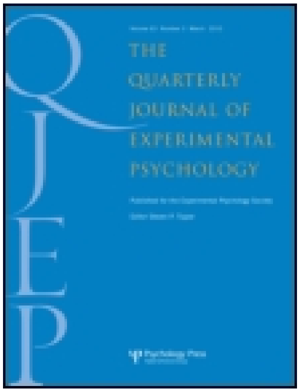

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Rapid Communication

Does tonal information affect the early stages of visual-word processing in Thai?

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Thai offers a unique opportunity to investigate the role of lexical tone processing during visual-word recognition, as tone is explicitly expressed in its script. In order to investigate the contribution of tone at the orthographic/phonological level during the early stages of word processing in Thai, we conducted a masked priming experiment—using both lexical decision and word naming tasks. For a given target word (e.g., ห้อง/hɔːŋ2/, room), five priming conditions were created: (a) identity (e.g., ห้อง/hɔːŋ2/), (b) same initial consonant, but with a different tone marker (e.g., ห่อง/hɔːŋ1/), (c) different initial consonant, but with the same tone marker (e.g., ค้อง/sɔːŋ2/), (d) orthographic control (different initial consonant, different tone marker; e.g., ค่อง/sɔːŋ1/), and (e) same tone homophony, but with a different initial consonant and different tone marker (e.g., ธ่อง/t^hɔːŋ2/). Results of the critical comparisons revealed that segmental information (i.e., consonantal information) appears to be more important than tone information (i.e., tone marker) in the early stages of visual-word processing in alphabetic, tonal languages like Thai. Thus, these findings may help constrain models of visual-word recognition and reading in tonal languages.

Keywords: Lexical decision; Masked priming; Rapid naming; Thai; Tone processing; Visual-word processing.

Current models of reading and visual-word recognition are notoriously Anglocentric, primarily focusing on a language (i.e., English) with an "outlier" orthographic system (Frost, 2012; see also Share, 2008). In many other languages, tone information (i.e., the pitch of a syllable) is used to distinguish words. For instance, the syllable /da/ in the most widely spoken tonal language, Mandarin Chinese, has quite different meanings depending on its tone: /da1/ (high level, first tone; "to put up"); /da2/ (rising, second tone; "to answer"); /da3/ (falling rising, third tone; "to hit"); and /da4/ (falling, fourth tone; "big"). Thus, one important issue for a universal model of visual-word recognition and reading is whether tonal information plays a role in the early stages

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of lexical access in tonal languages (as segmental information does) or whether its effect occurs at a later processing stage, after lexical retrieval.

Previous studies in Chinese have failed to find an effect of tonal information during the early stages of visual-word processing using a masked priming paradigm technique. In a series of word naming experiments, Chen, Lin, and Ferrand (2003) found faster response times on a bisyllabic target word when a briefly presented word prime shared the initial syllable with the target regardless of whether the syllable had the same tone or not as the target (e.g., the prime 爸/ba4/, "father", facilitated the processing 拔营/ba2.ying2/, "break up camp", more than the prime 败/bai4/, "failure"; see also You, Zhang, & Verdonschot, 2012, for a similar finding). The presence of an atonal effect of the syllable in Chinese suggests that "the syllable (lacking the tone) is a stored phonological chunk" (Chen et al., 2003, p. 116) and that the tone does not play a special role early in visual-word processing (see Taft, Zhu, & Peng, 1999, for a hierarchical model of character recognition in Chinese). Thus, at the phonological level, segmental metric (i.e., the syllable) seems to be more important than metrical encoding (i.e., the tone) in Chinese (see You et al., 2012). However, the tone is not explicitly written in Chinese (e.g., /da1/, /da2/, /da3/, and /da4/ would correspond to 搭, 答, 打, and 大, respectively), and, hence, it may be difficult to capture an early effect of lexical tone in Chinese word processing.

A more straightforward test of the role of the tones during the early stages of visual-word recognition would be provided in a language in which the tone is explicitly written in its script. This is the case of Thai, an alphabetic orthography with five tones (i.e., five different F0 contours) conceptualized as high, mid, falling, rising, and low, and four tone markers (*maj3 e:k1* ◌่, *maj3 tho:0* ◌้, *maj3 tri:0* ◌๊, and *maj3 tɕat1ta1wa:0* ◌๋) that orthographically occur above the consonant.[1] As in other tonal languages (e.g., Chinese), tone forms an integral element of the syllable in Thai and serves an essential function in distinguishing meanings of syllables and words with identical phonological structure. An example in Thai is ขาว/k^{h}a:w4/ (white), ข่าว/ k^{h}a:w1/ (news), and ข้าว/ k^{h}a:w2/ (rice). It is also pertinent for the current study to note here that a phonologically equivalent tone for the rime of the syllable, as in the latter example ข้าว/k^{h}a:w2/ "rice" (high-class consonant ข/k^{h}/), can be attained when an orthographically different consonant (from a different consonant class—in this case a low-class consonant น/n/) is combined with an orthographically different tone marker, as in the example, น่าว/na:w2/. (The consonant class distinction is explained in greater detail in a subsequent section.)

Thus, Thai offers a unique opportunity to investigate the role of lexical tone processing during visual-word recognition. Evidence concerning the effect of tone in Thai is very scarce. In a previous study, Winskel (2011, Experiment 3) investigated whether parafoveal lexical tone information contributed to the subsequent processing of the target word in continuous reading in Thai. The tone marker of the parafoveal preview was manipulated so that it was either identical or different from the target word (e.g., identity: ท้องฟ้า/t^{h}ɔ:ŋ3fa:3/ "sky", or control: ท่อง ฟ่า/ t^{h}ɔ:ŋ2fa:2/). If useful information were obtained from the parafoveal input of the tone markers, then the identical preview would have a greater facilitatory effect on processing of the target word than the incorrect tone marker preview (phonologically and orthographically different). Results indicated a facilitatory effect of the identical tone marker in comparison to the incorrect tone marker preview, and it was concluded that tone information plays a key role in the early processing of Thai words. However, there were no phonological controls included in this experiment, and, hence, it was unclear what the nature of the effect of tone information was. Finally, we should indicate that Thai is sensitive to subsyllabic manipulations—in a similar way to

[1] Tones are marked in the Thai examples cited in this paper as follows: 0 = mid, 1 = low, 2 = falling, 3 = high, 4 = rising. This is based on the system that was developed at the Linguistics Research Unit (LRU) of Chulalongkorn University (Luksaneeyanawin, 1993). International Phonetic Alphabet (IPA) transcription is used for the transcription of all other Thai text.

Indo-European languages. In a recent masked priming lexical decision experiment on Thai, Perea, Winskel, and Ratitamkul (2012) found form (transposed-letter) priming effects in Thai relative to the appropriate (replacement-letter) control condition (i.e., าบท– บาท faster than พะท–บาท) as well as an advantage of the identity priming condition over the transposed-letter priming condition (i.e., บาท– บาท faster than าบท–บาท; see also Winskel & Perea, 2013, for evidence of transposed-letter effects using parafoveal previews during normal silent reading).

In Thai, consonant letters are divided into three classes (11 high, 9 middle, 24 low), which reflects old voicing distinctions that have been neutralized in modern Thai (Gandour, 2013; Hudak, 1990). These particular classifications of the initial consonant (high, medium, low) in conjunction with the tone marker contribute to phonological tone realization in written Thai. These different features can be manipulated to investigate the contribution they make to early lexical processing. In the current study, a lexical decision task (Experiment 1a) and rapid naming task (Experiment 1b) in conjunction with the masked priming paradigm were used to investigate the contribution of orthographic and phonological features to lexical tone processing during the early stages of visual-word processing in Thai. The masked priming technique is a paradigm that taps into early processing (Forster & Davis, 1984; see Grainger, 2008, for a recent review of the masked priming literature). Given that the rapid naming task explicitly requires an articulatory response, it was important to use the same materials in a task in which phonological effects are not inherent, such as lexical decision (see Carreiras, Ferrand, Grainger, & Perea, 2005; New, Araújo, & Nazzi, 2008). The rationale here is that if a phonological effect occurs in several tasks (in particular in those that do not require a mandatory phonological output), this would provide support for the view that these phonological effects presumably reflect core (task-independent) processes rather than ancillary, task-specific processes. For instance, Carreiras et al. (2005) found masked phonological priming effects in French, for the initial phonological syllable (*fomie–FAUCON* faster than *fémie–FAUCON*; note that "fo" and "fau" correspond to the same syllable), regardless of whether or not an articulatory output was mandatory (i.e., the same effect was obtained in naming and lexical decision). Carreiras et al. concluded that phonological codes can be activated very rapidly and that this effect was not task dependent.

To study the contribution of tone at the orthographic/phonological level during the early stages of word processing in Thai, we used five different primes for a given target word (e.g., ห้อง/hɔːŋ2/ "room")—all the primes were nonwords except for the identity prime in word trials: (a) identity (e.g., ห้อง/hɔːŋ2/); (b) same initial consonant, but with a different tone marker (e.g., ห่อ ง/hɔːŋ1/); (c) different initial consonant, but with the same tone marker (e.g., ศ้อง/ sɔːŋ2/); (d) orthographic control (different initial consonant, different tone marker; e.g., ศ่อง/sɔːŋ1/); and (e) same tone homophony, but with a different initial consonant and different tone marker (e.g., ธ่อง/t^hɔːŋ2/; see Table 1). We should note here that, in the present experiment, the initial consonant could occur in the initial letter position (e.g., as in ห้อง/hɔːŋ2/ "room") or in the second letter position (e.g., โป้ง oːpŋ/poːŋ2/ "thumb"). In Thai, there are five misaligned vowels that occur orthographically prior to the consonant they phonologically follow and five vowels that occur after the consonant in which orthography and phonology are aligned or congruent (see Winskel, 2009, and Perea et al., 2012, for discussion on aligned/misaligned vowels in Thai).

The predictions are straightforward. First, if the orthographic representation of the tone marker is playing a role during the early stages of word processing (as captured by masked priming effects), then we expect Prime 1 (identity C + T + , where C = consonant and T = tone) to have a facilitative effect in comparison to Prime 2 (same consonant, but different tone marker C + T–)—this would replicate at the foveal level the effect obtained by Winskel (2011) at the parafoveal level. Second, if the initial consonant has an impact early in visual-word recognition (regardless of tone), then we expect Prime 2 (same consonant, different tone marker C + T–) to have a facilitative effect

Table 1. *Mean latencies for the lexical decision task with the five different types of prime*

Type of prime	*Target*	*Example*	*Stimuli*	
			Word	*Nonword*
	ห้อง/hɔ:ŋ2/ "room"			
1. Identity (C+T+)		ห้อง/hɔ:ŋ2/ (high-class initial consonant)	524 (2.4)	570 (4.0)
2. Same initial consonant (C+T–) different tone marker, different tone realization		ห่อง/hɔ:ŋ1/ (high-class initial consonant)	539 (3.2)	570 (3.5)
3. Same tone marker (C–T+) different initial consonant, same tone realization		ศ้อง/sɔ:ŋ2/ (high-class initial consonant)	553 (1.9)	569 (3.2)
4. Orthographic control (C–T–) different initial consonant, different tone marker, different tone realization		ศ่อง/sɔ:ŋ1/ (high-class initial consonant)	554 (2.6)	569 (3.7)
5. Same tone homophony (C–T–+) different initial consonant, different tone marker, same tone realization		ธ่อง t^hɔ:ŋ2/ (low-class initial consonant)	557 (3.0)	572 (1.4)

Note: Mean latencies in milliseconds. Percentage of errors is also given (in parentheses). Tones are marked as follows: 0 = mid, 1 = low, 2 = falling, 3 = high, 4 = rising. C = consonant, T = tone.

in comparison to Prime 4 (different consonant, different tone marker (C–T–). Third, if the tone (at least at an orthographic level) has an early effect during word processing (regardless of the accompanying consonant), we can expect Prime 3 (same tone marker, different consonant C–T+) to have a facilitative effect in comparison to Prime 4 (different tone marker, different consonant C–T–). And fourth, if there is a purely phonological effect due to the tone at the early stages of processing, then we can expect Prime 5 (same tone homophony, but different initial consonant and tone marker C–T–+) to have a facilitative effect in comparison to Prime 4, the orthographic control (C–T– –). The rationale of this contrast is that phonological priming effects are expected to be greater when primes and targets differ graphemically than when they are graphemically similar (Frost, Ahissar, Gottesman, & Tayeb, 2003). In a series of experiments, Frost et al. (2003) varied orthographic and phonological similarity between primes and targets in Hebrew using a lexical decision task with masked priming. They found relatively small effects with the homophonic-1-letter-different primes in comparison to the 2–3-phoneme-different primes (termed the large phonological contrast). As the computed phonological code may initially be coarse grained, substantial phonological contrasts are required to obtain purely masked phonological priming effects with the masked priming paradigm. Thus, according to this account, a difference between Primes 4 and 5 may occur in the absence of a difference between Primes 3 and 4 (i.e., the less orthographically similar the pairs are, the more likely there is an effect of phonology). Finally, as in prior masked priming experiments in orthographies in which there is no lower/upper case distinction, and to avoid visual continuity, primes were presented in lower size than the targets (e.g., see Perea et al., 2012).

Method

Participants

Seventy students and staff from Chulalongkorn University, Bangkok, participated for payment in the experiment, half of them in the lexical decision task and the other half in the naming task. All participants had normal or corrected-to-normal vision and were native speakers of Thai. None of them reported having any reading disability.

Materials

The targets were 120 Thai words with five different prime conditions. The words selected were mono- and bisyllabic and ranged in length from 3 to 6 letters ($M = 3.9$). The mean word frequency was 731 words per million and ranged from 1 to 2,542 words per million (the Thai National Corpus, TNC; Aroonmanakun, 2007). In each task, there were five counterbalanced lists with seven participants per list. All the primes were nonwords except for the identity prime. For the lexical decision task, a set of 120 orthographically legal pseudowords was created (average number of syllables = 1.49, and average number of letters = 3.88)—the corresponding primes were created in a similar way to those of the word targets.

Procedure

The lexical decision and the naming tasks were run using DMDX (Forster & Forster, 2003). Participants were tested individually in a quiet room. Presentation of the stimuli and recording of response times were controlled by DMDX software (Forster & Forster, 2003). Each participant received a total of 20 practice trials prior to the experimental phase. In the lexical decision task, each trial began with a forward mask consisting of a row of hash marks (#s) and was presented for 500 ms in the centre of the computer screen. Then, the prime was presented in 14-pt Courier Thai font and stayed on the screen for 50 ms (i.e., three refresh cycles in the computer monitor). The prime was immediately followed by the presentation of the target stimulus in 20-point Courier Thai font—note that the prime was presented in a smaller size to avoid visual continuity. Both prime and target were presented in the same screen location as the forward mask. The target stimulus remained on the screen until the participant's response—or until 3,000 ms had elapsed. In the lexical decision task, participants were told that words and nonwords would be displayed on the monitor in front of them, and that they should press the "yes" button to indicate if the stimulus was an existing Thai word or the "no" button if the stimulus was not a word. They were instructed to respond as quickly as possible while maintaining a reasonably high level of accuracy. Each participant received a different random order of stimuli. The lexical decision task session lasted approximately 15 min. For the naming task, the procedure was the same as that in the lexical decision task, except that the participants' task was to read aloud the words as quickly and as accurately as possible. Naming latencies were measured and recorded by DMDX via a microphone—after the experiment, naming times were analysed using CheckVocal (Protopapas, 2007). The naming task session lasted approximately 12 min.

Results

Experiment 1a: Lexical decision task

Incorrect responses (2.6% of the data for words and 3.2% for nonwords) and response times less than 250 ms or greater than 1,500 ms (0.75% of trials) were excluded from the latency analysis. The mean response times and error percentages from the subject analysis are presented in Table 1.

We conducted the planned comparisons outlined in the introduction for the word data in the lexical decision task. In addition, for the sake of completeness, the t and Markov Chain Monte Carlo p values of the linear mixed effects (LME) are also reported for the planned comparisons—in all these tests, on the basis of likelihood ratios, we chose the models with subjects and items as random effects (see Baayen, Davidson, & Bates, 2008). But before reporting these analyses, we should indicate that the omnibus analysis of variance (ANOVA) based on a 5 (type of prime: identity, Type 2, Type 3, Type 4, Type 5) by 5 (List: List 1, List 2, List 3, List 4, List 5) design revealed a main effect of type of prime: $F_1(4, 34) = 9.75$, $p < .001$, $\eta_p^2 = .245$; $F_2(4, 119) = 6.77$, $p < .001$, $\eta_p^2 = .045$. Neither the ANOVA on the (word) error data nor the ANOVAs on the latency/error data on the pseudowords revealed any effects of type of prime (all *F*s < 1).

Combined effects of consonant + tone marker. Response times on the target words were faster when preceded by the identity prime that had the same initial consonant with the same tone marker (e.g., ห้อง/ hɔ:ŋ2/–ห้อง/ hɔ:ŋ2/C + T+) than when the prime had the same initial consonant but did not have the same tone marker (ห่อง/hɔ:ŋ1/–ห้อง/ hɔ:ŋ2/C + T–), $F_1(1, 34) = 7.43$, $p < .01$, $\eta_p^2 = .199$; $F_2(1, 119) = 4.04$, $p < .05$, $\eta_p^2 = .017$ (LME: $t = 2.23$, $p_{MCMC} = .026$). This implies that the tone marker was being processed early during word processing in the lexical decision task.

The role of the initial consonant. Response times on the target words were faster when preceded by a prime that had the same initial consonant (ห่อง/hɔ:ŋ1/–ห้อง/hɔ:ŋ2/C + T–) than when the prime did not have the same initial consonant (ศ่อง/sɔ:ŋ1/–ห้อง/ hɔ:ŋ2/C–T–), $F_1(1, 34) = 4.58$, $p < .05$, $\eta_p^2 = .132$; $F_2(1, 119) = 4.66$, $p < .05$, $\eta_p^2 = .019$; LME: $t = -2.21$, $p_{MCMC} = .027$). This implies that the consonant alone facilitates the processing of the target word—regardless of tone information.

The role of the tone marker (without the correct initial consonant). Response times on the target words were similar when preceded by a prime that had the same tone marker as the target word but not the same initial consonant (ศ้อง/sɔ:ŋ2/– ห้อง/hɔ:ŋ2/C–T+) and when preceded by a prime that had a different tone marker and a different initial consonant (ศ่อง/ sɔ:ŋ1/–ห้อง/ hɔ:ŋ2/C–T–), both *F*s < 1 (LME: $t < 1$, $p_{MCMC} > .94$). Because we are relying on the null hypothesis in this comparison, we computed the probability of the null hypothesis being true, given the obtained data, *p*(H0|D; Wagenmakers, 2007; see also Masson, 2011). The corresponding values were $p(H_0|D) = .85$ and .92 for subject and item analyses. Thus, we can conclude that the tone marker alone does not facilitate the processing of the target word.

The role of tone homophony. Response times on the target words were similar when preceded by a prime that had the same phonological tone (but with a different tone marker) as the target word but different initial consonant (ธ่อง/tʰɔ:ŋ2/–ห้อง/ hɔ:ŋ2/C–T–+) and when preceded by a prime that had a different phonological tone, different initial consonant, and different tone marker (ศ่อง/ sɔ:ŋ1/–ห้อง/ hɔ:ŋ2/C–T—), both *F*s < 1 (LME: $t < 1$, $p_{MCMC} > .60$), $p(H_0|D) = .84$ and .91 for subject and item analyses, respectively. Thus, sharing the same phonological tone does not speed up the processing of the target word.

Experiment 1b: Naming task

Incorrect responses and response times less than 300 ms or greater than 900 ms (2.8% of the data) were excluded from the latency analyses. The mean response times are presented in Table 2. The statistical analyses were parallel to those on word targets in Experiment 1a, and the ANOVA on the mean response times revealed a main effect of type of prime: $F_1(4, 34) = 15.65$, $p < .001$, $\eta_p^2 = .343$; $F_2(4, 119) = 6.52$, $p < .001$, $\eta_p^2 = .211$. We conducted the planned comparisons outlined in the introduction for the naming task.

Combined effects of consonant + tone marker. Response times on the target words were faster when preceded by the identity prime that had the same initial consonant with the same tone marker (e.g., ห้อง/ hɔ:ŋ2/–ห้อง/ hɔ:ŋ2/C + T+) than when the prime had the same initial consonant but did not have the same tone marker (ห่อง/hɔ:ŋ1/–ห้อง/ hɔ:ŋ2/C + T–) for participants, $F_1(1, 34) = 16.06$, $p < .001$, $\eta_p^2 = .349$, and marginally for items, $F_2(1, 119) = 2.28$, $p = .08$ (LME: $t = 2.20$, $p_{MCMC} = .028$). Thus, as occurred in the lexical decision task, the tone marker in the naming task was also being processed early during word processing.

The role of the initial consonant. Response times on the target words were faster when preceded by a prime that had the same initial consonant (ห่อง/hɔ:ŋ1/–ห้อง/hɔ:ŋ2/C + T–) than when the prime did not have the same initial consonant (ศ่อง/sɔ:

Table 2. *Mean latencies for the naming task with the different types of primes*

Type of prime	*Target* ห้อง/*hɔ:ŋ2/ "room"*	*Example*	*RT*
1. Identity (C+T+)		ห้อง/hɔ:ŋ2/ (high-class initial consonant)	494
2. Same initial consonant (C+T–), different tone marker, different tone realization		ห่อง/hɔ:ŋ1/ (high-class initial consonant)	506
3. Same tone marker (C–T+), different initial consonant, same tone realization		ศ้อง/sɔ:ŋ2/ (high-class initial consonant)	515
4. Orthographic control (C–T–), different initial consonant, different tone marker, different tone realization		ศ่อง/sɔ:ŋ1/ (high-class initial consonant)	516
5. Same tone homophony (C–T–+), different initial consonant, different tone marker, same tone realization		ธ่อง t^hɔ:ŋ2/ (low-class initial consonant)	512

Note: Mean latencies (RT = reaction time) in milliseconds. Tones are marked as follows: 0 = mid, 1 = low, 2 = falling, 3 = high, 4 = rising. C = consonant, T = tone.

ŋ1/–ห้อง/hɔ:ŋ2/C–T–), $F_1(1, 34) = 6.95$, $p < .05$, $\eta_p^2 = .188$; $F_2(1, 119) = 3.77$, $p = .05$, $\eta_p^2 = .015$ (LME: $t = -2.13$, $p_{MCMC} = .03$). As in the lexical decision task, this implies that the consonant alone facilitates the processing of the target word in the naming task, regardless of tone information.

The role of the tone marker (without the correct initial consonant). Response times on the target words were similar when preceded by a prime that had the same tone marker as the target word but not the same initial consonant (ศ้อง/sɔ:ŋ2/–ห้อง/hɔ:ŋ2/C–T+) and when preceded by a prime that had a different tone marker and a different initial consonant (ศ่อง/sɔ:ŋ1/–ห้อง/hɔ:ŋ2/C–T–), both Fs < 1 (LME: $t < 1$, $p_{MCMC} > .89$). The corresponding $p(H_0|D)$ values were .84 and .87 for subject and item analyses. Thus, we can conclude that the tone marker alone does not facilitate the processing of the target word.

The role of tone homophony. Response times on the target words were similar when preceded by a prime that had the same phonological tone (but with a different tone marker) as the target word but different initial consonant (ธ่อง/t^hɔ:ŋ2/–ห้อง/hɔ:ŋ2/C–T–+) and when preceded by a prime that had a different phonological tone, different initial consonant, and different tone marker (ศ่อง/sɔ:ŋ1/–ห้อง/hɔ:ŋ2/C–T—), both Fs < 1 (LME: $t < 1$, $p > .46$), $p(H_0|D) = .85$ and .91 for subject and item analyses, respectively. Thus, sharing the same phonological tone does not speed up the processing of the target word.

Combined analysis of lexical decision and naming. We also conducted an overall ANOVA in which task (lexical decision, naming) was included as a between-subjects (but within-item) factor, with type of prime (identity, Type 2, Type 3, Type 4, Type 5) and List (List: List 1, List 2, List 3, List 4, List 5) as additional factors in the design. The ANOVA on the latency data showed that, unsurprisingly, latencies were significantly shorter for the naming than for the lexical decision task: $F_1(1, 69) = 6.53$, $p < .001$, $\eta_p^2 = .349$; $F_2(1, 119) = 145.89$, $p < .001$, $\eta_p^2 = .112$. The main effect of type of prime was also significant: $F_1(4, 69) = 19.71$, $p < .001$, $\eta_p^2 = .247$; $F_2(4, 119) = 10.58$, $p < .001$, $\eta_p^2 = .035$. More important, the effect of type of prime was similar in the lexical decision and naming tasks, as deduced from the lack of an interaction between the two factors (both Fs < 2).

Discussion

The present masked priming experiment in Thai revealed a number of findings, which were parallel in lexical decision and naming. First, the tone marker from the briefly presented masked prime is being processed early during visual-word processing because there is an advantage of the identity condition (ห้อง/hɔ:ŋ2/–ห้อง/hɔ:ŋ2/C + T+) relative to the priming condition, which had the same initial consonant but with a different tone marker (ห่อ ง/ hɔ:ŋ1/–ห้อง/ hɔ:ŋ2/C + T–). Second, we found that the consonant alone, regardless of the tone marker, facilitates the processing of the target word. This was apparent as there was an advantage of the priming condition that had the same initial consonant and a different tone marker (ห่อง/hɔ:ŋ1/–ห้อง/hɔ:ŋ2/C + T–) relative to the condition with a different initial consonant and a different tone marker (ศ่อง/sɔ:ŋ1/–ห้อง/hɔ:ŋ2/C–T–). Third, we found that the orthographic tone marker alone, regardless of the initial consonant, did not facilitate the processing of the target word. There were virtually no differences between the priming condition with the same tone marker as the target word but not the same initial consonant (ศ้ อง/ sɔ:ŋ2/–ห้อง/ hɔ:ŋ2/C–T+) and the priming condition with a different tone marker and a different initial consonant (ศ่ อง/ sɔ:ŋ1/–ห้อง/ hɔ:ŋ2/C–T–). And fourth, we found that phonological tone alone, regardless of the initial consonant, did not facilitate the processing of the target word either. The responses to the target words were similar when the prime had the same phonological tone (with a different tone marker) as the target word but different initial consonant (ธ่อง/t^hɔ:ŋ2/–ห้อง/hɔ:ŋ2/C–T–+) and when preceded by a prime that had a different phonological tone, different initial consonant, and different tone marker (ศ่อง/sɔ:ŋ1/–ห้อง/hɔ:ŋ2/C–T––).

Taken together, these results demonstrate that the identity of the initial consonant is more relevant in the initial stages of word processing than the identity of the tone marker. The lack of a purely phonological effect of tone occurred both when the tone in the prime had the same orthographic tone marker (ศ้ อง/ sɔ:ŋ2/–ห้อง/ hɔ:ŋ2/C–T + +) and when the tone had the same phonological tone (ธ่อง/t^hɔ:ŋ2/–ห้อง/hɔ:ŋ2/C–T–+) as in the target word. Furthermore, the present data suggest that there is an additive orthographic facilitative effect when the identical initial consonant is paired with the identical tone marker (e.g., ห้) in Thai, as response times on the target words were faster when preceded by the identity prime that had the same initial consonant with the same tone marker (e.g., ห้อง/ hɔ:ŋ2/–ห้อง/ hɔ:ŋ2/C + T+) than when the prime had the same initial consonant but did not have the same tone marker (ห่อ ง/ hɔ:ŋ1/–ห้อง/ hɔ:ŋ2/C + T–)—note that this effect of the tone marker was similar to the effect reported by Winskel (2011) with parafoveal previews in Thai.

Thus, the present data suggest that the influence of tone markers during the early stages of visual-word recognition occur when they are linked to the correct consonant, but are absent when concatenated with the incorrect consonant. It is important to note here that even though masked phonological priming effects may be subtle, they have been reported in various languages and labs (e.g., Carreiras et al., 2005; see Rastle & Brysbaert, 2006, for a review). In the present experiment, the number of participants was reasonably high ($N = 70$), and we conducted the manipulations across two well-known tasks (lexical decision and naming). Indeed, we found masked priming effects due to the initial consonant (regardless of tone marker) as well as masked priming effects due to the same/different tone marker (when the initial consonant of the prime was shared with the target). Furthermore, the two phonological contrasts provided strong statistical evidence in favour of the null hypothesis, as deduced from the $p(H_0|D)$ values (see Masson, 2011; Wagenmakers, 2007).

A similar pattern of results was found in both the naming and lexical decision tasks, and indeed there was no interaction effect found between task and priming effect, thus suggesting that the obtained findings reflect central processes rather than task-specific processes. In relation to the facilitative effect of the initial consonant—which was similar in lexical decision and naming—one additional explanation needs to be considered. A masked onset priming effect (MOPE; naming latencies are faster when initial sound is shared between prime and target) typically occurs in naming but not lexical decision tasks (e.g. fémie–

FOUCON faster than pémie–FOUCON in naming, but not in lexical decision; see Carreiras et al., 2005). However, we must keep in mind that the initial sound in Thai does not necessarily correspond to the initial letter (unlike in English or French, for example) but could correspond to the second letter in the word (i.e., words with misaligned vowels; see Winskel, 2009). In the current experiment, the initial consonant in the target words did not always occur in the first letter position (58%; e.g., ห้อง/ hɔ:ŋ2/ "room"), but also occurred in the second letter position (42%; e.g., โป้ง o:pŋ/po:ŋ2/ "thumb"). If a MOPE is occurring in our data, then we would expect it to occur in the aligned words where the initial consonant occurs in the first letter position (i.e., ห้อง/hɔ:ŋ2/ "room"), while it might be reduced/absent in the misaligned words where the initial consonant occurs in the second letter position (i.e., โป้ง o:pŋ/po:ŋ2/ "thumb"). In order to examine this further, we compared the latencies for the critical comparisons for the aligned and misaligned words in the naming task. The latencies for aligned words for the same initial consonant prime (C + T–) condition and orthographic control (C–T–) were 511 and 517 ms (a 6-ms effect), respectively, while for the misaligned words, the parallel differences were 500 and 513 ms (a 13-ms effect), respectively—the ANOVA failed to find an interaction between the effect under consideration and aligned/misaligned words (both $Fs < 1$). Thus, there was no clear evidence of a MOPE in a mixed list of words composed of words with aligned/misaligned vowels in Thai. Nonetheless, the present experiment was not specifically designed to test the MOPE, and an a priori manipulation would be needed to clarify this issue further. To examine in detail the MOPE in orthographies with aligned/misaligned vowels like Thai, it would be desirable to have specifically designed pure lists of words composed of aligned/misaligned vowels—in addition, it may be worth noting that most experiments on the MOPE have employed prime–target pairs that were less orthographically (and phonologically) similar than in the present experiment (e.g., see Carreiras et al., 2005).[2]

What are the implications of the present data for future models of visual-word recognition in alphabetic tonal languages (e.g., Thai, Lao, Vietnamese, Burmese)? At present, there are no computational models of visual-word recognition and reading in tonal orthographies. Indeed, the feature and letter levels of current computational models of visual-word recognition do not convey any diacritical marking—as tone information is expressed in these scripts. But leaving this issue aside, one needs first to know what to simulate in tonal languages. The present experiment represents a modest step in this direction. Even though the visual-word recognition system in Thai can process tonal information early in processing—as deduced from the advantage of the identity condition versus the priming condition that only differed in tone—this tonal information may be regarded as having an effect at an orthographic level rather than a phonological level. In particular, the data failed to show any signs of a purely phonological effect due to the tones, and this was so in two comparisons—one in which prime and target were relatively similar (e.g., ค้อง/ sɔ:ŋ2/-ห้อง/ hɔ:ŋ2/C–T + +), and the other in which the prime and target were graphemically more different (e.g., ธ่ อง/ t^hɔ:ŋ2/-ห้อง/ hɔ:ŋ2/C–T–+). The pattern of data in the lexical decision and naming tasks was quite similar, which suggests that the observed data reflect central processes of lexical access rather than task-specific processes. Thus, the most parsimonious account of the present data is that segmental information (i.e., consonantal information) is more important than tone information (i.e., tone marker) in the early stages of visual-word processing in Thai. In other words,

[2] As an anonymous reviewer indicated, one might argue that the obtained priming effects may reflect a form-priming effect on the basis of prime/target orthographic similarity [i.e., ห้อง (C+ T+) < ห่อง (C+ T–) < ค้อง (C– T+) = ธ่อง (C– T–+) = ค่อง (C– T–); ห้อง would be the target word] rather than a phonological effect. This interpretation would also support the main conclusion of the present experiment—namely, that segmental information plays a larger role than tonal information in the early stages of visual-word recognition.

the data suggest that access to (phonological) tone information during the process of visual-word recognition occurs relatively late—or at least that tone information is used relatively late. More research is necessary to examine in further detail the extent and time course of phonological processes in Thai in reading. For instance, using the boundary technique (i.e., manipulating the relationship between parafoveal previews and a target word) while the participants' eye movements are monitored during sentence reading may be more sensitive to subtle phonological effects than masked priming.

In sum, the present data in Thai are consistent with the data in Chinese visual-word recognition (i.e., a nonalphabetic orthography) with the masked priming technique, in which robust effects of syllable priming are obtained even when the phonological syllables of primes and targets had different tonal information (Chen et al., 2003; You et al., 2012). Taken together, these findings suggest that segmental information plays a greater role than tonal information during the early stages of visual-word recognition in tonal languages. We acknowledge that, because of its intrinsic characteristics, tonal information may play a more relevant role in spoken-word recognition than in visual-word recognition. Lee (2007), for example, found that monosyllabic Chinese words differing only in tone (i.e., segmentally identical, but tonally distinct) failed to cause the speeded responses typical of segmental form priming. Facilitation in direct priming was found only when the prime and target were identical in both tonal and segmental structure (i.e., hearing *lou2* "hall" speeded identification of the identical word *lou2* whereas *lou3* "hug" did not). This indicates that tone information is playing a more critical role in spoken word recognition than in visual-word recognition (see also Malins & Joanisse, 2010, for evidence of simultaneous access to tonal and segmental information in spoken-word recognition in Chinese). Future research needs to investigate this further in other tonal languages besides Chinese to examine whether there are common underlying processing mechanisms for tone across the spoken/written modalities.

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