word interference. RTs showed semantic interference and translation facilitation effects. The N400 amplitude was smaller on semantic and translation trials than on unrelated trials. These electrophysiological findings provide evidence that interference and facilitation priming underlie the RT effects. The results of computer simulations showed the utility of a within-language competition account of the findings.

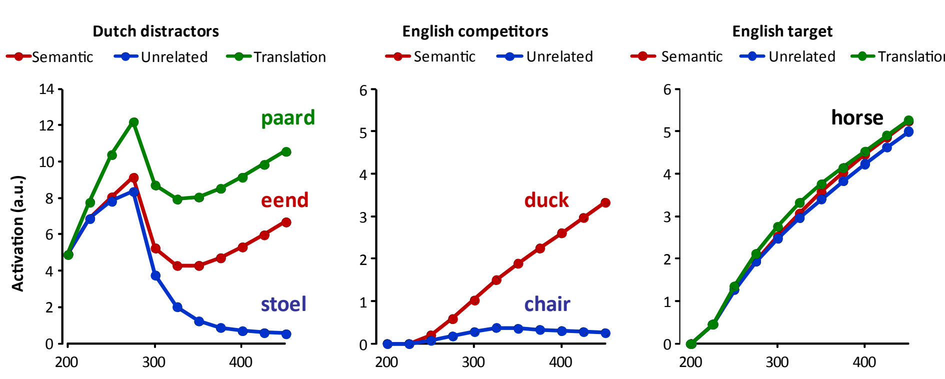

Fig. 6 – Activation curves for the lemmas of Dutch word distractors, English competitors, and the English target in WEAVER++ simulations.

Appendix. Basic-level names of the pictures in English (the target language) and their Dutch translation equivalents.

English name	Dutch name	English name	Dutch name
transportation		*clothing*	
car	auto	coat	jas
bicycle	fiets	sweater	trui
airplane	vliegtuig	skirt	rok
truck	vrachtwagen	dress	jurk
body parts		*kitchenware*	
toe	teen	cup	beker
leg	been	plate	bord
nose	neus	bowl	kom
ear	oor	jug	kan
animals		*buildings*	
deer	hert	castle	kasteel
swan	zwaan	mill	molen
rabbit	konijn	factory	fabriek
turtle	schildpad	church	kerk
furniture		*weapons*	
table	tafel	dagger	dolk
cupboard	kast	sword	zwaard
desk	bureau	rifle	geweer
chair	stoel	tomahawk	bijl

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