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Fast Morphological Effects in First and Second Language Word Recognition

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Abstract

In three experiments we compared the performance of native English speakers to that of Spanish-English and Dutch-English bilinguals on a masked morphological priming lexical decision task. The results do not show significant differences across the three experiments. In line with recent meta-analyses, we observed a graded pattern of facilitation across stem priming with transparent suffixed primes (e.g., *viewer-view*), opaque suffixed or pseudo-suffixed primes (e.g., *corner-corn*) and form control primes (e.g., *freeze-free*). Priming was largest in the transparent condition, smallest in the form condition and intermediate in the opaque condition. Our data confirm the hypothesis that bilinguals largely adopt the same processing strategies as native speakers (e.g., Lemhöfer et al., 2008), and constrain the hypothesis that bilinguals rely more heavily on whole-word processing in their second language (Ullman, 2004, 2005; Clahsen et al., 2010). The observed pattern of morphological priming is in line with earlier monolingual studies, further highlighting the reality of semantic transparency effects in the initial stages of word recognition.

Keywords: Morphological processing, bilingual word recognition, masked priming, semantic transparency.

Introduction

Over the last decade we have witnessed an exponential growth in studies investigating the role of morphology in visual word recognition using the masked priming paradigm (Forster & Davis, 1984). When target words are preceded by a morphologically related prime (e.g., *worker-work*), target recognition (typically measured using the lexical decision task) occurs faster relative to form controls (e.g., *freeze-free*) and semantic controls (e.g., *giraffe-safari*). In masked priming, participants are unaware of the primes, which are presented (a) immediately before targets, (b) between masks (e.g., hash signs) and (c) for around 40-50ms (see Diependaele, Grainger & Sandra, 2010, for a review). The results of masked morphological priming experiments suggest that morpheme-sized representations (shared by primes and targets) are automatically activated at a very early stage of visual word recognition. Interestingly, this does not exclusively depend on whether or not primes and targets share their stem (e.g., *worker-work*). Recent evidence has shown that morphological information is also taken into account when masked primes and targets share an affix (e.g., *darkness-happiness* vs. *shallow-follow*; Duñabeitia, Perea, & Carreiras, 2008; Chateau, Knudsen, & Jared, 2002), highlighting the visual word recognition system's reliance on morphological information.

A key result in stem priming is that morphological facilitation also occurs when targets are preceded by semantically opaque and pseudo-complex affixed masked primes (e.g., *department-depart* and *corner-corn*; see Rastle & Davis, 2008, for review)(footnote 1). This finding has revived so-called "blind decomposition" or sublexical accounts of morphological processing. In these accounts morphological activation occurs at the level of sublexical form representations. Inputs are parsed into morphemes, without any reference to whole-word lexical information (e.g., Taft & Forster, 1975). Further evidence for this view comes from the observation that newly constructed (i.e., unfamiliar) suffixed forms (e.g., *cornly*) elicit facilitation similar to that of familiar transparent primes, regardless of their interpretability (Longtin & Meunier, 2005, but see

Morris, Porter, Grainger & Holcomb, 2010). Morphological activation thus occurs regardless of semantic transparency and whole-word familiarity, two clearly lexical variables.

It remains the case, however, that priming effects are somewhat larger for semantically transparent familiar derivations. Feldman, O'Connor and Moscoso del Prado Martin (2009) showed that when the data of individual studies are combined in a meta-analysis, semantically transparent primes show a significant advantage over opaque or pseudo-complex primes, whereas this advantage is not always significant in the individual analyses (see also Davis & Rastle, 2010). In addition to their meta-analysis, Feldman et al. (2009) also conducted a new experiment in which they observed a clear semantic transparency effect (i.e., priming advantage of transparent over opaque items) with carefully controlled stimuli, in line with earlier results of Diependaele, Sandra and Grainger (2005, 2009) and Morris, Franck, Grainger and Holcomb (2007).

One way of explaining graded priming across transparent and opaque items is to assume that the morphological representations that are activated during sublexical processing, i.e., the *morpho-orthographic* (and/or *–phonological*) representations, rapidly send activation to corresponding whole-word representations, viz., the lexical representation of the full input and the stem (e.g., worker, work; corner, corn). These lexical representations could be form representations (e.g., Diependaele et al., 2005, 2009), more abstract *lemma* representations (e.g., Taft & Nguyen-Hoan, 2010) and/or whole-word semantic representations. The critical point is that if the competition among lexical these representations is somehow mediated by the (morpho-)semantic relationship, such that competition is smaller for transparent derivations than for opaque or pseudo-derivations, the activation of stem representations could rapidly become larger for semantically transparent familiar derivations. Giraudo and Grainger (2000) and Diependaele et al. (2005, 2009), for instance, proposed that the competition between lexical *form* representations is mediated by positive feedback from higher-level morpho-semantic (so-called "supra-lexical") representations (footnote 2). Taft and Nguyen-Hoan (2010) more recently proposed that sublexical morpho-orthographic representations map onto *lemma* representations. These representations are connected through positive links in the case of semantically transparent morphological relatives. No such links are present between the lemma representation of opaque derivations and their (pseudo-)relatives.

The graded pattern across transparent and opaque items constitutes simultaneous evidence for sublexical morphological processing (i.e., priming from opaque or unfamiliar derivations) and lexical morphological processing (i.e., larger effects with semantically transparent familiar derivations). Hence, there appears to be no immediate elimination of the sublexical morphemic activation in the case of opaque or unfamiliar complex words once (morpho-)semantic properties come into play. This could indicate a parallel architecture where lexical morphological processing is initiated through direct whole-word activation, while bypassing - and not immediately interfering with - sublexical morphological segmentation (e.g., Diependaele et al., 2005). It is also possible to account for this in a sequential view, however. Taft and Nguyen-Hoan (2010) consider for instance (among other possibilities) that: "… although the lemma for *corn* and *corner* vie with each other to reach a recognition threshold, such competition does not actually inhibit the activation level of the 'loser'. That is, all that matters is which lemma reaches threshold first." (p. 291). The simultaneous evidence for sublexical and lexical morphological processing thus does not necessitate a parallel architecture. It can be argued that the sequential view nevertheless implies an initial stage in processing, where morphemic activation is purely morpho-orthographic (i.e., sublexical) and morphological priming should therefore be matched across different levels of semantic transparency and familiarity. This prediction contrasts with the data of Diependaele et al. (2005, Experiment 2) who observed earlier stem priming with semantically transparent than with semantically opaque suffixed primes, in an experiment with different prime durations. Again, this pattern is in line with a parallel architecture, but it does not necessitate it. In the sequential view, assuming cascaded processing allows that morpho-semantically mediated lexical competition already starts before sublexically activated morphemic representations have reached a criterion activation level required for observing priming with brief prime exposure.

In the present study we consider the processing of morphologically complex words from a different angle, i.e., second language (L2) processing. In a recent review, Clahsen, Felser, Neubauer, Sato and Silva (2010) claimed that current evidence shows that adult L2 learners are not as sensitive to morphological information as native speakers, a statement based primarily on their own research and on studies with inflected forms. In a study by Silva and Clahsen (2008) no masked stem priming effects were found for L2 learners of English with regular past-tense primes (e.g., *boiled-boil*), whereas these effects were observed for native English speaking participants. Neubauer and Clahsen (2009) tested native and non-native German speakers in a series of experiments exploring the processing of irregular and regular participles. Critically, in Experiment 3 they used the masked priming procedure and showed that while facilitative priming effects were found for irregular and regular participles in the L1 group, non-natives exclusively showed priming effects for the irregular participles, concluding that L2 learners do not segment inflectional affixes from their stems during processing. The explanation that is provided by these authors is that, in general, the later in life words are acquired, the more their processing will rely on *direct* lexical retrieval instead of grammatical computation. This idea derives from the declarative/procedural model proposed by Ullman (2004, 2005). In this model, word recognition depends on two distinct memory subsystems: declarative memory, situated in the temporal lobe, and procedural memory, located in the frontal cortex and basal ganglia. The declarative system provides mechanisms to store and access whole-word representations. The procedural system on the other hand, provides mechanisms to acquire and use grammatical rules. Through this system, regular inflections do not have to be stored in separate whole-word representations, as they can be recognized and produced by applying combinatorial rules. However, through maturation, the declarative system becomes dominant later in life. As such, pure combinatorial forms in a non-native language will nevertheless acquire a whole-word representation. They are not handled by the procedural system, hence eliminating morphological priming in non-native languages.

Support for this explanation remains scarce. Neubauer and Clahsen (2009) did observe priming for non-native irregular inflections. It is difficult to see how the proposed maturation would differentially affect the processing of regular and irregular inflections. The implications of this view for derived words also remain unclear. The study of Silva and Clahsen (2008) did not show a similar *elimination* of stem priming in L2 with suffix-derived primes (*boldness-bold*) as was observed with past-participle primes (*boiled-boil*). There was nevertheless a noticeable reduction compared to the effects in L1. The authors concluded that “L2 learners employ morphologically structured representations for derived word forms during processing, albeit less effectively than native speakers” (p. 257). Hence, there appears to be some evidence for a general reduction in the use of morphology in L2 word recognition. It is difficult to explain that morphological effects are absent with inflection, but somewhat present with derivation, if one assumes a common origin for both (e.g., Bybee, 1985; Raveh & Rueckl, 2000). Results in L1 commonly show stronger morphemic activations with inflections than derivations (e.g., Feldman, 1994; Schriefers, Frederici & Graetz, 1992, see also Silva & Clahsen, 2008). Hence, one would expect the effects to be eliminated first in the case of derivations. The data seem to reveal the opposite pattern. Clahsen, Sonnenstuhl and Blevins (2003; see also Silva & Clahsen, 2008) have proposed an account that “treats productive inflection and derivation both as the result of combinatorial operations but associates productive derivation (like irregularly inflected items) with stored entries” (p. 24). In this approach, derivations are stored as whole-words with reference to their internal morphological structure, whereas inflections do not have a whole-word representation. Inflections are produced and recognized purely on the basis of stored rules. Even within this model, where morphological effects for inflections and derivations arise from qualitatively different mechanisms, it is not straightforward to explain the current data pattern. Following the declarative/procedural model, only the use of the rule-based route should be reduced in L2, which predicts no reduction of morphological effects in the case of derivations.

As Clahsen et al. (2010) also note, current data about L2 morphological processing is very limited. Silva and Clahsen (2008) only considered suffix-derived primes with the suffixes *–ness* and *–ity*, considerably limiting the scope of these findings. A recent study by Feldman, Kostić, Basnight-Brown, Filipović-Đurđević and Pastizzo (2009) also sheds a different light on the findings with inflections. In line with Silva and Clahsen (2008) and Neubauer and Clahsen (2009), late bilinguals only showed facilitated stem recognition in L2 with irregular past participle masked primes (Experiment 1; *taught-teach*). However, only the least proficient bilinguals showed this pattern and it was not found for participles that preserve stem letter length (*fell-fall*). Across different proficiency levels, bilinguals displayed highly similar effects as compared to native participants, at least when facilitation was assessed relative to an unrelated baseline (*billed-bill* vs. *careful-bill*). Relative to an orthographic control condition (*billion-bill*), the lowest proficient bilinguals showed no evidence for morphological effects, whereas the highest proficient participants only showed significant facilitation with regular past participle primes (*billed-bill*). Feldman et al. suggested that at relatively low L2 proficiency levels, there is a greater reliance on word forms and an impaired access to semantics. In some way, the undistinguishable masked orthographic and morphological effects could be interpreted by the declarative/procedural model, as showing an over-reliance on the declarative memory system, and poor compositional strategies, or under-reliance on the procedural memory system. However, the results for highly proficient bilinguals are at odds with to those obtained by Neubauer and Clahsen (2009).

It is thus far from clear what differences really do and do not exist between L1 and L2 morphological processing, and how these potential disparities might depend on the linguistic proficiency level of non-native speakers of a language. In this context, the present study sets out to provide a detailed test of the differences in the processing of suffix-derivations in L1 and L2. We adopt a large-scale masked morphological priming design in English (25 items per condition) with a group of native English speaking participants (n=65) and two groups of relatively proficient L2 participants: Spanish-English bilinguals (n=66) and Dutch-English bilinguals (n=65). As can be seen in Table 3, the two groups rated their L2 proficiency differently with respect to age of acquisition, age of relative proficiency, comprehension skill, reading skill and exposure. We can thus assess how well our conclusions generalize across bilinguals with different language backgrounds. Like in previous studies, we consider stem priming in the lexical decision task with semantically transparent and opaque derivational suffixed primes relative to a condition with form control items (cf. Rastle & Davis, 2008). We do not limit ourselves to any particular set of suffixes as opposed to those used in the study of Silva and Clahsen (2008). The comparison between semantically transparent and opaque items allows us to assess whether any L1-L2 differences interact with semantic transparency. Finally, the comparison with pure form priming allows us to test whether any reduction in the size morphological priming is accompanied by a stronger reliance on orthographic representations or on word forms in a non-native language, which would support the hypothesis of Feldman et al. (2009).

Experiment 1

Experiment 1 serves as the baseline for our study of L2 morphological processing. Native English speakers were tested with the English materials. We expected to find the general pattern found in the literature (cf. Rastle & Davis, 2008; Feldman et al., 2009): greater priming for transparent and opaque items relative to form controls and a (potentially weak) advantage of transparent over opaque primes.

Method

Participants

Sixty-five native speakers of English participated in Experiment 1. They were recruited from the Hampshire College community in the USA. Their age ranged from 18 to 32, with a mean of 22. There were 39 females and 26 males in the sample. Each participant reported having normal or corrected-to-normal vision.

Materials and Design

Words. 150 English words served as word targets in the experiment. Each target was paired with two primes: a related and an unrelated word. The pairs were selected from the large collection of similar experiments now available in the literature. Unrelated primes were unrelated to the target in both form and meaning. They were always suffixed words matched to the related primes on length and frequency. Related primes were either a transparent suffixed morphological relative of the target (e.g., *viewer-view*; n=50), a word that could be parsed into the target plus a suffix (e.g., *corner-corn*; n=50) or a word that could be parsed into the target plus a non-morphemic word ending (e.g., *freeze-free*; n=50). Relevant distributional characteristics of the related primes and targets are available in Table 1. There was always a maximal initial letter overlap between related primes and targets, i.e., a target was always fully embedded at the beginning of its related prime. We tested the manipulation of semantic transparency with Latent Semantic Analysis (LSA; Landauer & Dumais, 1997; http://lsa.colorado.edu). There was no significant difference between the LSA score for related prime-target pairs in the form and the opaque condition (.10 versus .09 respectively; *Welch* $t < 1$), whereas there was a significantly larger score in the transparent condition (.39; *Welch* t (62.80) = 7.69, $p < .001$ compared to the opaque condition and *Welch* t (62.28) = 7.60, $p < .001$ compared to the form condition). All word stimuli are available at http://users.ugent.be/~kdiepend/supp/bilingmorphstim.txt. We created two balanced experimental lists by rotating *Relatedness* within the levels of *Prime Type* using a Latin square design. These lists were distributed evenly across the participants.

Table 1. Length and frequency characteristics of the related primes and targets. Frequencies (log_{10} scale) were obtained from the CELEX English lexical database (Baayen, Piepenbrock & Gulikers, 1995). Token frequencies were computed per million. *Welch t* is provided for significant condition differences.

		Transparent	Opaque	Form	*Transparent-Opaque*	*Transparent-Form*	*Opaque-Form*
Primes	Number of characters	6.56	6.50	6.44			
	Surface frequency	0.74	0.82	0.73			
	Suffix family frequency	3.45	3.22	n.a.	$t(83.66) = 2.12, p < .05$		
	Suffix family size	2.87	2.63	n.a.	$t(89.27) = 2.22, p < .05$		
	Suffix form frequency	4.09	4.01	3.02		$t(70.44) = 5.92, p < .001$	$t(73.11) = 5.41, p < .001$
	Boundary frequency	4.08	4.14	3.91			
	Neighborhood size	6.62	7.80	9.78			
	Neighborhood frequency	-0.28	0.03	0.20			
Targets	Number of characters	4.30	4.16	4.09			
	Surface frequency	1.46	1.57	1.42			
	Family frequency	1.98	1.93	1.76			
	Family size	1.18	1.11	0.95		$t(94.23) = 2.79, p < 0.05$	
	Neighborhood size	31.96	33.60	43.16			
	Neighborhood frequency	2.01	2.24	2.04			

Nonwords. Each word list was coupled with the same nonword list, consisting of 150 nonword targets. The targets were constructed by altering one or two letters of existing English words, while making sure that the resulting strings were regularly pronounceable in English and that their length was similar to that of the word targets. Half of the nonword targets were paired with an orthographically related suffixed word (*purely-gure*), while the other half were paired with an unrelated suffixed word (*penalty-murf*). These primes were drawn from the same frequency range as the word target primes and also had a similar length.

Procedure

The experiment was controlled by the DMDX software package (Forster & Forster, 2003). All visual stimuli were presented in 12pt fixed width font (Courier New). Participants were instructed to focus on the middle of the screen at the beginning of each trial. A trial began with the central presentation of a forward mask (a row of hash signs). After 500ms the mask disappeared and the prime was presented for 53ms (4 refresh cycles of a 75Hz CRT monitor). The prime was immediately followed by the target in upper case, which stayed on the screen until the participant pressed one of the two response buttons or after a deadline of 2500ms. Reaction times were recorded using a two-button response box. Participants were asked to decide as quickly and accurately as possible whether or not the target corresponded to an existing English word by pressing the corresponding response button. The choice of buttons for word and nonword responses was left up to preference. Targets were presented in a different random order for each participant. The experiment started with four practice trials.

Results and Discussion

We analyzed the correct RTs and accuracies (95%) for word targets with linear mixed-effects (lme) models with participants and items as crossed random variables (cf. Baayen, Davidson & Bates, 2008) as implemented in the lme4 package (Bates & Maechler, 2009) in R (R Development Core Team, 2009). For accuracies, we used a generalized lme with logistic link function. There was no averaging of the data prior to the analyses. We inverse-transformed all RTs (i.e., -1000/RT) to reduce the positive skew in the distributions. Transformed RTs smaller than Q_1-3∗IQR or larger than Q_3+3∗IQR, by either participants or items (0.1%), were excluded from the analyses (with Q_1 the first quartile, Q_3 the third quartile, and IQR the interquartile range). Missing RTs were replaced on a by-participant basis using Multiple Iterative Regression Imputation (as implemented in the mi package; Gelman, Hill, Yajima, Su & Pittau, 2009) (footnote 3). Condition means are presented in Table 2. Significance values were obtained through the Markov Chain Monte Carlo (MCMC) sampling method (sample size = 10,000) for the RT data. In each analysis, we first look at the interaction of *Relatedness* and *Prime Type* in the ANOVA (footnote 4). If significant, we evaluate individual priming effects by checking the model's estimates for the contrast-coded levels of our design (footnote 5). If not significant, we eliminated *Prime Type* from the model to test the overall effect of *Relatedness*. Model estimates, along with p-values and MCMC-based confidence intervals are available at http://users.ugent.be/~kdiepend/supp/bilingmorphlmer.pdf.

Table 2. Mean reaction times and accuracy proportions per condition in Experiment 1.

Prime Type	Relatedness	*RT*	*Accuracy*
Form	related	636	0.94
	unrelated	637	0.93
	effect	*1*	*-0.01*
Opaque	related	612	0.95
	unrelated	627	0.94
	effect	*15*	*-0.01*
Transparent	related	592	0.97
	unrelated	628	0.95
	effect	*36*	*-0.02*

Relatedness interacted significantly with *Prime Type* ($F(2, 9744) = 8.06$, $p < .001$) in the RT data. As can be seen in Table 3, priming effects were largest in the transparent condition (36ms; $t = 7.51$, $p < .001$) and smallest in the form condition (1ms; $t = 1.93$, $p = .07$; interaction: $t = 3.94$, $p < .001$). Opaque primes elicited a priming effect in between that of the transparent and form items (15ms; $t = 3.81$, $p < .001$). However, only the difference with the transparent condition reached significance ($t = 2.62$, $p < .05$ versus $t = 1.32$, $p = .18$).

The accuracy analysis showed no significant interaction of *Relatedness* and *Prime Type*. There was nevertheless a significant overall effect of *Relatedness* ($z(9747) = 2.43$, $p < .02$; 1% more accuracy following related primes).

The pattern in Experiment 1 converges with earlier masked morphological priming results in L1 (cf., Rastle & Davis, 2008; Feldman et al., 2009; Davis & Rastle, 2010). We find significant priming for both transparent and opaque items, but not for form controls. The effect in the opaque condition is located in the middle of the form and transparent condition effects (cf. Table 2). The presence of significantly larger facilitation for transparent items is in line with the meta-analyses in Feldman et al. (2009) and Davis and Rastle (2010). Our statistical tests nevertheless diverge from earlier studies regarding the advantage of opaque items over form items, as it fails significance ($p = .18$). Strictly speaking, this means that we do not find sufficient (i.e. $p < .05$) evidence for a morphological effect with opaque items. It is important to consider normal between-experiment variability here, however. Inspecting the literature overview of Rastle and Davis (2008), the opaque-form difference in Experiment 1 (14ms) is clearly not an outlier (median = 16, Q_1 = 12, Q_3 = 18, mean = 20, sd = 20). The distance between the present difference and the sample median and mean corresponds to approximately one third of the IQR (6ms) and the sd, respectively. The transparent-opaque difference (21ms) is relatively large, but the distribution of this difference (median = 4, Q_1 = -2, Q_3 = 13, mean = 6, sd = 11) indicates that it is safest to conclude that the pattern in Experiment 1 fits the graded pattern in the recent meta-analyses (e.g., median+2.5*IQR = 42ms; mean+2.5*sd = 32ms), showing significant morphological effects with both transparent and opaque items together with a significant advantage for transparent items. We thus argue that Experiment 1 provides an adequate baseline for comparing masked morphological priming across L1 and L2. The first comparison is with Spanish participants with English as a second language. We return to the issue of between-experiment variability when performing a joint analysis of our Experiment 1, 2 and 3.

Experiment 2

Method

Participants

Sixty-six native speakers of Spanish participated in Experiment 2. They were undergraduate students following different majors at the University of the Basque Country in Donostia, Spain. At the moment of being tested, they were all enrolled in the national Language School (Escuela Oficial de Idiomas), where they attended regularly the final level courses of English as a second language. As can be seen in Table 3, their mean proficiency level was relatively high. They all reported having normal or corrected-to-normal vision.

Table 3. Characteristics of the bilingual participants in Experiment 2 and 3.

	Spanish-English	Dutch-English	*Statistic*	*p*
Age	27.02	19.49	W* = 3686	0.00
Female/Male	39/27	44/21	X^2 = 0.71	0.40
Age of acquisition	7.80	11.92	W = 581	0.00
Age of relative proficiency	19.05	16.55	W = 2819	0.00
Overall proficiency	7.35	7.34	W = 2089	0.79
Overall comfort	7.26	6.85	W = 2449	0.15
Speaking skill	7.21	7.08	W = 2207	0.77
Comprehension skill	7.57	8.30	W = 1443	0.00
Reading skill	7.92	7.58	W = 2614	0.03
Exposure (hours per week)	11.99	7.18	W = 2968	0.00

* Wilcoxon rank sum test with continuity correction

All other methodological aspects were kept identical to Experiment 1.

Results and Discussion

We cleaned and analyzed the data in the same way as was done for Experiment 1. Additionally, we tested the interaction of *Relatedness*, *Prime Type* and *L1* (English - Spanish) in the joint results of Experiment 1 and 2. Trimming led to the removal of 14 individual RTs (0.2% of the data). Condition means are shown in Table 4.

Table 4. Mean reaction times and accuracy proportions per condition in Experiment 2.

Prime Type	Relatedness	*RT*	*Accuracy*
Form	related	703	0.88
	unrelated	717	0.85
	effect	*14*	*-0.02*
Opaque	related	683	0.92
	unrelated	708	0.90
	effect	*25*	*-0.02*
Transparent	related	654	0.97
	unrelated	689	0.95
	effect	*35*	*-0.02*

The RT analysis showed a significant interaction of *Relatedness* and *Prime Type* ($F(2, 9894) = 5.13$, $p < .01$). Priming was again largest in the transparent condition (35ms; $t = 9.16$, $p < .001$) and smallest in the form condition (14ms; $t = 4.65$, $p < .001$; interaction: $t = 3.19$, $p < .01$). The opaque condition showed an intermediate effect (25ms; $t = 7.22$, $p < .01$). The individual comparisons with the transparent and form condition failed to reach significance, however ($t = 1.38$, $p = .17$ and $t = 1.82$, $p = .09$, respectively). The joint analysis of Experiment 1 and 2 showed no interactions with *L1*. The individual effect of *L1* was nevertheless significant ($F(1, 19643) = 28.52$, $p < .001$; the native participants were on average 71ms faster).

While the *Relatedness x Prime Type* interaction was not significant in the accuracy analysis, the overall *Relatedness* effect was significant ($z(9897) = 3.25$, $p < .01$; 2% higher accuracy following related primes). The joint analysis showed no interaction of this effect with *L1*. There was an interaction between *L1* and *Prime Type* ($X^2(2) = 37.57$, $p < .001$), showing significantly higher accuracies in Experiment 1 only for targets in the opaque and form condition (4% more; $z(19641) = 3.79$, $p < .001$; and 7% more; $z(19641) = 5.62$, $p < .001$, respectively).

The statistical analysis indicates that even though participants were processing their second language, a similar pattern to that of Experiment 1 arose: large facilitation for transparent items, significantly smaller facilitation in the form condition and an intermediate effect for opaque items. Although the transparent-opaque and opaque-form comparisons failed to reach significance ($p = .16$ and $p = .07$), the numerical differences (10ms and 11ms) are again not surprising, given the distributions in the recent meta-analyses (Rastle & Davis, 2008; Feldman et al., 2009; Davis and Rastle, 2010). The results of Experiment 2 do not follow the findings of Silva and Clahsen (2008) with *–ness* and *–ity* derivations, but instead indicate that non-native bilinguals adopt the same strategy as native speakers in processing derivations.

If we compare the separate analyses of Experiment 1 and 2, it nevertheless appears that, unlike natives, the Spanish-English bilinguals show clear form priming (14 vs. 1ms). At the same time, the transparency effect seems somewhat smaller (i.e., 10ms instead of 21ms). This pattern is in line with the conclusions of Feldman et al. (2009) in the context of inflections. Indeed, it suggests a greater reliance on form processing in L2. This could result from slower prime processing. In the model proposed by Taft and Nguyen-Hoan (2010), for instance, activations flow from graphemic units to morpho-orthographic units, to lemma units (and back). When primes are processed more slowly, the relative contribution of graphemic overlap and morpho-orthographic structure to target facilitation should become larger, while the contribution of morpho-semantic structure becomes smaller. We need to remain cautious about these interpretations, however, as the apparent differences with L1 are not supported statistically and undoubtedly fall within the between-experiment variability observed in the L1 literature.

In Experiment 3, we test a group of Dutch-English participants with relatively high English proficiency, allowing us to check the generality of our conclusions thus far. If bilinguals adopt the same morphological processing strategy as natives, we should observe a similar pattern as in Experiment 1. As can be seen in Table 1, the participants in Experiment 3 started learning English at a later age and report lower reading skills and less exposure. Despite this, they report an earlier age for relative proficiency and better comprehension skills (footnote 6). If significant differences with Experiment 1 emerge, we will need to interpret them along these proficiency characteristics.

Experiment 3

Method

Participants

Sixty-five native speakers of Dutch participated in Experiment 3. They were recruited from the undergraduate student population of the faculty of Psychology and Educational Sciences at Ghent University. All participants graduated from secondary schools where English is taught mandatorily as a second language from the age of 12-13 onwards. Their proficiency characteristics are listed in Table 3. They all reported having normal or corrected-to-normal vision.

All other methodological aspects were kept identical to the previous experiments.

Results and Discussion

We cleaned and analyzed the data in the same way as was done for Experiment 2. Trimming led to the removal of 3 individual RTs (0.03% of the data). Condition means are shown in Table 5.

Table 5. Mean reaction times and accuracy proportions per condition in Experiment 3.

Prime Type	Relatedness	*RT*	*Accuracy*
Form	related	744	0.85
	unrelated	758	0.86
	effect	*14*	*0.01*
Opaque	related	709	0.91
	unrelated	735	0.88
	effect	*26*	*-0.03*
Transparent	related	699	0.94
	unrelated	734	0.92
	effect	*35*	*-0.02*

The *Relatedness* x *Prime Type* interaction was again significant for the RT data ($F(2, 9744) = 7.35$, $p < .001$). As before, priming was largest in the transparent condition (35ms; $t = 8.63$, $p < .001$), smallest in the form condition (14ms; $t = 3.73$, $p < .001$; interaction: $t = 3.47$, $p < .001$) and intermediate in the opaque condition (26ms; $t = 4.17$, $p < .001$). The individual comparison of the opaque effect with the transparent and form condition was only significant in the former case, however ($t = 3.15$, $p < .01$ and $t < 1$, respectively). In the joint analysis of Experiment 1 and 3, there were no interactions with *L1*. The individual effect of *L1* was again highly significant ($F(1, 19493) = 38.10$, $p < .001$; the native participants were on average 108ms faster).

Unlike in the previous experiments, there was a significant interaction of *Relatedness* and *Prime Type* in the accuracy analysis ($X^2(2) = 10.74$, $p < .01$). There was 2% more accuracy following related primes in the transparent condition ($z(9742) = 2.59$, $p < .05$) and 3% more in the opaque condition ($z(9742) = 3.51$, $p < .01$). There was no significant difference between these effects and both differed significantly from the form condition ($z(9742) = 2.38$, $p < .05$ and $z(9742) = 3.01$, $p < .01$, respectively). The joint analysis with Experiment 1 showed no significant interactions with *L1*. The individual effect was nevertheless significant ($z(19493) = 6.61$, $p < .001$; 6% more accuracy for natives).

Experiment 3 again indicates that (late) bilinguals adopt a morphological processing in their L2 strategy similar to that of native speakers of that language. We replicate a graded priming pattern, with largest facilitation for transparent items, smallest for form items and an intermediate effect with opaque items. There were no significant differences with the outcome for natives, again contrary to the findings of Silva and Clahsen (2008). The condition means are quasi-identical to Experiment 2 (cf. Table 4 and 5), which implies that, compared to Experiment 1, form priming is more evident and the semantic transparency effect is somewhat smaller. We again need to remain cautious about this pattern, however. In the final part of our study we take advantage of the similarity of the two bilingual data sets and merge them together in order to compare them with the monolingual data. This analysis will determine our final conclusion about the influence of L2 processing in masked morphological priming.

The joint analysis also serves to establish the graded nature of priming. Up to now, the individual comparisons of the conditions did not always reach significance. Increasing statistical power should help to bring clarity in this respect. Finally, to help our theoretical discussion, we take advantage of the full power of our data to investigate the role of a number of important item characteristics.

For our primes we entered the covariates *Stem Family Size* and *Frequency*, *Suffix Family Size* and *Frequency*, *Suffix Form Frequency*, *Boundary Frequency*, *Semantic Transparency*, *Prime Neighborhood Size* and *Frequency* and *Word Form Frequency* as measured in the related condition. The stem family comprises all words that are derived from a given stem (e.g., view, viewer, viewpoint, etc.), whereas the suffix family comprises all words that contain a given suffix (viewer, baker, header, etc.). We calculated both the size and summed (lemma) frequencies of the family members in each set. A positive effect of these (correlated) morpheme frequencies on the magnitude of priming serves as a general marker for specialized morphemic unit involvement. The suffix form frequency represents the summed frequency of all word forms that carry the suffix as an orthographic word ending (e.g., viewer, corner, later, pier, etc.). This measure probes the reliance of priming on the presence of highly recurrent orthographic unit at the word ending. The boundary frequency counts the frequency of the bigram at the (pseudo-) morpheme boundary (e.g., *viewer:we*, *corner:ne*, *freeze:ez*). A negative effect on priming of this measure would support the reliance on local sublexical regularities (cf. Seidenberg, 1987; Rastle et al., 2004). LSA scores for the related prime-target pairs provide an opportunity to measure the effect of semantic transparency continuously. Positive effects would confirm the conditioning of priming by morpho-semantic characteristics. The lexical neighborhood was defined as all words located at an orthographic edit distance of exactly one. Primes with large and/or high frequency orthographic neighborhoods are potentially less effective due to an increased competition at the level of lexical form representations. If the observed transparency effects indeed have a lexical origin, we might especially observe such a negative effect for priming with transparent items. Finally, the word form frequency of our related primes serves as a diagnostic for whole-word processing. If transparency effects rely on such processing, this could manifest itself as a positive correlation with priming for transparent items and potentially also a negative effect in the case of opaque primes. The latter is not necessarily the case, since at least within some time window morphological effects for opaque items and semantic transparency effects appear to co-exist. This is in line with the idea that the lexical representation of the opaque suffixed prime does not actively inhibit the lexical representation of the (pseudo-)stem (e.g., Taft & Nguyen-Hoan, 2010).

Apart from these prime characteristics, we investigated whether priming was affected by the frequency and orthographic neighborhood characteristics of our targets (i.e., *Target Word Frequency*, *Target Neighborhood Size* and *Frequency*). The frequency of a target clearly stands out as the best predictor of lexical decision performance (e.g., Balota, Cortese, Sergent-Marshall, Spieler & Yap, 2004; Keuleers, Diependaele & Brysbaert, 2010). More frequent targets are responded to faster, which potentially makes them less susceptible to a priming manipulation. Hence, we might observe a general negative correlation between target frequency and facilitation. The orthographic neighborhood size and frequency of our targets could also result in a negative correlation with priming. The reason is that representations of targets are more difficult to activate within large and/or high frequency neighborhoods, given a stronger amount of form-based competition.

Joint Analysis

We merged the data of our 3 experiments. The factor *L1* was now coded as native (Experiment 1) vs. non-native (Experiment 2 & 3).

Results and Discussion

L1 x Relatedness x Prime Type

There were no interactions with L1 in both the RT and accuracy data. There was of course a large individual effect; RTs were 89ms smaller for natives and accuracies 5% higher ($F(1, 29393) = 49.01$, $p < .001$ and ($X^2(1) = 37.86$, $p < .001$)). Based on this outcome, our final conclusion is that there is no qualitative difference in processing semantically transparent and opaque complex words in English for L1 and L2 users. This does not exclude significant differences at lower proficiency levels, but it does mean that eventually, with increasing skills, these differences disappear.

Relatedness x Prime Type

The interaction of *Relatedness* and *Prime Type* ($F(2, 29393) = 19.45$, $p < .001$) showed that the transparent priming effect (36ms; $t = 14.28$, $p < .001$) was significantly larger than both the opaque effect (22ms; $t = 8.42$, $p < .001$; interaction: $t = 4.15$, $p < .001$) and form effect (10ms; $t = 5,65$ $p < .001$; interaction: $t = 6.11$, $p < .001$) and that the opaque effect was in turn significantly larger than the form effect ($t = 1.96$, $p < .05$). We therefore conclude that we are indeed dealing with a graded pattern of priming across our three conditions, reflecting morphological effects with both transparent and opaque primes together with a positive influence of semantic transparency.

The *Relatedness x Prime Type* interaction was also significant in the accuracy data ($X^2(2) = 8.01$, $p < .05$). There was a 2% higher accuracy following related primes in the transparent condition ($z(29391) = 4.12$, $p < .001$) and 2% more in the opaque condition ($z(29391) = 3.70$, $p < .001$). There was no significant difference between these effects and both differed significantly from the form condition, although only marginally so for opaque items ($z(29391) = 2.64$, $p < .05$ and $z(29391) = 1.96$, $p = .07$, respectively). The absence of a transparency effect in the accuracy data should be treated with caution. Overall, accuracies were quite high, making it difficult to pick up condition differences.

Item characteristics

All covariates were log-transformed and centered to their mean ($\kappa = 9.65$; Belsley, Kuh, & Welsch, 1980). We conducted separate analyses for each condition (transparent, opaque, form). The first reason is that the morpheme frequencies for suffixes are not available in the form condition. A second reason is that some of the covariates had different values across the three conditions (cf. Table 1). *Suffix Form Frequency* was lower in the form condition than in the transparent and opaque condition. *Semantic Transparency* was larger in the transparent condition. These differences are of course a natural consequence of our design. Two additional results were that *Stem Family Size* was larger for transparent than for form items and *Suffix Family Size* and *Frequency* were higher for transparent items. Considering the observed priming differences, these 5 unmatched variables are likely to interact with *Relatedness* in a joint analysis. We need to ascertain, however, that such interactions are present at the level of our items and not (merely) at the level of our conditions. Hence, we conduct three separate analyses on the joint data, where we test interactions between our covariates and *Relatedness* for the transparent, opaque and form condition, respectively. In each analysis, we entered covariates in interaction with *Relatedness* following a stepwise forward selection procedure.

For the RT data in the transparent condition, *Relatedness* interacted significantly with *Suffix Form Frequency* ($t = 2.71$, $p < .01$), *Boundary Frequency* ($t = 2.45$, $p < .05$), and *Prime Frequency* ($t = 2.22$, $p < .05$). Whereas *Suffix Form Frequency* and *Prime Frequency* showed a positive effect on priming, the effect of *Boundary Frequency* was negative. For opaque items, only *Target Neighborhood Frequency* interacted with *Relatedness* ($t = 2.82$, $p < .01$). The sign of this effect was negative: priming was smaller for targets with a high frequency neighborhood. There were no significant interactions with *Relatedness* in the form condition. This was also the case in each of the three accuracy analyses.

The results of our final analyses show an interesting different pattern of covariance across our three priming conditions. Only in the transparent condition, priming increased with increasing prime frequency. This supports the existence of positive lexical links between transparent suffixed words (primes) and their stem (targets). Such links could be explicit, as in the models of Taft and Nguyen-Hoan (2010) and Diependaele et al. (2005, 2009), for instance, but equally well implicit. An example of the latter possibility is lateral inhibitory links between lexical items that are less strong in the case of transparent morphological relatives. Our covariance analysis also nicely illustrates the role of sublexical variables. The more frequent the suffix, as an orthographic string, and the less frequent the morpheme boundary bigram, the more priming we observe for transparent items. This clearly provides support for a morpho-orthographic system that detects morphemes on the basis of the distinct distributional properties of letters and/or phonemes within morphologically complex words (cf. Rastle et al., 2004). The fact that this effect was only observed in the transparent condition could be related to the presence of a negative component in the opaque condition, i.e., an inhibitory target neighborhood frequency effect. The latter effect shows that although sublexical features give rise to morphological effects with opaque primes, these effects nevertheless show traces of lexical processing. It thus appears that morpho-orthographic activations are rapidly manifested at lexical levels. A final point regarding the covariance results is that some readers might be tempted to interpret the absence of effects of stem family size and continuous semantic transparency (LSA) as evidence against any semantic or morpho-semantic influence. Null-effects can never be taken as "negative evidence", however. Diependaele et al. (2009), for instance, did report a significant correlation of masked morphological priming with semantic transparency. They arguably used a more fine-grained measure, based on a large-scale rating study.

General Discussion

The present study investigated the processing of suffix-derivations in first and second language visual word recognition. We compared masked morphological priming in English across a group of native English, Spanish and Dutch speaking participants. The design followed that of many recent monolingual studies, including stem priming with semantically transparent suffixed primes (e.g., *viewer-view*), semantically opaque (including pseudo-) suffixed primes (e.g., *corner-corn*) and stem-embedded form control primes (e.g., *freeze-free*). Following the work of H. Clahsen, we were specifically interested in whether the results would show that bilinguals who reach L2 proficiency relatively late make less use of morphological information in the processing of suffixed derivations. Contrary to Clahsen et al.'s conclusions, similar priming patterns emerged for the native English participants and the two groups of bilinguals. The actual pattern we observe fits well with recent meta-analyses of the L1 masked morphological priming literature (Feldman et al., 2009; Davis & Rastle, 2010). Priming was largest with transparent primes, smallest with form primes and intermediate with opaque primes.

Native and non-native morphological processing

Our results diverge from Silva and Clahsen (2008), who found evidence for reduced morphological priming with suffix derivations in L2. We believe this is most likely due to a number of methodological shortcomings. First, Silva and Clahsen only used a limited number of items. Throughout the study, there were only 6 to 7 items per condition. They also only tested derivations with the suffixes *-ness* and *-ity*. Such limitations clearly allow questioning the generality of their findings. In the present experiments there were 25 items per condition with a range of different derivational suffixes. A further shortcoming is that none of the Clahsen et al. studies took measures to deal with the high error rates (i.e., missing data) that are typically present for bilingual participants. Lexical decision errors are far from random, which excludes simple mean replacement as a valuable technique to deal with missing values (footnote 7). In the present study we used state of the art techniques to deal with this (general) problem in L2 research (cf. footnote 3). It is also important to note that the present conclusion that there exist no qualitative or quantitative differences in the processing of suffixed derivations in L1 and L2 does not exclude that such differences do arise at earlier stages in L2 acquisition. The difference with Silva and Clahsen (2008) could also be considered from this perspective. Indeed, while our participants started to learn English at about 8 and 12 (and possibly much earlier via audio-visual media), the participants in the Clahsen et al. studies were only initially exposed to their L2

(English/German) at the age of 14 (on average). Furthermore, an account where L2 processing gradually approaches the functional architecture for natives can also predict that the speed by which this occurs is a positive function of the linguistic distance between an individual's L1 and L2. In this respect, it is potentially important that Silva and Clahsen's study included Chinese-English and Japanese-English participants. Over and above the script change between those language combinations, it is noteworthy that the distance between Spanish and English and Dutch and English is considerably smaller (Chiswick & Miller, 2004; Serva & Petroni, 2008).

It can be argued that the present conclusion, i.e., that morphology plays a similar role in the processing of suffix derivations in L1 and L2, has in fact nothing to say about the processing of inflections in L2. Indeed, comparing the present data with those of Neubauer and Clahsen (2009), for instance, one could try to explain the difference via a model where derivations and inflections are treated in a fundamentally different way (e.g., Clahsen et al., 2003). Recall that Neubauer and Clahsen (2009) found that stem priming with regular past participles (*worked-work*) was eliminated in L2, while priming with irregular forms remained stable (*taught-teach*). According to Clahsen et al. (2003), in L1 derivations as well as irregular inflections are stored as full forms in memory with reference to their morphological constituents. Regular inflections in L1, on the contrary, are not stored. They are produced and recognized by applying an online grammatical rule. This online computation of inflected forms and the retrieval of all other forms lie at the heart of the so-called dual-mechanism theory (e.g. Pinker, 1999). According to this view, the present findings have nothing to say about the domain of regular inflection. The declarative/procedural model (Ullman, 2004, 2005) states that L2 word recognition primarily relies on the direct lexical retrieval route in the dual-mechanism view, and not on the online segmentation route. It is precisely the direct route where morphological effects with derivations arise according to Clahsen et al. (2003). Hence, it is not surprising that we observe similar effects in L1 and L2, while Neubauer and Clahsen (2009) find a marked difference for regular inflections. Although this line of reasoning can be followed for the transparent items in our study, it arguably cannot for the morphological effects with opaque items. Our results with opaque items specifically show the same evidence for morpho-orthographic processing in L2 and L1. Such processing is typically conceptualized as an *online* sublexical morphological segmentation mechanism that applies to both derivations and regular inflections. Within the above line of reasoning it would thus appear that while the online morphological segmentation of regular inflections is heavily reduced and potentially nonexistent in L2 processing, it remains unaffected in the case of derivations. In other words, to explain the present results and those of Neubauer and Clahsen (2009) within the dual-mechanism view, one needs to assume that the sublexical segmentation of regular inflections and derivations occurs via separate mechanisms, which are also differentially affected by maturation. To our knowledge, there is no a priori reason for such an assumption. Therefore, it seems that the present data limit the scope of the declarative/procedural approach to L1 and L2 processing and its projection onto dual-mechanism theory. Future research needs to address this issue thoroughly. It is important to note that, in research on morphological productivity, single-mechanism computational models have been very successful at generating patterns of results that were regarded as evidence for a dual mechanism (e.g., Albright & Hayes, 2003; Chandler, 2010; Hahn & Nakisa, 2000; Keuleers et al., 2007; Keuleers & Daelemans, 2007). Recall also that the priming results of Clahsen et al. with respect to inflections have already been challenged by Feldman et al. (2009).

Our general conclusion that the processing of derivations in a given language takes on a similar functional shape, regardless of nativeness is in fact not an isolated finding in the literature. It is also supported by the work of Frost, Kugler, Deutsch and Forster (2005). With both Hebrew-English as well as English-Hebrew bilinguals, these authors found reliable masked form priming (e.g., *cat-hat*) in English, but not in Hebrew. Instead, the Hebrew results showed masked morphological priming, irrespective of semantic transparency. This pattern (i.e., form and morphological priming in English versus mere morphological priming in Hebrew) is fully compatible with the monolingual studies in both languages. Frost et al. conclude that the form similarities that define lexical competition among words are primarily determined by language-specific distributional properties. It is important to note that such a conclusion does not imply that L1 and L2 lexical representations have a different functional location. Indeed, many empirical results support that L1 and L2 processing occurs within the same architectural environment. This explains, for instance, why bilinguals are faster to recognize words whose form and meaning are highly similar across the languages they know (e.g., *appel-apple* for Dutch-English bilinguals; e.g., Dijkstra, Grainger & Van Heuven, 1999; Duñabeitia, Perea, & Carreiras, 2010; Van Hell & Dijkstra, 2002; Van Assche, Duyck, Hartsuiker & Diependaele, 2009). Furthermore, there is ample evidence that orthographic and phonological encoding occurs language-independently and that the results interact with each other (e.g., Van Heuven, Schriefers, Dijkstra & Hagoort, 2008; Dimitropoulou, Duñabeitia & Carreiras, 2010). Known languages are thus not represented, nor processed independently from each other. Several models of bilingual word processing incorporate this idea. The Bilingual Interactive Activation model (BIA; Dijkstra, Van Heuven & Grainger, 1998; Van Heuven, Dijkstra, & Grainger, 1998) and its more recent version, the BIA+ (Dijkstra & Van Heuven, 2002), for instance, assume that an input word simultaneously activates many related words in a language-independent manner. The present results simply imply that despite the integrated nature, L1 and L2 processing dynamics evolve to a state wherein they are primarily determined by their own linguistic properties. The exact same conclusion was drawn by Lemhöfer, Dijkstra, Schriefers, Baayen, Grainger and Zwitserlood (2008). They conducted a large-scale regression study where English, Dutch, French and German participants completed the same English word recognition task. The results showed that only predictors specific to English language accounted for significant proportions of the variance, the only exception being cognate status.

The role of form and meaning in morphological processing

The graded nature of the priming pattern in our data, where priming correlated with morphological (stem+suffix) surface structure and semantic transparency, further demonstrates that fast morphological activation is conditioned by both form and meaning characteristics. This can be accounted for in different ways, as illustrated in Figure 1. According to the first general architecture, there is a mandatory sublexical segmentation stage leading to the activation of morphemic representations regardless of semantic transparency. Positive links between the lexical representations of transparent relatives result in stronger morphemic activations for transparent derivations later on during processing. There are many possibilities for conceptualizing these links explicitly or implicitly. As we already discussed in the introduction, this view can account for the simultaneous observations of semantic transparency effects and morphological effects for opaque items with short prime durations if the assumption is made that there is a (relatively) passive decay of morpho-orthographic activations when they are not further supported (e.g., Taft & Nguyen-Hoan, 2010). In principle, this first approach predicts a moment in time where morphemic activations are *purely* morpho-orthographic in nature (i.e., equivalent across different levels of semantic transparency). This prediction is potentially very hard to verify empirically, however. If one assumes cascaded processing, incoming information (i.e., activation) does not have to be fully analyzed at one level before being passed on to more abstract levels. A lexical morphological influence could thus already start to develop before the representations involved in morpho-orthographic processing have reached a critical activation level needed for observing facilitation in the masked priming paradigm. Potentially, measures with a higher time-resolution, such as event-related potentials, and/or a higher activity-resolution, such as functional magnetic resonance, provide better candidates for testing this prediction (see Devlin, Jamison, Matthews & Gonnerman, 2004; Lavric, Clapp & Rastle, 2007; Morris, Holcomb & Grainger, 2008). The presence of semantic transparency effects in our study is thus not necessarily problematic for this account. It can also be remarked that the prime duration, 53ms, is slightly higher than the central tendency in the literature (median = 48, mean = 46, Q1 = 42, Q3 = 52, sd = 7; Rastle & Davis, 2008, Table 1). It could be argued that this contributed to the presence of semantic transparency effects, providing more time for lexical activations to become influenced by the primes.

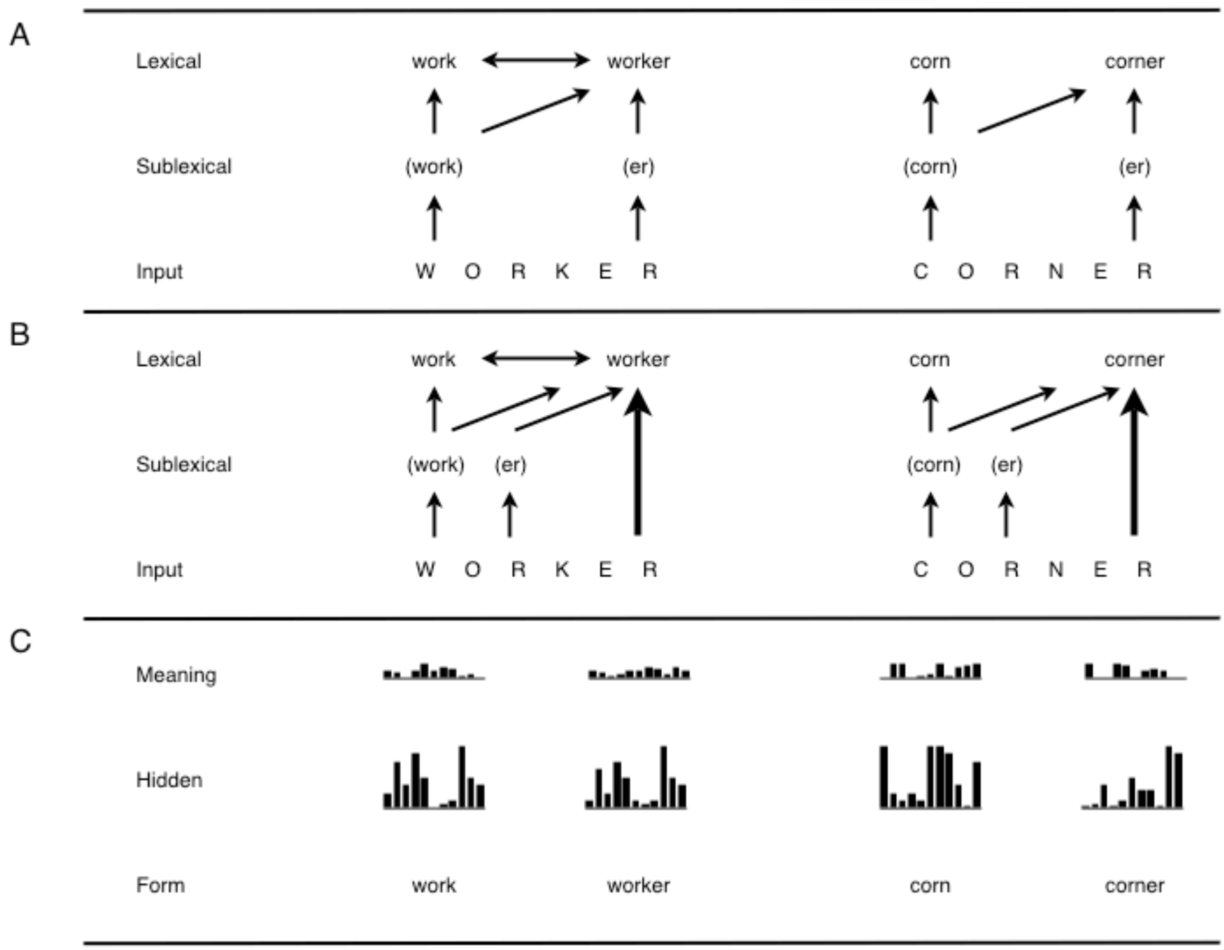

Figure 1. Three architectures that can account for the graded pattern of masked priming across the transparent, opaque and form conditions. The general framework in panel A predicts a mandatory sublexical morphological decomposition (e.g., Rastle and Davis, 2008; Taft & Forster, 1975; Taft & Nguyen-Hoan, 2010). Once the results of this decomposition are translated onto lexical levels, morpho-semantic relationships can come in to play. This happens because of

explicit or implicit positive links between representations of transparent relatives. Panel B shows a parallel dual-route architecture with simultaneous morpho-orthographic and morpho-semantic processing (e.g., Diependaele et al., 2005, 2009). The critical difference with the former models is that there is a direct link between low-level sublexical representations and lexical representations. This route in principle allows observing pure morpho-semantic effects, i.e., morphological effects without the involvement of a sublexical decomposition mechanism. In practice, except for irregular forms, there is cooperation between the direct and the sublexical decomposition route. Panel C illustrates the distributed connectionist view on morphological processing (e.g., Plaut & Gonnerman, 2000). Through statistical learning, continuous hidden unit representations (depicted as bar plot patterns) capture systematic correlations between form and meaning. Since morphological families are prototypical for such correlations, the representations for transparent relatives become more similar to each other than the representations for words that are only related in form or meaning.

According to the two other accounts depicted in Figure 1, semantic transparency plays a central role in the emergence of morphological activations and the present results in L1 and L2 can be viewed as a further illustration of this. The first model can be labeled as a parallel dual-route model with morpho-orthographic and morpho-semantic processing. The main departure from the previous architecture, is that there is a parallel and simultaneously operating route that provides the possibility of a fast direct activation of a lexical representations matching the whole input. The presence of positive links between lexical representations of transparent morphological relatives implies that this direct whole-word route can in principle generate masked morphological priming effects on its own, which is referred to as morpho-semantic processing. However, since morpho-orthographic segmentation is initiated at the same time, in practice there will be cooperative effects of the two sources of morphological activation, except for irregular forms (e.g., Diependaele et al., 2005, 2009). In this view, semantic transparency is able to affect morphological activations from the very start, given that the direct whole-word route is assumed to provide the fastest activation of lexical representations (see also Grainger & Dufau, 2010; Schreuder & Baayen, 1995).

The final account of the observed graded pattern has been formulated within the distributed connectionist approach to language processing (e.g., Harm & Seidenberg, 2004). In this view representations of form and meaning are in essence viewed as continuous values across a given set of features, i.e., orthographic/phonological and semantic vectors of a given dimensionality. The mappings between these representations are in turn viewed as continuous representations at the level of an intermediate ("hidden") feature set. Importantly, the values of these representations are the result of statistical learning. As a general rule, the more frequent and consistent a given form meaning feature mapping occurs, the more similar/or closer together/overlapping the hidden feature values will be across the individual occurrences. In the context of morphology this predicts that the hidden representation of morphological relatives will have a relatively high degree of similarity and that this is a positive function of the number of semantically transparent family members and their frequency/probability distribution, i.e., the higher the overall frequency/probability and the more equated across family members, the more similar hidden representations will be. Priming effects are assumed to provide a direct reflection of the similarity. Facilitation will thus generally be larger following morphologically related primes than other matched controls. Simulations with artificial language by Plaut and Gonnerman (2000) illustrate that at least under certain circumstances one can expect that hidden representations for opaque words exhibit some degree of similarity to those of the genuine (i.e., transparent) morphological family. As such, it is possible to predict the graded patterns of priming across transparent, opaque and form items shown in the literature.

The present findings do not provide a strong basis for deciding between these alternatives. Our covariance analyses nevertheless provide interesting information in this regard. First, there was a positive relationship between the facilitation for transparent items and the whole-word prime frequency. This is readily predicted by the first two accounts, where positive links are present between lexical representations of transparent morphological relatives. In the distributed connectionist account it is especially the family size and frequency of the stem that should positively influence priming. In fact, the word frequency of the prime could be predicted to have a negative effect on priming, since it would support a more idiosyncratic hidden representation of the prime word. The negative effect of the morpheme boundary bigram frequency in the case of transparent items is also easily integrated with the former two proposals. As shown by Rastle et al. (2004), the differential bigram frequency contours in morphologically complex and simplex words could play a crucial role in morpho-orthographic segmentation. It is less straightforward to see how the observed negative effect is to be explained within the distributed connectionist view. Arguably, such dependencies can only arise from mappings between different levels of orthographic/phonological representation and not from the mapping of form onto meaning. Finally, our covariance analyses also show a negative effect of stem neighborhood frequency in the case of opaque items. This can be accounted for within the two former frameworks if one assumes that morpho-orthographic activations are rapidly translated onto lexical levels. The more frequent the stem orthographic neighborhood, the harder it will be to pre-activate its lexical representation due to stronger competition from words with a similar form. In the case of transparent items, the positive links within the morphological family could immediately neutralize this competition. Again, it remains to be seen whether a distributed connectionist model can capture this effect.

Following the above discussion it would seem that our results are most easily explained by a pure morpho-orthographic and a simultaneous morpho-orthographic and morpho-semantic model. The former account is arguably more parsimonious, but it remains important to study its ability to predict large effects of semantic transparency and whole-word processing in general at an early stage. The masked priming studies that have led to the revival of this “blind decomposition” framework in the last decade, all showed statistically equivalent priming effects with transparent and opaque items (e.g., Longtin et al., 2003; Rastle et al., 2004). Current evidence, including the present data, clearly shows that fast semantic transparency effects cannot be overlooked. If we consider the recent meta-analysis by Davis and Rastle (2010), it appears that our joint analysis enters the literature as the one with the largest number of data points for the transparent-opaque and opaque-form priming contrasts. Following their calculations, we have more than 3 times the maximum number thus far (i.e., 9800 as opposed to 3000). This means that the present grand averages for the transparent-opaque and opaque form contrasts (13ms and 12ms) would appear well on top in the funnel plots. Especially if the means across studies were weighted by the number of data points, it would seem that the Davis and Rastle analysis underestimates the transparent-opaque difference (7ms vs. 14ms in the present study) and overestimates the opaque-form difference (20ms vs. 12ms). Thus, although a pure morpho-orthographic explanation can account for a graded priming pattern as presently observed, proponents should be aware that semantic transparency effects in fast morphological priming are very real and potentially more equal in size to the morphological effect with opaque items than the present meta-analyses suggest.

A simultaneous morpho-orthographic/semantic account obviously goes hand in hand with accepting the reality of fast semantic transparency effects. The critical difference is the independent origin of morphological effects with opaque items and semantic transparency effects. Like earlier parallel dual-route accounts (e.g., Schreuder & Baayen, 1995), the speed of whole-word processing (leading to morpho-semantic activation) and “blind” decomposition (morpho-orthographic activation) is relative, rather than absolute. This is a critical property that needs to be considered in future research. A further reason for considering this alternative is that it readily accounts for masked priming effects with irregular inflections. Indeed, in a recent set of masked priming lexical decision experiments, Crepaldi, Rastle, Colthaert and Nickels (2010) found that irregularly inflected primes (*fell*) consistently primed their stems (*fall*) relative to both orthographic (e.g., *full-fall*) and morpho-orthographic (*raid-ray*, *cheese-choose*) controls. Crepaldi et al. argue that this can be accounted for by extending the pure morpho-orthographic view with a *lemma* level. This level contains shared representations for inflectional, but not derivational morphological relatives. They argue against the possibility of a morpho-semantic level, i.e., a level where representations instead reflect the combination of orthographic and semantic similarity for *all* words, because "masked priming studies typically show that priming effects for semantically transparent derivational pairs like darkness-DARK do not differ significantly from priming effects for pseudo-morphological pairs like corner-CORN (see Longtin et al. (2003), Marslen-Wilson, Bozić & Randall (2008), Rastle et al. (2004)). If the combination of semantic and orthographic similarity were playing a strong role in masked priming, then it seems that a convincing effect should be apparent across this comparison." (Crepaldi et al., 2010, p. 91). The present conclusion regarding semantic transparency effects clearly sheds a different light on this line of reasoning. Fast semantic transparency effects are not to be overlooked and simultaneous morpho-orthographic/-semantic processing readily predicts that irregular inflectional primes will only result in a morpho-semantic effect. This effect will also be considerably larger than the semantic transparency effect with derivations, given the generally stronger semantic similarity among inflections.

The question remains, however, why there exists such considerable variability regarding masked priming with transparent and opaque items. We believe at least one contributing factor might be that a factorial treatment of semantic transparency can be misleading, given the nature of this variable. There is clearly an underlying continuum with a considerable grey area when it comes down to building a factorial contrast. Our covariance results further highlight a number of potentially important variables. We can arrive at the prediction that priming will become larger for transparent, but not opaque items, the higher the prime word frequency is. At the same, we can predict that priming with opaque will become smaller as the target neighborhood frequency becomes larger. As such, studies with relatively high frequency primes and high frequency target neighborhoods should have a better chance of providing semantic transparency effects or, put differently, studies with relatively low frequency primes and low frequency target neighborhoods should have a better chance of observing matched facilitations across transparent and opaque items. Interestingly, compared to Rastle et al. (2004), the present target neighborhood sizes were about 3-4 times as high. Following the above reasoning, this could explain why Rastle et al. found a larger priming effect for opaque items than we did in Experiment 1 (i.e., 22ms vs. 15ms) and why they failed to obtain a significant transparency effect. These hypotheses should be addressed systematically in future research.

Conclusions

The present results show that the processing of morphologically complex words occurs along similar principles and to the same degree in L1 and L2 processing. This supports the general idea that the language itself primarily determines the functional properties of processing in L2. This conclusion does not exclude that significant differences arise with lower levels of proficiency. Future research should consider this possibility. If differences emerge, we argue that this will reflect an intermediate state in the transition towards the target (L1) architecture rather than a fundamentally different way of handling native and non-native language input. Regarding the functional properties of morphological processing itself, our results highlight the reality of semantic transparency effects within the very first stages of word recognition. We sincerely hope that the scale of our study will be an incentive for future researchers to investigate the true functional origin of these effects, rather than to look for presumed methodological flaws in studies that show them.

References

Albright, A., & Hayes, B. (2003). Rules vs. analogy in English past tenses: A computational/experimental study. *Cognition*, *90*, 119–161.

Baayen, R. H. (2009). languageR: Data Sets and Functions with "Analyzing Linguistic Data: A practical introduction to statistics". R package version 0.955. http://CRAN.R-project.org/package=languageR.

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*, 387-556.

Baayen, R. H., Piepenbrock, R., & Gulikers, L. (1995). *The CELEX Lexical Database (CD-ROM)*. Philadelphia: Linguistic Data Consortium, University of Pennsylvania.

Balota, D. A., Cortese, M. J., Sergent-Marshall, S. D., Spieler, D. H., & Yap, M. J. (2004). Visual Word Recognition of Single-Syllable Words. *Journal of Experimental Psychology: General*, *133*, 283–316.

Bates, D., & Maechler, M. (2009). lme4: Linear Mixed-Effects Models Using S4 Classes. R package version 0.999375-32. http://CRAN.R-project.org/package=lme4.

Belsley, D. A., Kuh, E., & Welsch, R. E. (1980). Regression Diagnostics: Identifying Influential Data and Sources of Collinearity. New York: Wiley.

Benjamini, Y. and Hochberg, Y. (1995). Controlling the False Discovery Rate: A Practical and Powerful Approach to Multiple Testing. *Journal of the Royal Statistical Society, Series B*, *57*, 289-300.

Bybee, J. L. (1985) *Morphology: A Study of the Relation Between Meaning and Form*, Philadelphia: John Benjamins.

Chandler, S. (2010). The English past tense: Analogy redux. *Cognitive Linguistics*, *21*, 371–417.

Chateau, D., Knudsen, E. V., & Jared, D. (2002). Masked Priming of Prefixes and the Influence of Spelling-Meaning Consistency. *Brain and Language*, *81*, 587–600.

Chiswick, B. R. & Miller, P. W. (2004). Linguistic Distance: A Quantitative Measure of the Distance Between English and Other Languages. IZA Discussion Papers 1246, Institute for the Study of Labor (IZA).

Clahsen, H., Felser, C., Neubauer, K., Sato, M. & Silva, R. (2010). Morphological Structure in Native and Non-Native Language Processing. *Language Learning*, 60, 21-43.

Clahsen, H., Sonnenstuhl, I., & Blevins, J. P. (2003). Derivational Morphology in the German Mental Lexicon: A Dual-Mechanism Account. In H. Baayen & R. Schreuder (Eds.), *Morphological Structure in Language Processing*. Berlin: Mouton de Gruyter, 125-155.

Crepaldi, D., Rastle, K., Coltheart, M., & Nickels, L. (2010). 'Fell' Primes 'Fall', but Does 'Bell' Prime 'Ball'? Masked Priming with Irregularly-inflected primes. *Journal of Memory and Language*, *63*, 83-99.

Davis, M. H. & Rastle, K. (2010). Form and Meaning in Early Morphological Processing: Comment on Feldman, O'Connor and Moscoso del Prado Martin. *Psychonomic Bulletin & Review*.

Devlin, J. T., Jamison, H. L., Matthews, P. M. & Gonnerman, L. M. (2004). Morphology and the Internal Structure of Words. *Proceedings of the National Academy of Sciences*, *101(41)*, 14984-14988.

Diependaele, K., Grainger, J., & Sandra, D. (in press). Derivational Morphology and Skilled Reading: An Empirical Overview. In M. Spivey, M. Joanisse & K. McRae (Eds.), *The Cambridge Handbook of Psycholinguistics*, Cambridge UK: Cambridge University Press.

Diependaele, K., Sandra, D., & Grainger, J. (2005). Masked Cross-Modal Morphological Priming: Unraveling Morpho-Orthographic and Morpho-Semantic Influences in Early Word Recognition. *Language and Cognitive Processes*, *20*, 75– 114.

Diependaele, K., Sandra, D., & Grainger, J. (2009). Semantic Transparency and Masked Morphological Priming: The Case of Prefixed Words. *Memory & Cognition*, *37*, 895-908.

Dijkstra T., Van Heuven W.J.B. (2002). The Architecture of the Bilingual Word Recognition System: From Identification to Decision. *Bilingualism: Language and Cognition*, *5*, 175-197.

Dijkstra, T., Grainger, J., & Van Heuven, W.J.B. (1999). Recognition of Cognates and Interlingual Homographs: The Neglected Role of Phonology. *Journal of Memory and Language*, *41*, 496-518.

Dijkstra, T., Van Heuven, W.J.B., & Grainger, J. (1998). Simulating Cross-Language Competition with the Bilingual Interactive Activation Model. *Psychologica Belgica*, *38*, 177-196.

Dimitropoulou, M., Duñabeitia, J.A., Carreiras, M. (in press). Phonology by Itself: Masked Phonological Priming Effects With and Without Orthographic Overlap. *European Journal of Cognitive Psychology*.

Duñabeitia, J.A., Perea, M., & Carreiras, M. (2008). Does Darkness Lead to Happiness? Masked Suffix Priming Effects. *Language and Cognitive Processes*, *23*, 1002-1020.

Duñabeitia, J.A., Perea, M., & Carreiras, M. (2010). Masked translation priming effects with highly proficient simultaneous bilinguals. *Experimental Psychology, 57*(2), 98-107.

Feldman, L. B., Kostić, A., Basnight-Brown, D. M., Filipović-Đurđević, D., & Pastizzo M. J. (2009). Morphological Facilitation for Regular and Irregular Verb Formations in Native and Non-Native Speakers: Little Evidence for Two Distinct Mechanisms. *Bilingualism: Language and Cognition*, *13*, 119-135.

Feldman, L. B., O'Connor, P. A., & Moscoso del Prado Martín, F. (2009). Early Morphological Processing is Morpho-Semantic and not Simply Morpho-Orthographic: A Violation of Form-then-Meaning Accounts of Word Recognition. *Psychonomic Bulletin & Review*, *16*, 684-691.

Feldman; L. B. (1994). Beyond Orthography and Phonology: Differences between Inflections and Derivations. *Journal of Memory and Language*, *33*, 442-470.

Forster, K. I., & Davis, C. (1984). Repetition Priming and Frequency Attenuation in Lexical Access. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *10*, 680-698.

Forster, K. I., & Forster, J. (2003). DMDX: A Windows Display Program with Millisecond Accuracy. *Behavioral Research Methods, Instruments & Computers*, *35*, 116-124.

Frost, R., Kugler, T., Deutsch, A., & Forster, K. I. (2005). Orthographic Structure Versus Morphological Structure: Principles of Lexical Organization in a Given Language. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *31*, 1293-1326.

Gelman, A., Hill, J., Yajima, M., Su Y.-S., & Pittau, M. G. (2010). mi: Missing Data Imputation and Model Checking. R package version 0.08-06. http://CRAN.R-project.org/package=mi.

Giraudo, H., & Grainger, J. (2000). Effects of Prime Word Frequency and Cumulative Root Frequency in Masked Morphological Priming. *Language and Cognitive Processes*, *15*, 421-444.

Grainger, J. & Dufau, S. (in press). The front-end of visual word recognition. To appear in J.S. Adelman (Ed.) *Visual Word Recognition Vol. 1: Models and Methods, Orthography and Phonology*. Hove, UK: Psychology Press.

Hahn, U., & Nakisa, R.C. (2000). German Inflection: Single or Dual Route? *Cognitive Psychology*, *41*, 313-360.

Harm, M. W., & Seidenberg, M. S. (2004). Computing the meanings of words in reading: Cooperative division of labor between visual and phonological processes. *Psychological Review*, *111*, 662-720.

Keuleers, E., & Daelemans, W. (2007). Memory-based learning models of inflectional morphology: a methodological case study. *Lingue e linguaggio*, *6*, 151–174.

Keuleers, E., Diependaele, K. & Brysbaert, M. (in press). Practice Effects in Large-Scale Visual Word Recognition Studies: A Lexical Decision Study on 14,000 Dutch Mono- and Disyllabic Words and Nonwords. Frontiers in Language Sciences.

Keuleers, K., Sandra, D., Daelemans, W, Gillis, S., Durieux, G., & Martens, E. (2007). Dutch Plural Inflection: The Exception that Proves the Analogy. *Cognitive Psychology*, *54*, 283-318.

Landauer, T.K. & Dumais, S.T. (1997). A Solution to Plato's Problem: The Latent Semantic Analysis Theory of Acquisition, Induction, and Representation of Knowledge. *Psychological Review*, *104*, 211-240.

Lavric, A., Clapp, A., & Rastle, K. (2007). ERP Evidence for Morphological Analysis from Orthography: A Masked Priming Study. *Journal of Cognitive Neuroscience*, *19*, 866-877.

Lemhöfer, K., Dijkstra, T., Schriefers, H., Baayen, H.R., Grainger, J., & Zwitserlood, P. (2008). Native Language Influences on Word Recognition in a Second Language: A Mega-Study. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *34*, 12-31.

Longtin, C. M., & Meunier, F. (2005). Morphological Decomposition in Early Visual Word Processing. *Journal of Memory and Language*, *53*, 26-41.

Longtin, C. M., Segui, J., & Hallé, P. A. (2003). Morphological Priming without Morphological Relationship. *Language and Cognitive Processes*, *18*, 313-334.

Marslen-Wilson, W. D, Bozić, M. & Randall, B. (2008). Early Decomposition in Visual Word Recognition: Dissociating Morphology, Form, and Meaning. *Language and Cognitive Processes*, *23*, 394-421.

Morris, J., Franck, T., Grainger, J., & Holcomb, P.J. (2007). Semantic Transparency and Masked Morphological Priming: An ERP Investigation. *Psychophysiology*, *44*, 506-521.

Morris, J., Holcomb, P. J., & Grainger, J. (2008). An Electrophysiological Investigation of Early Effects of Masked Morphological Priming. *Language & Cognitive Processes*, *23*, 1021-1056.

Morris, J., Porter, J. H., Grainger, J. & Holcomb, P. J. (in press). Effects Of Lexical Status And Morphological Complexity In Masked Priming: An ERP Study. *Language and Cognitive Processes*.

Neubauer, K. & Clahsen, H. (2009). Decomposition of Inflected Words in a Second Language: An Experimental Study of German Participles. *Studies in Second Language Acquisition*, *31*, 403-435.

Pinker, S. (1999). *Words and rules: The ingredients of language*. New York: Basic Books.

Plaut, D. C. & Gonnerman, L. M. (2000). Are Non-Semantic Morphological Effects Incompatible with a Distributed Connectionist Approach to Lexical Processing? *Language and Cognitive Processes*, *15*, 445-485.

R Development Core Team (2009). R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Rastle, K., & Davis, M. H. (2008). Morphological Decomposition Based on the Analysis of Orthography. *Language and Cognitive Processes*, *23*, 942-971.

Rastle, K., Davis, M. H., & New, B. (2004). The Broth in my Brother's Brothel: Morpho-Orthographic Segmentation in Visual Word Recognition. *Psychonomic Bulletin & Review*, *11*, 1090–1098.

Raveh, M., & Rueckl, J. G. (2000). Equivalent Effects of Inflected and Derived Primes: Long-Term Morphological Priming in Fragment Completion and Lexical Decision. *Journal of Language and Memory*, *42*, 103-119.

Schafer, J. L., & Graham, J. W. (2002). Missing Data: Our View of the State of the Art. *Psychological Methods*, *7*, 147-177.

Schreuder, R., & Baayen, R. H. (1995). Modeling Morphological Processing. In Feldman, L. B. (Ed.), *Morphological aspects of language processing* (pp. 131- 156). Hillsdale, NJ: Erlbaum.

Schriefers, H., Frederici, A., & Graetz, P. (1992). Inflectional and Derivational Morphology in the Mental Lexicon: Symmetries and Asymmetries in Repetition Priming. *Quarterly Journal of Experimental Psychology*, *44*, 373–90.

Seidenberg, M. S. (1987). Sublexical structures in visual word recognition: Access units or orthographic redundancy? In Coltheart, M. (Ed.), *Attention and Performance XII: The Psychology of Reading* (pp. 245-263). London: Erlbaum.

Serva, M., & Petroni, F. (2008). Indo-European Languages Tree by Levenshtein Distance. *EPL*, *81*.

Silva, R., & Clahsen, H. (2008). Morphologically Complex Words in L1 and L2 Processing: Evidence from Masked Priming Experiments in English. *Bilingualism: Language and Cognition*, 11, 245-260.

Taft, M., & Forster, K. I. (1975). Lexical Storage and Retrieval of Prefixed Words. *Journal of Verbal Learning and Verbal Behavior*, *14*, 638-647.

Taft, M., & Nguyen-Hoan, M. (2010). A sticky stick: The locus of morphological representation in the lexicon. *Language and Cognitive Processes*, *25*, 277-296.

Ullman, M. (2004). Contributions of Memory Circuits to Language: The Declarative/Procedural Model. *Cognition*, *92*, 231-270.

Ullman, M. (2005). A Cognitive Neuroscience Perspective on Second Language Acquisition: The Declarative/Procedural Model. In C. Sanz (Ed.), *Mind and Context in Adult Second*

Language Acquisition: Methods, Theory and Practice (pp. 141- 178). Washington, D.C.: Georgetown University Press.

Van Assche, E., Duyck, W., Hartsuiker, R. & Diependaele, K. (2009). Does Bilingualism Change Native-Language Reading? Cognate Effects in a Sentence Context. *Psychological Science*, *20*, 923-927.

Van Hell J.G., Dijkstra T. (2002). Foreign Language Knowledge can Influence Native Language Performance in Exclusively Native Contexts. *Psychonomic Bulletin & Review*, *9*, 780-789.

Van Heuven, W., Schriefers, H., Dijkstra, A., & Hagoort, P. (2008). Language Conflict in the Bilingual Brain. *Cerebral Cortex*, *18*, 2706-2716.

Van Heuven, W.J.B, Dijkstra, T., & Grainger, J. (1998). Orthographic Neighborhood Effects in Bilingual Word Recognition. *Journal of Memory and Language*, *39*, 458-483.

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Footnotes

1. Words like *department* are called semantically opaque because they originated as true semantic derivatives of their stem, but gradually acquired an idiosyncratic meaning. Words like *corner* are called pseudo-complex because they have no true morphological status, even though they comprise the letter patterns of a stem and an affix.

2. The model of Giraudo and Grainger lacks a sublexical morphological processing component. This extension is implemented in the model of Diependaele et al., 2005, 2009).

3. The predictors for the by-participant multiple imputations were *Prime Type*, *Relatedness*, *Trial Number*, *Lexicality Previous Trial*, *Accuracy Previous Trial*, *Log Prime Frequency*, *Prime Length*, *Log Target Frequency, Target Length* and *Log Target Family Size*. Missing RTs were replaced because of an imbalance in the amount of non-available data across the L1 and L2 experiments (6% versus 9% versus 11% in Experiment 1, 2 and 3, respectively). Such an imbalance is harmful for a straightforward comparison. Since lexical decision errors are *not* random (i.e., they correlate with item difficulty and participant proficiency), simple mean imputation (and related intuitive strategies) are depreciated in favor of regression-based multiple imputation techniques (cf. Schafer & Graham, 2002). In the present context it turned out that the pattern of statistical results across all our experiments remained unaltered by the imputation. For good practice, we nevertheless only report the results from the analyses without missing values.

4. For RTs, we looked at the empirical p-value for the hypothesis that the MCMC sample values for the 2 interaction terms in the model had a mean of zero versus a general multivariate distribution with elliptical contours (implemented in the *aovlmer.fnc* function of the *languageR* package; Baayen, 2009). For errors, we looked at the log-likelihood ratio between the full and the main effects model.

5. We tested the model 3 times with a different reference level for *Prime Type* (transparent, opaque, form) in order to obtain estimates for the individual effects. The multiple comparison p-values were corrected following Benjamini and Hochberg (1995).

6. It might seem odd that even though proficiency is associated with an earlier age, the age of acquisition is larger compared the Spanish-English bilinguals. There is a reasonable explanation for this, however. In Flanders, each child is obliged to learn English at school from the age of 12-13 onwards (up to 18 years). The average age of acquisition score of 11.97 clearly reflects this. Children are nevertheless already greatly familiarized with English via television at this age. There are a lot of child-oriented television programs that are English spoken with Dutch subtitles. So it is in fact quite natural that our Flemish participants report a relatively early age of proficiency for English, even though they only received formal education from the age of 12.

7. If missing values are ignored and condition means are analyzed in standard repeated measures ANOVA, one implicitly replaces missing values with the condition means.