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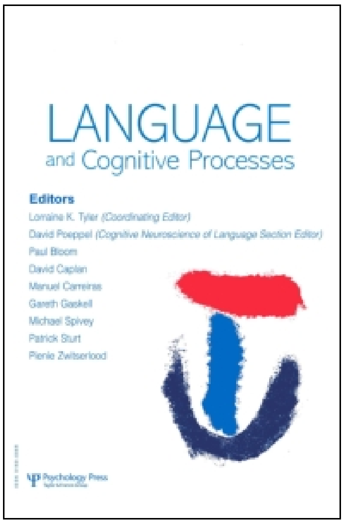

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Orthographic and semantic opacity in masked and delayed priming: Evidence from Greek

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Research using the masked priming paradigm has suggested that there is a form of morphological decomposition that is robust to orthographic alterations, even when the words are not semantically related (e.g., *badger/badge*). In contrast, delayed priming is influenced by semantic relatedness but it is not clear whether it can survive orthographic changes. In this paper, we ask whether morpho-orthographic segmentation breaks down in the presence of the extensive orthographic changes found in Greek morphology (orthographic opacity). The effects of semantic relatedness and orthographic opacity are examined in masked (Experiment 1) and delayed priming (Experiment 2). Significant masked priming was observed for pairs that shared orthography, irrespective of whether they shared meaning (mania/mana, "mania/mother"). Delayed priming was observed for pairs that were semantically related, irrespective of orthographic opacity (poto/pino, "drink/I drink"). The results are discussed in terms of theories of morphological processing in visual word recognition.

Keywords: Morphology; Visual word recognition; Masked priming; Delayed priming; Greek.

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INTRODUCTION

What is the nature of the orthographic and semantic codes that support the recognition and comprehension of visually presented words and what is the role that morphological elements play in this process? Research on the processing of morphologically complex words has provided a large body of evidence that morphologically complex words are decomposed in visual word recognition and they are recognised in terms of their constituent morphemes (e.g., *darkness* is segmented into {dark-} + {ness}; see Feldman, 1991; Seidenberg & Gonnerman, 2000, for reviews). Although the process of morphological decomposition in visual word recognition is now widely accepted, the role of semantic and orthographic factors therein is still controversial.

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Morphological decomposition and semantic transparency

One view holds that morphological decomposition is based on semantic information (Davis, van Casteren, & Marslen-Wilson, 2003; Giraudo & Grainger, 2001; Marslen-Wilson, Tyler, Waksler, & Older, 1994; Plaut & Gonnerman, 2000; Rueckl & Raveh, 1999). This morpho-semantic perspective on decomposition has gained support from different tasks such as cross-modal priming (Gonnerman, Seidenberg, & Andersen, 2007; Longtin, Segui, & Halle, 2003; Marslen-Wilson et al., 1994), visual priming with visible primes (Rastle, Davis, Tyler, & Marslen-Wilson, 2000), and delayed priming (Drews & Zwitserlood, 1995; Marslen-Wilson & Zhou, 1999; Rueckl & Aicher, 2008). For example, Marslen-Wilson et al. (1994) reported robust cross-modal priming effects for stem-target pairs that were morphologically and semantically related (e.g., *hunter/hunt*) but not for pairs that were not semantically related (*department/depart*) (henceforth referred to as "semantically opaque"). This finding led the authors to suggest that decomposition is only applied to morphologically complex words that are related in meaning to their stems, i.e., they are semantically transparent.

Contrary to this prediction, a number of studies using the masked priming paradigm have reported findings suggesting that the visual word recognition system handles semantically transparent and semantically opaque words in the same way. The main finding is that under masked priming conditions, robust priming is observed for semantically transparent and semantically opaque morphological relatives, and importantly, these effects are different from those obtained for pairs with orthographic overlap only, without a morphological relationship (e.g., *brothel/broth*; Rastle, Davis, & New, 2004). Priming effects for semantically opaque pairs have now been reported in a number of studies and in different languages (though see Diependaele, Sandra, & Grainger, 2005; Feldman, O'Connor, & Moscoso del Prado

Martin, 2009, for exceptions; Russian: Kazanina, Dukova-Zheleva, Geber, Kharlamov, & Tonciulescu, 2008; French: Longtin & Meunier, 2005; Longtin et al., 2003; see Rastle & Davis, 2008, for a review). These results have lent support to the morpho-orthographic view on segmentation, which holds that morphological decomposition is guided by orthographic information. This means that the word *department* is analysed in terms of its apparent morphemic structure, facilitating the subsequent recognition of the stem *depart*, despite the lack of a semantic relationship between the prime *department* and the target *depart*.

Morphological decomposition and orthographic transparency

Interestingly, this process applies even when the orthographic overlap between the morphological relatives is partial, as in the semantically transparent pairs *adorable/adore*, *metallic/metal* or in the semantically opaque pair *fetish/fete* (McCormick, Rastle, & Davis, 2008, 2009). This finding suggests that the process of morpho-orthographic segmentation is insensitive to regular orthographic alterations found in complex words as well as to their semantic characteristics. Consistent with this proposal, priming for regular and irregular inflected Greek words matched for orthographic overlap (50%) was equivalent at a short SOA (35 ms), although at the longer SOA (150 ms) there was more priming for regular than for irregular verbs (Tsapkini, Jarema, & Kehayia, 2002). In contrast, however, Voga and Grainger compared priming for high- vs. low-overlap pairs and observed priming only for the high-overlap pairs at an SOA of 33 ms, although the low-form overlap pairs in this study were similar to the Tsapkini et al. (2002) study (46% overlap). At the 50 ms SOA both conditions showed equivalent priming (Voga & Grainger, 2004).

Such discrepancies indicate that it is unclear whether morpho-orthographic segmentation can still proceed in the presence of more disruptive orthographic changes (e.g., *abundant/abound,* henceforth referred to as "orthographic opacity") found in morphologically complex words. This is one of the key questions we sought to answer in the experiments reported in this paper. The aforementioned studies with Greek materials (Tsapkini et al., 2002; Voga & Grainger, 2004) highlight the potential for Greek data to be informative regarding the role of extreme orthographic changes in the context of solid morphological relationships. However, these studies focus on inflectional morphology, where priming despite extreme orthographic changes can be due to either increased amount of semantic overlap for inflectional variants, or because orthographic irregularities are more systematic in inflectional morphology than in derivational morphology. In either case, this motivates further experiments to explore the impact of orthographic and semantic

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transparency in derivation, where these two factors can be independently varied, as we have sought to do in the experiments reported in this paper.

Morphological decomposition in masked and delayed priming

Interestingly, it has been shown that with increased prime duration (e.g., 72 ms and 230 ms) the effect of semantic transparency on paired visual priming increases (Rastle et al., 2000). However, these effects may also reflect increased semantic priming, which can also be seen for morphologically unrelated pairs (cf. Perea & Gotor, 1997). In contrast, when the interval between prime and target is long and filled with unrelated words (as in delayed priming paradigms), morphological priming effects can be dissociated from semantic priming and yet are still conditioned by semantic transparency. In a delayed priming study, Rueckl and Aicher (2008) reported that semantically transparent primes facilitated responses to a larger extent than semantically opaque primes, consistent with results from German (though see Bentin & Feldman, 1990; Bozic, Marslen-Wilson, Stamatakis, Davis, & Tyler, 2007; Drews & Zwitserlood, 1995). The dissimilarity of masked and delayed priming in the effects of semantic transparency led to the proposal of two processing stages in visual word recognition: an early morpho-orthographic stage, possibly reflected in masked priming, and a later occurring morpho-semantic stage, reflected in delayed priming effects (Rastle & Davis, 2008).

The experiments presented in this paper explore an important consequence of this proposal, namely that if masked priming reflects orthographic levels of processing, then it should be disrupted when the orthographic overlap between prime and target is diminished, while delayed priming will be more robust to orthographic opacity. To our knowledge this prediction has not been investigated in a single study. Previous research has shown that masked priming is predominantly sensitive to overlap at the level of form (e.g., Forster, Davis, Schoknecht, & Carter, 1987; Forster & Taft, 1994), while orthographic similarity between prime and target is not necessary in order to observe effects of morphological relatedness at long lags (although gradations in the degree of similarity produce small but systematic differences in the magnitude of priming, Feldman, 2003). In line with this prediction, Rueckl, Mikolinski, Miner, Raveh, and Mars (1997) found more masked priming in a fragment completion task for irregular pairs with modest orthographic changes (*awake/awoke*) than for irregular pairs with more disruptive changes (*bear/bore*). Contrary to the masked priming data, Stolz and Feldman (1995, Experiment 1) reported equal amounts of facilitation in delayed priming between visually presented pairs such as *mark/marked* and *speak/spoke*, although the authors admit that the amount of priming tends to increase as form overlap increases. In Greek, delayed priming was more

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pronounced for regular than irregular inflected words matched for orthographic overlap (Tsapkini et al., 2002).

The present studies

On the basis of the preceding considerations we decided to examine the influence of semantic and orthographic transparency on the recognition of morphologically complex words under masked (Experiment 1) and delayed (Experiment 2) priming conditions in a single study. Following previous research in the field we compare priming effects for semantically transparent and opaque morphological relatives. Furthermore, we explore the sensitivity of masked and delayed priming to more extensive orthographic changes than the ones tested by McCormick et al. (2008, 2009), e.g., duplicated consonant, missing "e"). To this end, we use Greek morphologically complex words.

Greek is a morphologically rich language, in which morpho-phonological rules produce morphologically related but orthographically dissimilar words. This kind of morphological relatives is quite common in Greek also because there has been massive borrowing by Greek from its own history, resulting in the coexistence of related words representing different diachronic developments. At this point, we should emphasise that in Greek every word is morphologically complex and can be parsed into a stem and a legal suffix, even in the presence of extensive orthographic changes that occur within the stem or at the morphemic boundaries. For example, in derivation the verb πλέν-ω, *pleno*, "I wash" undergoes a phonological and orthographic change of the stem and becomes πλυν-τήριο, *plin-tirio*, "washing-machine". An example of change at the morphemic boundaries is the verb γράφ-ω, *graf-o,* "I write", which becomes γράψ-ιμο, *graps-imo*, "writing". These changes do not affect the decomposability of the derived word because both words can be parsed into stem and suffix (*plen-o, plin-tirio* and *graf-o, graps-imo*) but the resulting stems are orthographically dissimilar. These stems are existent and legal stems and in some cases they can be traced back to the perfective stem of the verb (perfective past tense *e-graps-a* and *e-plin-a*) or to other words belonging to the same morphological family (e.g., in the pair πίν-ω/ποτ-ό, *pin-o*/*pot-o*, "I drink/drink", we also have the word ποτ-ήρι, *pot-iri,* "glass" with the stem *pot*-). In English, however, removing the suffix -*able* from *adorable* leaves the nonexistent stem *ador*- and removing -*ant* from *abundant* leaves the nonexistent stem *abund*-.

Since Greek has been described as a stem-based language (Ralli, 1988) throughout this paper we use the term orthographic opacity/transparency to refer specifically to whether the stem has undergone orthographic changes, i.e., whether prime and target share (or not) the same stem at the level of orthography. Likewise, semantic transparency refers to whether the prime and the target share the same stem at the level of meaning. Thus, as in

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previous work (e.g., McCormick et al., 2008), semantic relationships are achieved through the inclusion of pairs that share morphemic elements with consistent meanings. Sharing meaning is the conventional definition of morphological relationships.[1] However, in processing terms, both orthographic and semantic overlap may be critical for morphemic representations at different levels. In the present paper we test this by factorially crossing semantic and orthographic factors. In a similar vein, experimental conditions are described in terms of the morpho-semantic (+S/M and −S/M) and orthographic (+O/−O) characteristics of the stem of the prime and the target.

In the two experiments reported here we compare priming effects yielded by four conditions that factorially manipulate the orthographic and semantic transparency of the stems of two complex words. The conditions are as follows:

(1) Our first condition contains word pairs that share an orthographically and semantically transparent stem (e.g., θεωρία/θεωρώ, *theoria/theoro*, "theory/I theorize").[2] In this condition the prime and target can be decomposed into stem and suffix, they are morphologically related and they share the same stem (*theor*-) at the level of meaning and orthography. The only difference between the stems could be a stress change (30 pairs, e.g., γραφ-ή/γράφ-ω, *grafi/grafo*, "writing/I write"). We included two pairs where the stem of the verb contains a pseudoderivational suffix (-αζ, *-az*), γκρίνια/γκρινι-άζ-ω, *gkrinia/gkriniazo*, "nagging/I nag", and νύστα/νυστάζω, *nista/nistazo*,

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[1] In Greek it is possible to say that there are very few words that are related (strongly) in meaning but not in morphology (except of course for synonyms). However, one should be cautious in making this statement as it is possible that the different diachronic developments of the Greek language can give the appearance of morphological relatedness to words that are only related in meaning. One example could be a pair like ποταμός/πίνω (*potamos/pino*, "river/I drink"), where *potamos* is not actually morphologically related to *pino* but to the ancient Greek verb πίπτω, *pipto*, "I fall", πέφτω, "pefto" in modern Greek) (as verified by the Dictionary of Modern Greek, Babiniotis, 2006). We should note though that the semantic relationship between *poto/pino* (a pair used in the +S/M, –O condition) is intuitively stronger than the one in *potamos/pipto*.

[2] In the examples, the Greek word is first written in the modern Greek alphabet, followed by the Latin transliteration in italics and lastly by the English translation between quotation marks. The transliteration is according to the transliteration system of Greek into Latin adopted by the United Nations and ELOT (ISO 843–743) (Hellenic Organisation for Standardisation). The hyphen separates the stem from the inflectional and derivational affixes. In addition, all pairs are written in low case to reflect the way they were presented in the experiments (both prime and target in low case in order to preserve the stress marker) instead of the widely used convention of low case for prime and upper case for target. The second word in the pair is the target and the first word is the prime.

"sleepiness/feeling sleepy". We refer to this as the + Stem Meaning, + Stem Orthography condition (+ S/M, + O).

(2) The second condition is the –Stem meaning, + Stem Orthography condition (− S/M, + O) with semantically opaque and orthographically transparent primes (e.g., μανία/μάνα, *mania*/*mana*, "mania/mother"). The prime and the target can be decomposed into stem and suffix, they are not morphologically related, and they have orthographically similar stems, which are not related in meaning (*mani*- and *man*-, but the root is the same *man*-. Note that because the suffix -*ia* is very productive in modern Greek, both words could be decomposed synchronically as *man* + *a* and *man* + *ia*). The closest English example to these pairs would be *tender*/*tendon* in which both -*er* and -*on* are affixes but the shared stem "tend" is not related to either of the complex words. Such pairs are rare in English and so have seldom been tested in the literature (a few examples can be found in Experiment 2 of Rastle et al., 2000, however, this experiment failed to distinguish between affix and nonaffix endings). One possible difference between the Greek and the English pairs is that both *mania* and *mana* are very clearly morphologically structured and can be decomposed into a stem and suffix. This is the –Stem meaning, + Stem orthography condition (− S/M, + O). The types of pairs included fall in five categories: (1) the stems are the same orthographically (and phonologically) ($n = 15$), e.g., μούσ-α/μούσ-ι, *mousa*/*mousi*, "muse/beard"; (2) the stems are orthographically and phonologically the same apart from a stress change ($n = 10$), e.g., ξερ-ός/ξέρ-ω, *kseros*/*ksero* "dry/I know"; (3) the stems are pseudohomonyms ($n = 9$), e.g., σφυρίζ-ω/σφυρ-ί, *sfirizo*/*sfiri* "hammer/I whistle" (*sfirizo* contains the pseudoderivational affix −*iz*; $n = 9$); (4) the stems are different in their final letter(s) but one stem is still contained in the other ($n = 13$), e.g., μανί-α/μάν-α, *mania*/*mana*, "mania/mana"), or the whole word is contained ($n = 6$), e.g., πρόβατ-ο/πρόβ-α, *provato*/*prova*, "sheep/rehearsal"; and (5) the stems differ in their final letter ($n = 1$), σελίδ-α/σέλιν-ο, *selida*/*selino*, "page/celery".

(3) The third condition is (to our knowledge) unique to the present study and contains orthographically opaque and semantically transparent pairs (e.g., ποτό/πίνω, *poto*/*pino*, "drink/I drink"). Here, the prime and the target can be decomposed into stem and suffix, they are morphologically related but they have orthographically dissimilar stems (*pin*-, *pot*-), which are nonetheless highly related in meaning. This situation is different to the majority of orthographic changes observed in English derivational morphology (e.g., *adorable*/*adore*),

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where the orthographic changes do not allow a perfect parse of the word into complete morphemic units (e.g., removing the suffix -*able* from *adorable* leaves the nonstem *ador* instead of the stem *adore*). The most extreme orthographic alternations that exist in English derivation are pairs like *decision/decide*. However, by comparison to the materials in the present study, this is a subtle and systematic change compared to the examples found in our + Stem meaning, − Stem orthography condition (+ S/M, − O). All the pairs in this condition contain stem allomorphs. For example, the two stems in the pair *poto/pino* are part of the stems of the morphological family of the verb *pino* (*pi(n)-, pot-,* the last one actually appears in the ancient Greek deverbal adjective of the verb *pino* "potos"). In other words, *pino* is the imperfective stem and *pot*- represents a stem allomorph, as confirmed by the dictionary etymology. Other pairs represent different diachronic developments, e.g., in κλοπή/κλέβω, *klopi/klevo*, "robbery/I steal", the stem *klop*- can be traced back to the ancient Greek version of *klevo*, "klepto". In other cases we included pairs containing the perfective stem allomorph (active or passive) ($n = 20$), e.g., in φυγάς/φεύγω, *figas/fevgo*, "fugitive/I leave", *fig*- is the perfective stem as it appears in the past tense *e-fig-a*, "I left" (a suppletive stem as in the case of *think/thought*).

(4) The fourth condition consisted of semantically and orthographically opaque primes (e.g., τρίχα/τρίβω, *tricha/trivo*, "hair/I rub"). Although the prime and the target can be decomposed into stem and suffix, they are not morphologically related and they have orthographically dissimilar stems (*trich-, triv-*), which are not related in meaning but are equated for average orthographic overlap with the + S/M, − O condition. This is the − stem meaning, − stem orthography condition (− S/M, − O).

A few comments should also be made about conditions that were not included in the present experiment. For example, a true nonmorphological condition (corresponding to the *brothel/brother* pairs of the English studies) is not possible in Greek. All words are morphologically complex (stems require an inflectional and/or a derivational suffix to surface as words) and there are consequently no legal word endings (like -*el*) that are not an inflectional or derivational affix. We also chose not to include purely semantically related prime–target pairs as semantic priming has not been reported with either the delayed (e.g., Feldman, 2000; Raveh & Rueckl, 2000; Rueckl & Aicher, 2008) or the masked priming procedures (Frost, Forster, & Deutsch, 1997; see also Marslen-Wilson, Bozic, & Randall, 2008; Perea & Gotor, 1997; Rastle et al., 2000). It has been suggested that when the processing of the prime (or perhaps prime visibility) is restricted, as in masked priming paradigms, or when there

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are intervening items between prime and target (average lag 10 items), effects of semantic relatedness are generally absent, whereas morphological effects are preserved (Feldman, 2003).

EXPERIMENT 1: MASKED PRIMING

The primary question posed by this experiment was whether morpho-orthographic segmentation can survive orthographic opacity (ποτό/πίνω, *poto/pino*, "drink/I drink"), and whether this is conditioned by semantic transparency (τρίχα/τρίβω, *tricha/trivo*, "hair/I rub"). Also, this experiment would provide additional data from Greek on the effects of semantic transparency under masked priming conditions. Consistent with previous research in English (e.g., Rastle et al., 2004) and other languages (e.g., Longtin et al., 2003) we expect that orthographically and semantically transparent pairs (θεωρία/θεωρώ, *theoria/theoro*, "theory/I theorize") and orthographically transparent but semantically opaque pairs (μανία/μάνα, *mania/mana*, "mania/mother") will show comparable amounts of priming.

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Method

Participants

Forty-seven volunteers took part in this study. All were native speakers of Greek between the ages of 18 and 40 years living in Athens, Greece. Each gave informed consent after the experimental procedure was explained. Testing was conducted in Athens, Greece.

Materials

The stimulus set consisted of 192 prime–target pairs, 48 in each of the four conditions. All prime–target pairs could be parsed into stem and suffix because in Greek all words are morphologically complex and the stem has to be combined with a suffix to emerge as a word. Prime–target pairs in the + S/M, + O condition were semantically and orthographically related (θεωρία/θεωρώ, *theoria/theoro*, "theory/I theorize"). The average form overlap in this condition was 0.75 (expressed as "number of prime letters present in the target/number of prime letters", following McCormick et al., 2008). Prime–target pairs in the − S/M, + O condition were orthographically related but not related in morphology or meaning (e.g., μανία/μάνα, *mania/mana*, "mania/mother"). The average form overlap in this condition was 0.73. Prime − target pairs in the + S/M, − O condition were semantically related but their orthographic relationship was opaque due to extensive orthographic alterations to the stem (e.g., ποτό/πίνω*, poto/pino,* "drink/I drink";

κλοπή/κλέβω, *klopi/klevo*, "robbery/I steal"; σπόρος/σπέρνω, *sporos/sperno*, "seed/I plant"). The average form overlap of these pairs was 0.53. Prime–target pairs in the − S/M, − O condition had an opaque orthographic relationship (average form overlap 0.51) and were not semantically, or morphologically related (e.g., τρίχα/τρίβω, *tricha/trivo*, "hair/I rub"; αλάτι/αλείφω, *alati/aleifo*, "salt/I spread"). To ensure that the prime–target pairs in the different conditions were morphologically related or not, the etymology of all the pairs was checked using the Dictionary of the Greek Language (Babiniotis, 2006). Table 1 provides a summary of all experimental conditions with examples. Further example items can be found in the Appendix and a full set of items can be obtained from the first author on request.

Stimuli in the two + S/M conditions and the two + O conditions were matched on a number of variables (length, number of syllables, lemma frequency, and form overlap, see Table 2). Frequency counts were provided by the Hellenic National Corpus as in February 2007 (http://hnc.ilsp.gr/statistics.asp). Targets were not matched on neighbourhood size as this information only became available for Greek after the experiment was designed (information retrieved from the ILSP PsychoLinguistic Resource (IPLR); at speech.ilsp.gr/iplr; see Protopapas, Tzakosta, Chalamandaris, & Tsiakoulis, 2010). Each target in the + S/M, + O, the + S/M, − O, and the − S/M, − O conditions had a maximum neighbourhood size of eight (mean

TABLE 1
Test conditions and sample stimuli in Experiments 1 and 2. All stimuli are morphologically decomposable into a stem and affix. The different conditions are distinguished by the degree to which the stem in the prime and target shares meaning/morphology (+/−S/M) and orthography (+/−O)

Condition	*prime − target*	*+/− Semantics/Morphology*	*+/− Orthography*
1	θεωρία/θεωρώ *theoria/theoro* *theory/I theorize*	+S/M	+O
2	μανία/μάνα *mania/mana* *mania/mother*	−S/M	+O
3	ποτό/πίνω *poto/pino* *drink/I drink*	+S/M	−O
4	τρίχα/τρίβω *tricha/trivo* *hair/I rub*	−S/M	−O

Note: +/−S/M, word pairs that contain the same/different stem meaning; +/−O, word pairs that contain the same/different stem orthography.

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TABLE 2
Stimulus characteristics for primes and targets in Experiments 1 and 2. Frequency values are per million

	+S/M, +O	*−S/M, +O*	*ANOVA*	*+S/M, −O*	*−S/M, −O*	*ANOVA*
Target frequency	1.47	1.22	$F < 1$	1.58	1.31	$F < 1$
Prime frequency	1.01	0.75	$F < 1$	0.91	1.12	$F < 1$
Prime length	5.54	5.52	$F(1, 95) = 2.3$, *ns*	5.88	5.50	$F(1, 95) = 1.8$, *ns*
Target length	5.85	5.52	$F < 1$	5.90	5.65	$F(1, 95) = 1.8$, *ns*
Semantic relatedness	6.06	1.45	$F(1, 95) = 2961$, $p < .001$	5.99	1.4	$F(1, 95) = 3944$, $p < .001$
Form overlap	0.75	0.73	$F < 1$	0.49	0.53	$F < 1$

neighbourhood size in each of these conditions: 2, 2, and 2.5, respectively). However, in the −S/M, +O condition there were seven targets with neighbourhood size higher than eight and the mean neighbourhood size for the targets in this condition was five. This condition was significantly different from the other three conditions in neighbourhood size (all $ps < .001$). There were no other differences between conditions in neighbourhood size (all $ps > .05$). As we will see, however, this difference in neighbourhood size does not prevent reliable masked priming being observed for the −S/M, +O condition (contra Forster et al., 1987).

The prime–target pairs in the +S/M, +O and +S/M, −O conditions were semantically related, contrary to pairs in the semantically unrelated conditions (−S/M, +O and −S/M, −O). Due to the lack of pre-existing ratings for Greek, a Semantic Relatedness Pretest was run. In addition to the pairs corresponding to the four experimental conditions described above, 33 filler pairs were included to reduce the proportion of related pairs and to introduce different relationships into the related pairs. These fillers consisted of semantically unrelated pairs, as in ομπρέλα/μολύβι, ombrela/molivi, "umbrella/pencil" and weakly semantically related pairs, as in μήλο/πορτοκάλι, *milo/portokali*, "apple/orange". Participants were given a booklet with the word pairs and a scale from 1 to 7: "1" for not related in meaning and "7" for very related in meaning. In the instructions it was emphasised that pairs such as *mania/mana*, although related in sound, were completely unrelated in meaning. Twenty participants took part and they were all native speakers of Greek living in Athens, Greece. None of these participants was tested in the two experiments reported here.

Following the methodology of morphological priming studies, for each target in the 192 prime–target pairs we selected an unrelated control prime of the same length. The set of the unrelated primes was matched groupwise on lemma frequency to the set of related primes. Sixty-four unrelated filler word/word pairs and 256 unrelated filler word/pseudoword pairs were added in order to reduce the proportion of related trials to 19% and to balance the number of "Yes" and "No" responses in the experiment. Filler word targets were matched groupwise to the test targets on frequency and length and filler word primes were matched groupwise to the test primes on frequency and length. Nonword targets were matched groupwise to the test and filler targets on length. Nonword targets were preceded by unrelated word primes that were matched groupwise to the other primes on length and frequency. The stimulus set—192 prime–target pairs along with their unrelated controls corresponding to the four experimental conditions—was divided into two lists, with half of the targets in each list preceded by related primes and half by unrelated control primes. The lists were matched in the length, frequency, and form overlap of the primes and targets. Each participant was assigned to one of the two lists (hence, two groups of participants), and was thus

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presented with each of the 192 targets only once, either with a related or an unrelated prime, but participated in all priming conditions and saw all the 66 filler unrelated word/word pairs and the 256 filler word/pseudoword pairs, which appeared in the same position in both lists.

Apparatus and procedure

For each trial, a forward mask consisting of a row of 12 hash marks (#) was presented in the middle of the screen for 500 ms, followed immediately by the prime displayed for 42 ms, and then immediately masked by the target that remained on the screen for 1,000 ms. Participants had 2,000 ms, in which to respond until the programme moved on to the next item, while the intertrial interval was 1,500 ms. Reaction times (RTs) and accuracy were measured from the onset of the target display. Primes were displayed with a 12-point Arial in lower case and targets were displayed with a 16-point Arial in lower case, both in black on a white background. The targets had a larger font size than the primes to make sure that the latter were appropriately masked. We decided that the stimuli should appear in lower case so that stress diacritics appear in both primes and targets. The stress pattern of words in Greek is contrastive, i.e., words may be differentiated simply by the position of the stress (e.g., γέρος/γερός, *yeros*/*yeros*, "old man/strong", cf. Holton, Mackridge, & Philippaki-Warburton, 1997). For this reason we use lowercase for both the primes and the targets throughout the paper.

The stimuli were presented on a Toshiba laptop using DMDX software (Forster & Forster, 2003). The participant's task was to make a lexical decision to the visual target, using a four-button response device, in which only the two buttons were relevant for the experiment. The YES response was controlled by the dominant hand. Participants were advised that they were to decide as quickly and as accurately as possible whether what they saw was a real word or not. The presence of a visual prime was not mentioned. Each session started with a practice block, followed by the four blocks of the experiment proper. Participants made 512 lexical decisions in this experiment.

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Results and discussion

Mean RTs and error rates (ERs) were calculated for each participant and each item in each condition. No items or participants were excluded but 20 outlying data points over 1,900 ms were removed. All incorrect responses were discarded from the RT analyses and were treated in separate analysis of the ERs. The ERs were very low overall and the analyses both by participants and by items did not show any significant effects and so these analyses are not reported.

The reaction time data were inversely transformed to reduce the influence of outliers (Ratcliff, 1993). Analyses of variance by participants (F_1) and items (F_2) were performed on the inverse transformed data. The significance level adopted in the present study is .05 (see Table 3 for RTs and ERs for this experiment).

In the participants analysis prime (two levels), semantics (two levels, + semantics/ − semantics), and orthography (two levels, + orthography/ − orthography) were entered as repeated factors. Version (two levels) was entered as an unrepeated factor. In the items analysis prime was entered as a repeated factor and semantics, orthography, and version were entered as unrepeated factors.

The ANOVAs revealed a significant interaction between prime and orthography, $F_1(1, 45) = 6.9$, $p = .012$, $F_2(1, 184) = 6.8$, $p = .010$, and an orthography by semantics interaction, $F_1(1, 45) = 37.8$, $p < .001$, $F_2(1, 184) = 5.6$, $p = .019$, indicating increased priming for both sets of + O pairs. The interaction between prime and semantics did not reach significance, $F_1(1, 45) = 1.6$, $p = .213$, $F_2(1, 184) = 1.3$, $p = .251$. To establish the source of these interactions, t tests were performed on individual conditions. There was significant priming in the + S/M, + O condition, $t_1(46) = 5.6$, $p < .001$, $t_2(47) = 4$, $p < .0015$, and the − S/M, + O condition, $t_1(46) = 3$, $p = .005$, $t_2(47) = 4.1$, $p < .001$. Priming effects in the + S/M, + O condition (28 ms) were numerically larger than priming effects in the − S/M, + O (20 ms) condition, but this difference did not reach statistical significance, $t_1(46) = 0.793$, $p = .432$, $t_2(47) = 0.806$, $p = .406$. In the + S/M, − O condition there was a trend towards the 12 ms priming effect being statistically significant, $t_1(46) = 1.9$, $p = .065$, $t_2(47) = 2$, $p = .052$, while there was no priming in the − S/M, − O condition, $t_1(46) = 1.5$, $p = .136$, $t_2(47) = 1.7$, $p = .092$. Priming effects did not differ between these two conditions, $t_1(46) = 0.358$, $p = .722$, $t_2(47) = 0.411$, $p = .683$. However, a significant difference was observed

TABLE 3
Mean RTs and ERs (in parentheses) for Experiment 1 (by participants)

Condition	*+S/M, +O (theoria/theoro)*	*−S/M, +O (mania/mana)*
Related primed	651 (0.01)	686 (0.02)
Control primed	679 (0.01)	706 (0.02)
Priming effect	28	20
Condition	*+S/M, −O (poto/pino)*	*−S/M, −O (tricha/tivo)*
Related primed	676 (0.02)	670 (0.02)
Control primed	688 (0.03)	678 (0.02)
Priming effect	12	8

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between the + S/M, + O and + S/M, − O conditions, $t_1(46) = 2.1$, $p = .035$, $t_2(47) = 1.9$, $p = .052$, with larger priming in the + S/M, + O condition than the + S/M, − O condition.

Lastly, it should be noted that there were some baseline differences between the conditions. Specifically, RTs for targets following unrelated primes were longer in the − S/M, + O and the + S/M, − O conditions (706 ms and 688 ms, respectively) than in the other two conditions (+ S/M, + O: 679 ms, − S/M, − O: 678 ms; see also McCormick et al., 2008). We examined the effect of baseline differences on the magnitude of priming by running two additional analyses. In the first analysis, the overall RT for each item (i.e., the average RT for control and related primes) was entered as a covariate in the items analysis. This analysis replicated the prime by orthography interaction, $F_2(1, 183) = 7.2$, $p = .008$, and the lack of an interaction between prime and semantics ($F_2 < 1$). However, it also showed a significant interaction between prime and the average control and prime RT, $F_2(1, 183) = 9.8$, $p = .002$, suggesting that the magnitude of priming was modulated by the overall RTs. To investigate the direction of this effect, in a subsequent analysis we correlated the overall RT for each item with the magnitude of priming for each item. This analysis showed a significant positive correlation between priming and overall RT ($r = .21$), such that longer RTs produced more priming. Instead of making priming effects more difficult to observe in the − S/M, + O condition, these analyses suggest that the baseline differences actually biased us against finding more priming in the + S/M, + O condition (correlation $r = .37$), which had the shortest overall RT (665 ms), than the − S/M, + O condition, which had the longest overall RT (696 ms).

Consistent with results from English (e.g., Rastle & Davis, 2003; Rastle et al., 2004) and other languages (e.g., French; Longtin et al., 2003) masked priming facilitated responses to targets irrespective of whether they were semantically related to their primes (+ S/M, + O) or not (− S/M, + O). Although there was a hint of priming (12 ms) for the + S/M, − O pairs this was significantly smaller than the priming for the orthographically transparent, semantically related pairs. Thus, it seems that the robustness to orthographic change in morpho-orthographic decomposition applies for regular orthographic alterations of the type found in English, as in *writer/write* (McCormick et al., 2008, 2009) but is reduced in the face of more disruptive orthographic changes. Using a shorter SOA, Voga and Grainger (2004) reported similar effects of orthographic overlap (i.e., priming only in the high-form overlap condition). However, Tsapkini et al. (2002) found robust masked priming effects (32 ms SOA) for regular and irregular inflected pairs with 50% overlap. In this study there were no pairs with higher form overlap, which may have influenced the results, and critically the pairs were inflectionally related.

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EXPERIMENT 2: DELAYED PRIMING

Experiment 2 sought to determine whether the same pattern of effects —insensitivity to semantic relatedness but sensitivity to orthographic opacity—is maintained when the prime is fully visible and there is a delay between prime and target. Previous research has shown that long-term priming is influenced by semantic and morphological transparency (Rastle et al., 2000; Rueckl & Aicher, 2008) but it has not been established whether this form of priming can survive the extreme orthographic changes typical of Greek derivational morphology (e.g., ποτό/πίνω, *poto/pino,* "drink/I drink"). In Greek, inflected verbs matched orthographically at both the stem and surface overlap with their past-tense primes produced priming effects that were proportional to the degree of morphological transparency, i.e., those pairs who bore an allomorphic stem elicited less priming than those who had the same stem (Tsapkini et al., 2002). Priming effects for visible primes in Greek inflectional morphology despite similarly extensive orthographic changes have also been reported elsewhere (Voga & Grainger, 2004) but all the pairs in these studies were morphologically and semantically related and it is known that nonmorphological, semantic priming can be observed at this latency (Perea & Gotor, 1997). The comparison between masked (Experiment 1) and delayed priming (Experiment 2) is a strong test of the proposal of two functionally distinct forms of decomposition (morpho-orthographic, morpho-semantic) operating in masked and delayed priming conditions respectively (Rastle & Davis, 2008).

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Method

Participants

Forty-six volunteers took part in this study. All were native speakers of Greek between the ages of 18 and 40 years living in Athens, Greece. Each gave informed consent after the experimental procedure was explained. Testing was conducted in Athens, Greece.

Materials

The experimental pairs were the same as in Experiment 1 (i.e., 192 prime–target pairs, and each prime was also associated with an unrelated control). In this experimental setting, 192 filler nonword/nonword pairs were added to the stimulus material such that orthographic repetition was not consistently associated with a "yes" lexical decision (see also Rueckl & Aicher, 2008). Hence, for each of the 48 related word/word pairs in each experimental condition we constructed 24 nonword/nonword pairs that were matched groupwise to the word/word pairs on prime/target form overlap as well as prime and target length. The remaining 24 nonword targets were always preceded by unrelated nonword primes that were matched groupwise to the other primes on length. The nonwords were created by changing one or two letters of an existing word, which did not appear in the experiment. The relatedness proportion in this experiment was 25%. The counterbalancing of items across participants was achieved in the same way as in Experiment 1.

Apparatus and procedure

Each trial consisted of the visual presentation of the stimulus, which stayed on the screen for 1,000 ms. Participants had 2,500 ms in which to respond before the programme moved on to the next item. The intertrial interval was 1,000 ms. Repetitions occurred after approximately 12 intervening items (30 seconds delay between first and second presentation). In this experimental setting, the participants had to make a lexical decision response to every trial (both to the prime and to the target, unlike in the masked priming situation, where participants are only aware and respond to the target). This resulted in 768 lexical decisions in this experiment (384 experimental trials in response to the 192 prime–target (or control) pairs, and 384 filler trials in response to the 192 filler nonword/nonword pairs), split in three sessions of 256 trials each. In all other respects, the procedure used in this experiment was identical to Experiment 1.

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Results and discussion

Mean RTs and ERs were calculated for each participant and each item in each condition. No items or participants were excluded but four outlying data points over 1,900 ms were removed. All incorrect responses were discarded from the RT analyses and were treated in separate analysis of the ERs. The ERs were very low overall and no significant effects emerged in the errors analysis, which is not reported. As in Experiment 1, the reaction time data were inversely transformed to reduce the influence of outliers (Ratcliff, 1993) and analyses of variance by participants (F_1) and items (F_2) were performed on the inverse transformed data (see Table 4 for RTs and ERs for this experiment).

In the participants analysis prime (two levels), semantics (two levels, + semantics/ − semantics/), and orthography (two levels, + orthography/ − Orthography) were entered as repeated factors. Version (two levels) was entered as an unrepeated factor. In the items analysis, prime was entered as a repeated factor and semantics, orthography, and version were entered as unrepeated factors.

The ANOVAs revealed a significant interaction between prime and semantics, $F_1(1, 45) = 11.1$, $p = .002$, $F_2(1, 184) = 12.3$, $p < .001$, indicating the increased priming for the + S/M pairs. There was neither an interaction

TABLE 4
Mean RTs and ERs (in parentheses) for Experiment 2 (by participants)

Condition	*+S/M, +O (theoria/theoro)*	*−S/M, +O (mania/mana)*
Related primed	571 (0.01)	579 (0.02)
Control primed	592 (0.01)	589 (0.02)
Priming effect	22	10
Condition	*+S/M, −O (poto/pino)*	*−S/M, −O (tricha/trivo)*
Related primed	568 (0.01)	577 (0.01)
Control primed	588 (0.01)	578 (0.01)
Priming effect	20	1

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between prime and orthography, $F_1(1, 45) = 2.4$, $p = .127$, $F_2(1, 184) = 1.3$, $p = .256$, nor between orthography and semantics (F_1, $F_2 < 1$). To establish the source of this interaction, t tests were performed on individual conditions. There was significant priming in the + S/M, + O condition, $t_1(46) = 4.2$, $p < .001$, $t_2(47) = 5.1$, $p < .001$, and the + S/M, − O condition, $t_1(46) = 4$, $p < .001$, $t_2(47) = 4.1$, $p < .001$, and these priming effects were not different from each other, $t_1(46) = -0.173$, $p = .863$, $t_2(47) = -0.174$, $p = .864$. There was a suggestion of priming in − S/M, + O condition, though this was marginal by items, $t_1(46) = 2.2$, $p = .032$, $t_2(47) = 1.9$, $p = .062$, and no priming in the − S/M, − O condition, $t_1(46) = 0.179$, $p = .859$, $t_2(47) = 0.023$, $p = .982$. There was neither a difference in the magnitude of priming between these latter two conditions, $t_1(46) = 1.5$, $p = .159$, $t_2(47) = 1.5$, $p = .131$, nor between the − S/M, + O condition and the + S/M, + O condition, $t_1(46) = 1$, $p = .301$, $t_2(47) = 1.6$, $p = .117$.

Contrary to Experiment 1 delayed priming facilitated responses only in the two conditions that included semantically related prime–target pairs (+ S/M, +/− O). Furthermore, this was the case irrespective of whether the prime was orthographically related to the target (e.g., θεωρία/θεωρώ, *theoria/theoro*, "theory/I theorize") or not (e.g., ποτό/πίνω, *poto/pino*, "drink/I drink"). Although the magnitude of priming was larger in the + S/M, + O conditions than the − S/M, + O condition, there was some suggestion that the semantically unrelated but orthographically related primes (− S/M, + O) facilitated the recognition of their targets (10 ms). This result is consistent with the delayed priming effects reported by Bozic et al. (2007) with English materials, where equivalent priming was observed for pairs like *archer/arch* (semantically and morphologically unrelated) and semantically and morphologically related pairs like *bravely/brave* (see though Rueckl & Aicher, 2008). Therefore, the weak delayed priming for the *mania/mana* pairs is an intermediate outcome between two outcomes reported in English. An important difference between the present experiment and the delayed priming experiments in English is that the orthographic condition (*mania*/*mana*) in the present experiment consists of morphologically structured pairs, where both the prime and target can be decomposed into stem and suffix, unlike the orthographic condition in the English studies (e.g., *corner*/*corn*), where this process can be applied only for prime. Thus, the observation of a weak delayed priming effect for the Greek orthographically related pairs could be based on the common process of morphological decomposition that could be applied equivalently to prime and target (see Bozic et al., 2007, for a discussion of the decomposability of the stimuli and its relationship to the orthographic priming effects in delayed priming). Unfortunately, to our knowledge the previous studies on Greek morphology (e.g., Tsapkini et al., 2002; Voga & Grainger, 2004) have not included an orthographic condition to allow comparisons with the present results. This result may also indicate that the mechanism producing priming effects in masked priming for semantically unrelated words with an apparent morphological relationship may not be completely distinct from the mechanism that produces delayed priming (see also Rueckl & Aicher, 2008, Experiment 2). We will come back to this point in Section "General discussion".

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COMPARISON BETWEEN EXPERIMENTS

Given the differences between the two experiments in the effects of orthography and semantics on priming, an additional analysis was performed comparing directly the magnitude of priming effects in the two experiments. In this analysis, experiment was entered as an unrepeated factor in the participants analysis and as a repeated factor in the items analysis.

The ANOVA showed a main effect of semantics, $F_1(1, 89) = 22.1$, $p < .001$, $F_2(1, 184) = 10.9$, $p = .001$, on the magnitude of priming, an effect of orthography in the items analysis only, $F_1 < 1$, $F_2(1, 184) = 6.2$, $p = .014$, and a main effect of experiment by participants only, $F_1(1, 89) = 34$, $p < .001$, $F_2 < 1$, suggesting that there were small differences in the amount of priming between experiments (larger masked priming than delayed priming). Experiment interacted with semantics, $F_1 < 1$, $F_2(1, 94) = 3.9$, $p = .050$, in the items analysis but not with orthography, $F_1(1, 89) = 2.7$, $p = .107$, $F_2 < 1$, and there was a three-way interaction between experiment, orthography, and semantics that showed only a trend towards significance, $F_1(1, 89) = 3.3$, $p = .075$, $F_1(1, 89) = 1$, $p = .312$. These results indicate that there were differences between experiments in the effects of semantics but not in the effects of orthography on priming. To explore further these interactions, *t* tests were used to compare the amount of priming in the two critical conditions, i.e., the $-$S/M, +O condition and the +S/M, $-$O condition, where potentially

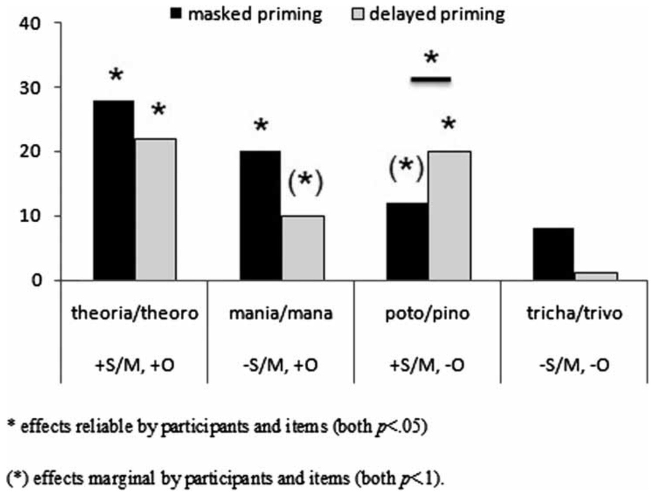

Figure 1. Priming effects in masked (Experiment 1) and delayed priming (Experiment 2).

interesting differences between masked and delayed priming could emerge. These tests showed differences between experiments (see Figure 1), mainly in the + S/M, − O condition, $t_1(45) = 3.4$, $p < .001$, $t_2(47) = 2.2$, $p = .030$, and a less reliable difference in the − S/M, + O condition, $t_1(45) = 5$, $p < .001$, $t_2(47) = -0.609$, $p = .546$. These differences reflect greater priming for the − S/M, + O condition in the masked priming experiment than the delayed priming experiment (20 ms vs. 10 ms, respectively) and additional priming for the + S/M, − O condition in delayed priming compared to masked priming (20 ms vs. 12 ms, respectively).

GENERAL DISCUSSION

The experiments in this paper intended to broaden our understanding of the conditions under which semantic and orthographic transparency influence the decomposition of morphologically complex words during recognition. To this end we compared in a single study the effects of semantic and orthographic transparency in masked and delayed priming. Previous research using delayed priming (and other paradigms; e.g., Drews & Zwitserlood, 1995) has provided evidence for a semantically constrained decomposition such that only complex words that are related in meaning are decomposed during recognition (e.g., Rueckl & Aicher, 2008). In contrast, research using the masked priming paradigm has provided evidence for a form of decomposition that segments all words that appear to be morphologically complex into their constituents, referred to as

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"morpho-orthographic decomposition" (e.g., Rastle et al., 2004). Two recent studies demonstrated that this process is not hindered by regular orthographic alterations (McCormick et al., 2008, 2009). Our aim was to further characterise the robustness of morpho-orthographic decomposition to semantic opacity and to orthographic changes (Experiment 1) and in the same time to compare it with the form of decomposition occurring under delayed priming conditions (Experiment 2). Thus, the experiments reported here represent a strong test of the idea of two processing stages in visual word recognition: an early morpho-orthographic stage and a later occurring morpho-semantic stage (Rastle & Davis, 2008), these stages of processing are most apparent in masked and delayed priming, respectively.

The results indicate that masked priming is modulated by orthographic opacity but not by semantic opacity: responses were facilitated by orthographically transparent primes but not by orthographically opaque primes. This pattern was not significantly affected by the semantic relationship between prime and target. Admittedly, priming effects for semantically unrelated pairs were numerically reduced compared to semantically related pairs, but they were still reliable and did not differ significantly between these two conditions. In Experiment 2, the results indicate that delayed priming is modulated by semantic opacity: responses were facilitated by morphologically and semantically transparent primes but not by semantically unrelated primes that share apparent morphological relationships. This pattern was not affected by the orthographic relationship between prime and target, with equivalent priming for orthographically transparent and opaque pairs. Critically, a comparison between the two experiments showed that masked and delayed priming are differentially affected by semantic factors, namely, that delayed priming relies more on the semantic/morphological information that is present in the words (or absent, in the case of semantically and morphologically unrelated words) than masked priming. Although the difference between experiments in the effects of orthographic transparency did not reach significance, posthoc comparisons revealed that the magnitude of delayed priming for morphologically complex words with an orthographically opaque relationship was larger than the magnitude of masked priming.

With regards to the effects of semantic transparency in masked priming, the results from Greek add to the body of evidence from a number of languages (e.g., Kazanina et al., 2008; Longtin & Meunier, 2005; Rastle & Davis, 2003) for a form of morphological decomposition that is insensitive to semantic characteristics and operates on the basis of apparent morphological complexity. However, in contrast to previous research showing that this form of decomposition is a flexible process that can tolerate regular orthographic alterations (McCormick et al., 2008), we found that it is not flexible enough to tolerate more extensive orthographic alterations found in morphologically

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complex words. Even though the effects of orthographic opacity on masked priming have not been systematically explored, the above observation is corroborated by some previous findings in inflectional morphology. For example, Rueckl et al. (1997) using masked fragment completion found more priming for irregular past-tense forms that differed by a single letter from their base form (e.g., *make/made*) than for past-tense forms that differed by at least two letters from their base form (e.g., *take/took*) (see also Voga & Grainger, 2004 for convergent results in Greek). Similar findings have also been observed in the nonconcatenative morphological system of Hebrew, where weak roots, in which one consonant is removed in certain conjugations, fail to prime targets comprising of the whole root (Frost, Deutch, & Forster, 2000). However, highly flexible masked priming has been observed in Arabic (Boudelaa & Marslen-Wilson, 2005), French (Meunier, Marslen-Wilson, & Ford, 2000), Greek (Tsapkini et al., 2002), and English (Crepaldi, Rastle, Coltheart, & Nickels, 2010; see also Pastizzo & Feldman, 2002) with irregular inflected pairs. Future work will need to specify the exact conditions under which masked priming can appear to be more or less bound to the orthographic appearance of the stimuli (e.g., inflectional vs. derivational morphology). For example, a potentially critical difference between inflectional and derivational morphology is that the latter creates new words, i.e., new lexical entries (cf. Blevins, 1999) with new meanings, unlike inflection that does not change the meaning or grammatical category of a word. Along these lines, a recent account of masked priming in inflectional morphology holds that it may not always be morpho-orthographic, especially for irregular cases, where the base stem cannot be extracted on the basis of orthographic analysis alone. Instead, Crepaldi et al. (2010) proposed that inflectional masked priming arises from an intermediate level between morpho-orthographic segmentation and semantic representations (lemma level), where inflected words but not derived words share their representation irrespective of orthographic regularity (Crepaldi et al., 2010).

With regard to the effects of semantic transparency in delayed priming, the results from the present study are consistent with previous evidence from delayed priming (e.g., Rueckl & Aicher, 2008) and other procedures (e.g., cross-modal priming; Gonnerman et al., 2007) for a form of morphological decomposition that is sensitive to the semantic characteristics of the morphologically complex words. The present data also advance our understanding of this form of decomposition in showing unambiguously that it is robust to orthographic opacity. These results extend previous findings of equivalent facilitation in delayed priming for morphological relatives without (*healer/heal*) or with regular orthographic alterations (*health/heal*) (Fowler, Napps, & Feldman, 1985; Marslen-Wilson, Zhou, & Ford, 1996; Napps, 1989). Regarding more disruptive orthographic changes, data from inflectional morphology are informative. In delayed visual priming (Stolz &

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Feldman, 1995), regular inflected forms (e.g., *walked*) and irregular inflected forms (e.g., *gave*) are efficient primes of their base verb (*walk* and *give* respectively) (see also Marslen-Wilson & Tyler, 1998, for auditory presentation). Similar results have been reported in Hebrew, where priming in a lexical decision task for visual prime/target pairs related by inflection or derivation was not influenced by changes in the repeated root morpheme (the word pattern did or did not visually disrupt the letter sequence that forms the root; Feldman & Bentin, 1994).

The divergence of masked and delayed priming in the effects of semantic transparency and to a lesser extent of orthographic opacity provides support for the notion put forward by Rastle and Davis (2008) for two stages in the recognition of morphologically complex words. According to this theory, the recognition of morphologically complex words starts with a rapid morphemic segmentation, which decomposes all visual stimuli with an apparent morphological structure, irrespective of their semantic features. This process seems to operate early in visual word recognition, since the priming effects for the semantically unrelated words are usually evident in masked priming but not in other priming paradigms. This rapid morpho-orthographic decomposition can proceed despite orthographic alterations in morphologically complex words but is not flexible enough to survive more extensive orthographic changes. At later points in the time course of visual word recognition, morpho-orthographic decomposition is replaced by a form of decomposition that is semantically informed (Rastle & Davis, 2008). This process is sensitive to the semantic relationship between morphological relatives, operates later in word recognition and is insensitive to orthographic opacity.

Another way to explain the present results is to assume that these two types of decomposition observed in masked and delayed priming are the product of a single processing stage during visual word recognition (Rastle & Davis, 2008; Rueckl & Aicher, 2008). According to this theory, all complex words are initially decomposed and at later points in the time course of recognition inappropriate decompositions are being ruled out (e.g., interpreting *corner* as *corn + er,* -er cannot be combined with nouns*)*. One problem with this theory and the present results is that in Greek (and potentially in other morphologically rich languages), all words can be decomposed into stem and affixes. This means that the morphologically structured and semantically unrelated pairs like *mania/mana* can be decomposed (*man + ia, man + a,* these two words share the homophonic root *man*-, which has a different meaning in each case*)* without this resulting in the kind of inappropriate decomposition we find in the case of corner/CORN (both -*ia* and -*a* can be combined with *man*-). Another issue with this account is that it does not provide a straightforward explanation of why there is no (or less) priming for the decomposable, semantically related and

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orthographically opaque pairs like *pot + o/pin + o* in masked priming, unlike delayed priming. It is not the case that an incorrect early segmentation is "ruled out", rather that an orthographically opaque relationship is revealed to be morphological when semantic information is available. It is hard to see how this could be achieved without using a top-down process.

A last aspect of the results we wish to consider involves the robustness of delayed priming to orthographic opacity. McCormick et al. (2008) explained the robustness of masked priming to regular orthographic changes (e.g., missing "e") in terms of the underspecification of stems that undergo regular orthographic changes (see Taft, 1979). The authors argued that such stems may be represented orthographically such that surface variations can be tolerated once a suffix is segmented (e.g., by marking a final "e" as optional). Thus, the orthographic representation of a stem like *adore* may include an underspecified final "e", which would allow the activation of the stem for derived words like *adorable* where the final "e" is missing. However, it is difficult to envisage how this would be possible for the extensive and unpredictable changes to the stem in the case of the orthographic opacity. One possible mechanism discussed by Marslen-Wilson and Tyler (1998) for the recognition of auditory irregular inflected words in English is that both phonological alternants of irregular verbs are listed, but they share semantic and syntactic features. By analogy to visual word recognition then, we could argue that for words that undergo extensive orthographic changes to their stems, there are separate orthographic representations of the two stems but they share some features in the semantic system (see also Tsapkini et al., 2002, for a similar account of regular and irregular inflected words in Greek; Crepaldi et al., 2010). This would explain why priming is not observed for this kind of words in masked priming but they do emerge in delayed priming. Note that this account implicitly assumes that masked and delayed priming reflect different processing stages in visual word recognition, consistent with other dissociations of morpho-orthographic and morpho-semantic decomposition.

To conclude, the experiments reported here provided definitive evidence that semantically transparent primes produce more facilitation in delayed priming than semantically opaque primes, while orthographically transparent primes produce more facilitation in masked priming than orthographically opaque primes. However, there was some suggestion that semantically opaque primes facilitated recognition of their targets in delayed priming, and similarly for orthographically opaque primes in masked priming. Thus, on the basis of the present results we may propose that morpho-orthographic decomposition is dominated by orthographic information, while morpho-semantic decomposition is dominated by semantic information but we also note that orthographic and semantic information is not overlooked by the process that produces delayed priming and, similarly, that morphological/

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semantic information is not overlooked by the process that produces masked priming (see also Rueckl & Aicher, 2008). A complete theory of the nature of the representations used in skilled reading will have to determine precisely the weight of the different kinds of information (orthographic and semantic) during visual recognition of the various types of words encountered by readers of different languages (e.g., irregularly inflected words and semantically opaque words) and how these characteristics are reflected in different behavioural indices.

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APPENDIX

Sample stimuli for each condition (related prime, target, and unrelated control). Transliterations are according to ISO 843: 1996, International Organisation for Standardisation

Condition	*Related prime*	*Target*	*Unrelated control*
+S/M	**ωφέλεια** /ofeleia/	**ωφελώ** /ofelo/	**αγκαλιά** /agkalia/
+O	"benefit"	"I benefit"	"hug"
	αντλία /antlia/	**αντλώ** /antlo/	**δοχείο** /docheio/
	"pump"	"I pump"	"container"
	τιμωρία /timoria/	**τιμωρώ** /timoro/	**σκοπεύω** /skopeuo/
	"punishment"	"I punish"	"I intend"
	γραφή /grafi/	**γράφω** /grafo/	**σπίτι** /spiti/
	"writing"	"I write"	"house"
	οδηγός /odigos/	**οδηγώ** /odigo/	**σφίγγω** /sfiggo/
	"driver"	"I drive"	"I tighten"
S/M	**στεριά** /steria/	**στερώ** /stero/	**ωραίος** /oraios/
+O	"land"	"I deprive"	"beautiful"
	φύση /fisi/	**φυσάω** /fisao/	**χώμα** /choma/
	"nature"	"I blow"	"mud"
	σφυρί /sfiri/	**σφυρίζω** /sfirizo/	**άγχος** /angchos/
	"hammer"	"I whistle"	"stress"
	σελίδα /selida/	**σέλινο** /selino/	**λαχείο** /lacheio/
	"page"	"celery"	"lottery"
	ξερός /kseros/	**ξέρω** /ksero/	**σκέψη** /skepsi/
	"dry"	"I know"	"thought"
+S/M	**κάψιμο** /kapsimo/	**καίω** /kaio/	**τρύγος** /trigos/
−O	"burn"	"I burn"	"vine harvest"
	πλυντήριο /plintirio/	**πλένω** /pleno/	**τουρίστας** /touristas/
	"washing-machine"	"I wash"	"tourist"
	φθορά /fthora/	**φθείρω** /ftheiro/	**τρέμω** /tremo/
	"decay"	"I wear down"	"I tremble"
	κλοπή /klopi/	**κλέβω** /klevo/	**χρήση** /chrisi/
	"robbery"	"I steal"	"usage"
	φυγάς /figas/	**φεύγω** /feugo/	**αρετή** /areti/
	"fugitive"	"I leave"	"virtue"
−S/M	**πλήθος** /plithos/	**πλάθω** /platho/	**ενοχλώ** /enochlo/
−O	"crowd"	"I mold"	"I bother"
	μυρωδιά /mirodia/	**μοιράζω** /moirazo/	**φοβάμαι** /fovamai/
	"smell"	"I distribute"	"I am afraid"
	μέλι /meli/	**μιλάω** /milao/	**δώρο** /doro/
	"honey"	"I talk"	"gift"
	ψαλίδι /psalidi/	**ψέλνω** /pselno/	**αρπάζω** /arpazo/
	"scissors"	"I chant"	"I grasp"
	σειρά /seira/	**σέρνω** /serno/	**ρόλος** /rolos/
	"order"	"I drag"	"role"

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