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SOA does not Reveal the Absolute Time Course of Cognitive Processing in Fast Priming Experiments

Boaz Tzur and Ram Frost

Department of Psychology The Hebrew University

Abstract

Applying Bloch's law to visual word recognition research, both exposure duration of the prime and its luminance determine the prime's overall energy, and consequently determine the size of the priming effect. Nevertheless, experimenters using fast-priming paradigms traditionally focus only on the SOA between prime and target to reflect the absolute speed of cognitive processes under investigation. Some of the discrepancies in results regarding the time course of orthographic and phonological activation in word recognition research may be due to this factor. This hypothesis was examined by manipulating parametrically the luminance of the prime and its exposure duration, measuring their joint impact on masked repetition priming. The results show that small and non-significant priming effects can be more than tripled as a result of simply increasing luminance, when SOA is kept constant. Moreover, increased luminance may compensate for briefer exposure duration and vice versa.

Models of visual word recognition are primarily concerned with the time course of computing orthographic, phonological, and semantic information from print. The speed of generating these various codes have traditionally set the demarcation line between the different theories of visual word recognition. Consider for example the Dual-Route-Cascaded (DRC) model offered by Coltheart and his colleagues (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). The model suggests that prelexical phonological computation is, in most cases, relatively slow, lagging behind orthographic processing. Thus, the grapheme-phoneme-conversion route in the DRC computational model operates only after several cycles of the simulation have taken place, and each letter is made available for the computation process only after a constant number of cycles have elapsed. Given that prelexical computation is serial, the model is structured so that the lexical activation of the final phonemes will usually precede their prelexical activation. This architecture was probably implemented to avoid high rates of regularization on exception words. It poses, however, interesting constraints on the ability of the model to account for lexical access occurring via fast prelexical phonological encoding (see Rastle & Brysbaert, 2006, for a detailed discussion). In contrast, to dual-route models, the strong phonological theory (e.g., Frost, 1995, 1998; Lukatela & Turvey, 1994a,b; Van Orden, Pennington & Stone, 1990) regards prelexical phonological computation as the initial cognitive operation launched in the reading process, and considers it to be very fast. Thus, findings regarding the speed of phonological computation are expected to provide distinguishing evidence between the two

Correspondence should be addressed to Ram Frost, Department of Psychology, The Hebrew University, Jerusalem, 91905 Israel..

Mailing address: Ram Frost Department of Psychology The Hebrew University Jerusalem, 91905 Israel Email: frost@mscc.huji.ac.il

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theories, or alternatively, shape their models by providing important constraints for specific implementations.

To examine the relative speed of computing orthographic, phonologic, or semantic information, researchers have traditionally used experimental paradigms which focus on very early and automatic processing of print. In most cases, these involve fast priming, either with backward or with forward masking. In the backward masking paradigm (Perfetti, Bell, & Delaney, 1988; Berent & Perfetti, 1995; Verstaen, Humphreys, Olson, & d'Ydewallt, 1995; Tan & Perfetti, 1999), a target word is presented for a very short duration (usually 15-30 ms). The target word is followed (i.e., masked) by a pseudoword that appears for 15-60 ms and is then replaced by a simple pattern mask. The pseudoword can be phonemically similar to the target, graphemically similar, or a dissimilar control. The subjects' task is to report in writing what they have perceived. Typically, subjects perceive only one event, the target word, and do not have any conscious recollection of the nonword mask. This is because the nonword suffers from the masking effect of the initially presented target and from the subsequent presentation of the pattern mask, which erases it from iconic memory. Since the target is presented very briefly as well, it is reported in full only in some of the trials (the probability of detecting the target changes with exposure duration and can, therefore, be set to a specific range by the experimenter). Thus, target detection probability in the various experimental conditions is examined with different exposure durations to monitor the exact time course of phonological or graphemic activation. For example, using backward masking, Berent and Perfetti (1995) have proposed that the phonological structure of printed words is computed in two cycles: while the time course of generating the consonantal information in English is about 15-30 ms, vowel information is integrated at 30-60 ms following stimulus onset.

In the 3-field masking technique developed by Forster and Davis (1984), a pattern mask is presented before the prime, with a very brief temporal interval between the onset of the priming stimulus and the subsequent target stimulus. Because the prime is presented briefly, and is masked by a combination of forward and backward masking (the latter coming from the target), the prime itself is unavailable for report. As with backward masking, the experimenter manipulates the linguistic properties of the prime (e.g., phonology, orthography) examining its effect on response latencies to the target. Whether or not a priming effect is obtained at a given Stimulus Onset Asynchrony (SOA) would reveal, according to this experimental logic, the time course of computing the various linguistic codes. Suppose, for example, that the prime and the target have an identical phonological structure but a different orthographic structure (e.g., klip and CLIP) and suppose that the exposure duration of the prime is 30 ms, and suppose that no priming is obtained relative to a control condition in which the prime and the target are orthographically and phonologically dissimilar (plip and CLIP). The straightforward conclusion of this experiment would be that the phonological features of the prime were not computed within the 30 ms of the prime's exposure. The standard theoretical implications would be that phonological computation takes longer than 30 ms, hence the prime could not have exerted its influence on the target. Thus, the basic axiom underlying this common procedure is that the SOA between the prime and the target reveals the absolute time course of computing a given linguistic code. Indeed, exposure duration is the main experimental factor that researchers in visual word recognition manipulate to determine the speed of various cognitive operations.

A brief overview of the relevant literature reveals that these axiomatic assumptions are well accepted by researchers of visual word recognition. The following quotations are taken from recent papers simply to exemplify this state of affairs:

--"Phonological facilitation only starts to emerge at exposures of 50 ms" (Ferrand & Grainger, 1993).

--“Phonological priming is absent at 29-ms prime exposures (Ferrand & Grainger, 1994).

--“As in English and in French, we did find a reliable pseudohomophone effect with prime durations longer than 40 ms but not with prime durations shorter than 30 ms (Brysbaert, 2001).

--“We also found superior pseudohomophonic priming at a prime duration (29 ms) previously considered too brief for the emergence of phonological codes (Lukatela, Frost, & Turvey, 1998).

Considering the theoretical issue of phonological computation, the above quotations seems to demonstrate a general consensus among researchers in visual word recognition that breaking the “29 ms barrier” is valid proof that prelexical phonological computation is indeed fast. For example, the significant advantage for homophonic primes at an SOA of 29 ms, reported by Lukatela et al. (1998), generated subsequent unsuccessful attempts to replicate the results, mainly by proponents of dual-route theory (e.g., Coltheart & Woollams, unpublished manuscript; Mahoney & Forster, unpublished manuscript). This is because this result seemed to demonstrate “fast phonology”. Moreover, the phonological priming effect obtained at the 29 ms SOA seemed important enough to deserve an explicit and lengthy discussion by Coltheart et al. (2001) who dismissed it on the grounds that the exposure conditions for obtaining the effects were not clear enough. However, more importantly, these discussions clearly suggest yet another implicit assumption that is shared by many investigators concerned with the time course of processing linguistic information. Namely, that the SOA between prime and target indeed reflects the absolute speed of cognitive processes. The present paper is concerned with the axiomatic assumption underlying this procedure. Note that the implicit axiom that SOA reflects absolute time course is not related exclusively to phonological computation, but is relevant to any theoretical investigation aiming at measuring the duration of a given cognitive process. The presupposition that exposure duration monitors cognitive chronometry in absolute terms is thus more prevalent than we may think. For example, in their review of orthographic priming effects, Budelaa & Marslen-Wilson (2001) noted that in English at 32 or 43 no orthographic priming is obtained. Similarly, following a comprehensive study manipulating SOA, Dominguez, Segui, & Cueto (2002) conclude that “morphology could operate at 64 ms”. In the same vein, any discussion of the SOAs in which orthographic, phonological, semantic and morphological priming can or cannot be obtained that is based on comparing findings across different studies (e.g., Dominguez et al.) hinges on the presupposition that the SOAs employed in these different experimental settings reflect absolute time course of processing. This presupposition, however, does not take into consideration the findings that exposure duration interacts with luminance to determine the time of processing, as revealed by Bloch's law.

Bloch's law

According to Bloch's law (see Hood & Finkelstein, 1986) exposure duration and luminance are interchangeable within the range of parameters applied in our experiments (where luminance is defined as the luminous intensity per unit area projected in a given direction). Although Bloch's law originally referred to the psychophysical detection of simple visual stimuli (see for example, Di Lollo, von Muhlenen, Enns, & Bridgeman, 2004), its relevance to the present controversy seems straightforward. Researchers of visual word recognition are mainly concerned with the *linguistic* aspects of their stimuli. Nevertheless, the speed of cognitive events occurring in word perception must be energy dependent, just as it is with the detection of a dot or a line orientation. Crucially, both luminance and exposure time determine the amount of energy that is provided to the cognitive system for the perception and identification of the distal stimulus. Whereas luminance monitors energy directly, exposure duration monitors energy through summation across time. Yet, although the luminance of the stimuli has been extensively investigated in vision research while studying effects such as

masking, metacontrast, or perception of motion, it has been generally ignored in the word-recognition literature. Researchers seldom report it in their experimental settings, and in most cases manipulate only the SOA between prime and target to monitor speed of processing

A demonstration that both SOA and luminance affect visual word recognition was recently demonstrated by Frost, Ahissar, Gotesman, & Tayeb (2003). In this study, Frost and his colleagues investigated the structure of the phonological code computed from print by monitoring the effect of phonological and orthographic prime-target similarity in two independent sets of experiments. In one set, the luminance of the stimuli was kept constant (as is the default procedure in word perception laboratories) while SOA varied from 10 ms to 40 ms. However, in the second set the SOA between prime and target was kept constant, while the luminance of the stimuli varied from 0.75 cd/m² to 7.0 cd/m². Although the main goal of this study was to examine the efficacy of various phonological contrasts to produce priming, one striking finding reported by Frost et al. (2003) was that these different experimental procedures yielded similar patterns of results, with similar priming effects.

This leads us to the aims of the present investigation. If both exposure duration and luminance determine the energy of the stimuli in fast priming experiments, thereby creating similar priming effects, then one should consider the possibility that at least within a certain range of exposure parameters, short exposure durations may be substituted by brighter stimuli and vice-versa. If this is indeed correct, then within these ranges, small insignificant priming effects in short SOAs may become robust if prime luminance is increased, and significant priming effects may vanish if prime luminance is decreased. This disturbing possibility could perhaps account for some of the current inconsistencies in findings regarding the speed of orthographic or phonological computation, but more generally, it would strongly suggest that SOA or exposure duration alone do not reflect the absolute speed of a given computational process in word recognition. The present study was designed not only to explore this hypothesis, but also to provide a preliminary investigation regarding the ranges of exposure parameters in which luminance and exposure duration are interchangeable when linguistic stimuli are concerned. In the following three experiments we manipulated the SOA between primes and targets in conjunction with the luminance of the prime only (Experiment 1), the luminance of both the prime and the target (Experiment 2), and their contrast with the background (Experiment 3). We were specifically interested in relatively brief exposure durations, which have been traditionally the focus of debates in visual word recognition. We, therefore, crossed these SOA values with a wide range of luminance values to map the impact of their potential interaction.

Experiment 1

In Experiment 1, we manipulated the exposure duration of the prime together with its luminance. The experiment was based on monitoring identity-priming effects under various exposure conditions. Identity (repetition) masked priming was chosen because it is a well-accepted and robust finding in visual word recognition (Forster & Davis, 1984; and see Forster, 1987, for a review). Typically, when the prime contains exactly the same letters as the target, the strongest priming effects are obtained.

Two exposure durations, 20 ms, and 40 ms, were used. Forty ms is the typical SOA that is chosen by experimenters conducting three-field masked priming experiments. Twenty ms is an exposure duration that is typically considered to reflect “fast” processing in word recognition literature (e.g., Lukatela et al., 1998). The two levels of exposure duration were crossed by five levels of luminance (1, 2, 4, 8, and 16 cd/m²) to create four levels of “energy”. “Energy” was defined in the present context as the multiplication of the exposure duration by the luminance of the stimulus. Although there is no a-priori criterion regarding how exactly to combine exposure duration with luminance in a psycholinguistic experiment, the logic of this measure

follows from Bloch's law; namely, summing the luminance of the stimulus across time. Table 1 provides the parameters of the energy manipulation.

As can be seen in Table 1, each of the four levels of energy was obtained by two methods: one, by exposing the prime for the shorter duration with higher levels of luminance, the other, by exposing the prime for the longer duration with lower levels of luminance. In both cases, the values of multiplying the luminance by exposure time were identical. Note that we did not have an a-priori validation of the equality of the multiplied values in terms of the perceived effect within the range of the present exposure parameters. Hence the present "energy" values were set for the purpose of an initial exploration of the potential interchangeability of luminance and SOA.

We were concerned with the following two questions: first, is identity priming modulated by luminance level within a given exposure duration? A positive answer to this question would mean that SOA alone cannot reveal the absolute time course of cognitive processing. Second, if priming is indeed modulated by luminance at a given SOA, does it matter whether energy is determined by high luminance and short exposure, or by low luminance and long exposure, in terms of the net priming effect?

Method

Subjects—The participants were fifty-six undergraduate students at the Hebrew University, who participated in the experiment for course credit or for payment.

Stimuli—The stimuli were 224 Hebrew words and 224 nonwords, which were 4 or 5 letters long. We employed a very large number of stimuli in order to collect a large number of data points in each experimental condition. All in all, about 24,000 data points were collected in the experiment. The target words had an average frequency of 33.8/million (median=15), and an average neighborhood size of 9 (median=7). Frequency and neighborhood sizes were calculated using the Plaut & Frost Hebrew Word Frequency Database (<http://word-freq.mscc.huji.ac.il/index.html>).

Design—Each target word or nonword was primed by itself (the identity prime), and by an unrelated control prime, which differed from the targets in most of its letters. The control condition served as the baseline from which the identity priming effects were calculated. The target stimuli were presented in four levels of energy. The stimuli were thus divided into four lists. Each list contained 56 words and 56 nonwords in each of the four energy conditions. Half of the stimuli were presented in the identity condition and half in the control condition, and within each level of energy, half of the stimuli were presented using the short exposure and the higher luminance levels, while the other half were presented using the long exposure and the lower luminance levels.

The stimuli were rotated within the experimental conditions of each list using a Latin Square design. Fourteen different participants were tested in each list. This procedure allowed each participant to provide data points in each condition while avoiding stimulus repetition effects.

Procedure and Apparatus—The experiment was conducted on an IBM Pentium III computer, with a 17" Sony monitor. Stimuli were presented using a VSG graphics card (made by Cambridge Research Systems), which is designed for accurate control of stimulus contrast and timing. Each trial consisted of three sequential visual events. First, a forward mask consisting of a row of five hash marks appeared for 500 ms. The mask was immediately followed by the prime with the variable exposure parameters. The primes were then replaced by the targets, which remained on the screen until the participants responded. Participants were required to make lexical decisions with respect to the targets. Since we were concerned with

the time course of processing the *primes*, in Experiment 1 we manipulated only the primes' luminance,¹ whereas the luminance of the forward mask and the targets remained constant at 8 cd/m². The luminance of the screen was less than 0.01 cd/m². Thus, the contrast in all conditions was close to 1.0. The room was totally dark. Luminance was measured and verified using OptiCAL photometer (made by Cambridge Research Systems) and the LightScan software provided with it.

All visual stimuli were centered in the viewing screen and were superimposed on the preceding stimuli. Although only the Hebrew square font was used, two versions of this font, one 25% larger than the other, were included.² Targets were always presented in the larger font. This guaranteed complete visual masking of the primes by the targets and made the primes and the targets physically distinct stimuli (see Frost et al., 2003, for a detailed description). Although perceptibility of the prime was not explicitly measured, none of the subjects reported seeing the prime. Each participant completed the experiment in a single session.

Results and Discussion

The reaction times (RTs) were averaged for correct responses in the experimental conditions across participants and across items. Within each participant, RTs that were outside a range of 2 SDs from the participant's mean were curtailed. Establishing cutoffs of 2 SDs above and below the mean for each participant minimized the effect of outliers, which accounted for less than 5%. A summary of mean latencies, standard errors percent errors for all experimental conditions as well as overall ANOVAs in the present study are presented in Appendix B.

We first examined whether identity-priming effects were modulated by luminance level when exposure duration was kept constant. Figure 1 demonstrates the effect of the luminance manipulation for words and nonwords at the two exposure durations. As can be seen in Figure 1, priming effects increased when the luminance of the primes was increased, for both words and nonwords. The effects obtained for words were dramatic, ranging from 7 to 60 ms with an SOA of 20 ms, and from 15 to 67 ms with an SOA of 40 ms. ANOVA revealed that these differences were highly significant ($F(3,165)=32.6$, $p<0.001$; $F_2(3,440)=41.0$; $p<0.001$, $\text{min}F'(3,453)=18.2$). The priming effects for nonwords were much smaller but the effect of energy was significant as well ($F(3,165)=5.7$, $P<0.001$, $F_2(3,440)=3.9$; $p<0.009$; $\text{min}F'(3,533)=2.3$). Figure 1 shows that this facilitation is also modulated by luminance. No priming was apparent with the lower levels of energy, but substantial identity priming was obtained for nonwords if the prime's luminance was set to the third or fourth energy level.

Our second question was whether it matters if energy is determined by high luminance and short exposure, or by low luminance and long exposure, in terms of the net priming effect. Figure 1 provides a contrast of the priming effects for words, in each of the four levels of energy, when each level of energy was obtained either by combining short exposure duration with high luminance or by combining long exposure duration with low luminance. As Figure 1 demonstrates, at the first three levels of energy, increasing exposure duration produced about twice as much priming as increasing luminance. Thus, for these energy levels, exposure duration and luminance do not affect priming to the same extent. However, at the fourth, highest energy level, Bloch's law seems to apply, as exposure and luminance were interchangeable. The priming obtained with an SOA of 20 ms with luminance of 16 cd/m² was almost identical to the priming effect obtained with an SOA of 40 ms and luminance of 8 cd/m² (60 and 67 ms, respectively).

¹RGB values for each luminance level in this study are specified in appendix A.

²In English the separation of primes and targets is often achieved by using upper case and lower-case scripts. Although Hebrew has two forms of script (regular print and cursive), the cursive script is hardly ever used in print, and we therefore adopted the manipulation of size rather than form. This procedure has been validated in several studies (e.g., Frost, Forster, & Deutsch, 1997; Frost et al., 2003).

The right side of figure 1 presents the results obtained with nonwords. In general, identity priming under masked conditions occurs reliably for words only (Forster, 1987), whereas the effects for nonwords are small and often insignificant. This is because facilitation in the masked-priming paradigm is traditionally considered as deriving from a faster recognition of the word target, given its shared properties with the prime. Since target nonwords are not lexically represented and recognized, they cannot benefit from the prime. Therefore, priming effects for nonwords reflect a prelexical computation component that registers the orthographic and phonological properties of the prime, and these form the basis for the subsequent lexical search or activation. Thus, the prelexical computational component is reflected in less facilitation (see Forster, 1998, and Frost et al., 2003 for a discussion). However, focusing on the two higher energy levels where priming was indeed obtained, it appears that the nonwords produced a similar pattern of results as the words. At energy level 3, longer exposures with low luminance resulted in larger priming effects than shorter exposures with high luminance (10 and 17 ms, respectively), but this difference in the priming effect became smaller in energy level 4 (14 and 18 ms, respectively).

The results of Experiment 1 lead us to two main conclusions. First, very substantial differences in priming emerged with various levels of prime luminance within a given exposure duration. Similar findings have been reported by Jacobs, Grainger & Ferrand (1995), who employed an incremental priming technique to determine within-condition priming effects. In this study, response latencies obtained in any given priming manipulation were compared to a baseline condition in which prime presentation involved minimal intensity. Although the aim of this research was to determine a correct control baseline for priming experiments, the results nevertheless suggested that larger and more stable priming effects indeed emerged with greater stimulus intensity.

Our second conclusion concerns the interchangeability of luminance and exposure duration. Within the range of parameters employed in this experiment, it seems that luminance and exposure duration were not necessarily interchangeable in a simple linear fashion, although they were under certain conditions. At lower energy levels, simply multiplying luminance values by their time of exposure did not provide an unequivocal measure of energy. Our findings suggest that increasing exposure duration produced more priming than increasing luminance. However, at higher energy levels, Bloch's law applied to masked priming, and exposure duration and luminance became interchangeable. Print exposure could be shortened significantly to produce the same priming effect, if print luminance was proportionally increased. Note that if researchers simply fire up their computers without explicitly controlling for luminance levels, print luminance would probably be at these higher levels (sometimes reaching 100-110 cd/m²).

Experiment 2

Although the results of Experiment 1 clearly demonstrated that luminance determined the size of the priming effect when exposure duration was kept constant, the practical relevance of this finding to recent studies involving masked priming is not yet clear. Note that in Experiment 1 only the prime's luminance was manipulated. Since in most priming studies the primes and targets are equally bright, it could be argued that under equal luminance conditions, luminance would not affect the priming effect. The logic of the argument is simple. At a given SOA, if the processing of the prime would be slowed down or speeded up by presentation under low or high luminance conditions, the processing of the target would be affected to the same extent, as long as primes and targets were equally bright. Since the priming effect is determined by the time allocated to processing the prime until the target is fully processed, reducing or increasing the time allowed for processing the prime and the target to the same extent would not change the size of the priming effect.

This comforting possibility, however, is not necessarily true. In the three-field masking procedure, the prime is masked both by the forward mask and by the target, whereas the target suffers only from the forward masking of the prime. It is possible then that the prime is more affected by luminance than the target. This state of affairs would necessarily mean that primes and targets are not affected by luminance to the same extent. Experiment 2 was designed to test this possibility. We, therefore, employed the same experimental parameters as in Experiment 1 but manipulated target luminance as well, as is done in typical masked priming experiments.

Method

Subjects—The participants were 56 undergraduate students at the Hebrew University who participated in the experiment for course credit or for payment

Design and Apparatus—The stimuli, design and procedure were identical to Experiment 1 except that the luminance of the forward mask, the prime, and the target were kept constant within each of the four energy conditions. The experimental room was totally dark. The experiment was conducted on an IBM Pentium III computer, with a 17" Eizo monitor. The software for stimulus presentation and accurate recording of response durations was the DMDX display system developed by K.I. Forster and J.C. Forster at the University of Arizona. Luminance was measured and verified using a SpectraScan tool and the SpectraView software provided with it.

Results and Discussion

As in Experiment 1, we established cutoffs of 2 SDs above and below the mean for each participant. Outliers accounted for less than 5%. Figure 2 demonstrates the effect of the luminance manipulation for words and nonwords at the two exposure durations.

As can be seen in Figure 2, the effect of luminance in the shorter exposure of 20 ms and the longer exposure of 40 ms differed. With the exposure duration of 40 ms, priming effects did not vary much with luminance, ranging erratically from 29 to 41 ms. However, with the SOA of 20 ms, clear differences in the net priming effect were obtained with the lower levels of luminance (2 and 4 cd/m²), compared with the higher levels of 8 and 16 cd/m² (14 and 8 ms, compared with 33 and 31 ms, respectively). Planned contrasts revealed this difference to be significant ($t(111)=3.93$, $p<0.001$, 95%CI=15.1±9.6, $d=0.65$). These results resemble the findings of Experiment 1, as increased luminance produced larger priming effects even though both primes and targets had equal luminance.

The figure also presents the priming effects for words, in the four energy levels, where each level of energy was obtained either by combining short exposure duration with high luminance or by combining long exposure duration with low luminance. Again, similar to Experiment 1, increasing exposure duration produced more priming than increasing luminance with the lower levels of energy. However, with Energy levels 3 and 4, Bloch's law seems to apply, and exposure and luminance were almost interchangeable. The priming obtained with an SOA of 20 ms with luminance of 8 cd/m² was 33 ms, whereas the priming obtained with an SOA of 40 ms and luminance of 4 cd/m² was 39 ms. Similarly, the priming effect obtained with an SOA of 20 ms with the luminance of 16 cd/m² was 31 ms, whereas for the SOA of 40 ms with the luminance of 8 cd/m² the priming effect was 41 ms. Planned comparisons revealed that the 6 and 10 ms difference in both energy conditions was not significant ($t(55)=0.9$, $p<0.4$, 95%CI=6.2±13.4, $d=0.16$; $t(55)=1.5$, $p<0.13$, 95%CI=10.0±13.2, $d=0.29$; respectively). Only very small and insignificant priming effects were obtained with nonwords.

Experiment 2 thus demonstrated that when the luminance of the prime and the target were jointly manipulated, the effect on priming was somewhat reduced, and was apparent only in the shorter SOA. Our results suggest, then, that the effects of luminance on priming are discontinuous. With the longer exposure duration of 40 ms, luminance levels do not seem to modulate priming. One possible interpretation of this outcome is that if the prime and the target are equally luminous, once the prime has sufficient energy to initiate lexical processing, then further increase of luminance becomes irrelevant. However, considering the priming obtained at the shorter SOA of 20 ms, the results of Experiment 2 resemble, to a large extent, the results of Experiment 1, as significantly larger priming effects were obtained with increased luminance. Note that the argument regarding fast phonology involves the very brief exposure durations of about 20 ms, and in most studies, given the typical variance of lexical decision latencies, the difference between 8 ms and 33 ms of priming is the difference between rejecting and not rejecting the null hypothesis. Also, at the higher luminance levels, Bloch's law seems to apply and exposure duration can be substituted by increased luminance. Thus, the results of Experiment 2 suggest that at least for brief exposures SOA alone does not determine the size of the priming effect even when the primes and the targets are equally luminous, as is the case in most studies of visual word perception.

Experiment 3

Presenting white print on a dark screen is not the exclusive method used in priming experiments. Researchers often employ the reverse display consisting of dark letters on a luminous background. The aim of Experiment 3 was to investigate whether this experimental setting is immune to luminance effects. Note that if dark print is presented on a white screen, then the factor to consider is the contrast. Since there are several levels of grayness that can be used, and the luminance of the background is an adjustable parameter, each possible display will create a different contrast. In Experiment 3 we examined whether employing high or low levels of contrast indeed affects priming. Thus, the design of Experiment 3 was similar to that of Experiment 2, only the letters were now presented in black while the background was white.

Method

Subjects—The participants were twenty-eight undergraduate students at the Hebrew University, who participated in the experiment for course credit or payment.

Stimuli, Procedure and Apparatus—The stimuli, procedure and apparatus were similar to those of experiment 2. However, contrary to Experiment 2, the luminance of the screen exceeded that of the printed stimuli. To maximize the contrast manipulation only two levels of contrast were employed. Screen luminance was set to 40 cd/m², while the luminance of the printed stimuli was either 1 or 32 cd/m². This created a high-contrast and a low-contrast condition, with contrast values of 0.95 and 0.11, respectively (Contrast was calculated as the difference in luminance values divided by the sum of these values). The experimental room was totally dark. Exposure durations were identical to the previous experiments, 20 and 40 ms.

Results and Discussion

As in the previous experiments, all results beyond 2 SDs above and below the mean for each participant were curtailed. Outliers accounted for less than 5% of results. Figure 3 demonstrates the priming effect separately for each of the exposure durations. Considering first the word targets, the priming effect with the high contrast values was about double the size as the priming effect with the low contrast values. Thus, when contrast increased from 0.11 to 0.95, with the SOA of 20 ms, priming increased from 8 ms to 16 ms, and with the SOA of 40 ms, priming increased from 22 ms to 39 ms. ANOVA revealed that the effect of contrast on priming was significant ($F(1,27) = 10.7, p < 0.003$; $F_2(1,440) = 3.4, p < 0.06$, $\eta^2(1,471) = 2.6$) and so was

the effect of SOA ($F(1,27)=6.9$, $p<0.01$; $F_2(1,444)=7.6$, $p<0.006$; $\min F'(1,363)=3.6$). The interaction was not significant ($F(1,27)<1.0$, $F_2(1,444)<1.0$). For nonwords, priming effects were relatively small, ranging from 4 to 17 ms, and contrast did not exert any significant effect on priming.

Experiment 3 thus demonstrates that the effect of luminance on the priming effect is not exclusive to procedures where bright stimuli are presented on dark background, but is also apparent when contrast is manipulated when dark stimuli are presented on a bright background.

General Discussion

The present study was concerned with an implicit assumption that often underlies research in visual word recognition. The view that the time course of orthographic, phonological, or semantic computation, may be unequivocally monitored by manipulating the SOA between primes and targets, has often been taken as an axiom in psycholinguistic research. A typical example is the ongoing controversy regarding the speed of prelexical phonological computation. A large number of studies were designed to investigate whether or not phonological priming can be obtained at a given SOA, where SOA was implicitly regarded as an absolute value. The subsequent labeling of a given computational process (orthographic or phonological) as “fast” or “slow” has been based exclusively on the exposure duration of the prime, while monitoring its potential influence on the processing of the target (e.g., Berent & Perfetti, 1995; Brysbaert, 2001; Ferrand & Grainger, 1992, 1993; Grainger & Ferrand, 1996; Lukatela & Turvey, 1994a, 1994b; Lukatela et al., 1998; Coltheart et al., 2001). Considering, for example, the recent debate in the scientific community regarding the pseudohomophone priming effect reported by Lukatela et al. (1998), the subsequent discussions of these findings (e.g., Coltheart et al., 2001, Frost et al., 2003) emerged simply because 29 ms was indeed considered by some researchers to be “too fast” for generating a phonological code.

The results of the present experiments suggest that such debates may not necessarily have clear theoretical relevance. In Experiment 1 we found that presenting the primes at various luminance levels relative to targets and forward masks which had fixed luminance, created differences in priming that ranged from 7 to 67 ms for words, and from -4 to 19 ms for nonwords. Moreover, at least within one energy level that we used, luminance and SOA were entirely interchangeable, in accordance with Bloch's law. Very similar priming effects were obtained by reducing exposure duration by half, while multiplying luminance by 2. Experiment 2 explored the impact of luminance on priming, mimicking the standard procedure of priming experiments. Thus, all three masking fields were equally bright. Although the impact of manipulating luminance was less dramatic, some aspects of the results were similar to those obtained in Experiment 1. At least with the shorter exposure duration of 20 ms, priming effects were significantly modulated by luminance, ranging from 8 ms to 33 ms. Moreover, in two levels of energy, Bloch's law seemed to apply, as SOA and luminance were almost interchangeable. Note that the 20 ms of exposure duration is the court in which the game of “fast” versus “slow” processing is being played. In Experiment 3 we extended the relevance of these findings to the presentation of black print on white background, by manipulating the contrast of the black print with the luminous screen, changing grayness levels. We found similar results, as priming was reduced significantly when contrast was reduced.

The first question to examine is the practical relevance of our findings to laboratory experiments that manipulate SOA in fast priming paradigms. Experiment 1 provides a clear demonstration of the dramatic effects of luminance on priming but admittedly presents an atypical setting where only the luminance of the prime is manipulated (but see Jacobs et al., 1995 for a similar manipulation). Experiment 2, which employed the more typical experimental setting when primes and targets are equally luminous, suggests that luminance effects are discontinuous.

They were not found at the longer SOA of 40 ms, and were conspicuous only at the lower SOA of 20 ms. One conclusion to be drawn from Experiment 2 is that luminance becomes perhaps less relevant at the higher end of energy levels. However, the discontinuity of the effect should be a cause for concern for researchers involved in mapping the time course of cognitive processing. Since such experimental designs often employ several exposure durations with linear increments (e.g., 20, 40, 60, 80 ms), the discontinuity of luminance modulation of priming may hide unexpected effects. Experiment 3 focused on the use of black print on a white screen, demonstrating a significant modulation of priming when two levels of contrast were compared. The lower contrast level employed in Experiment 3 (0.11) may not be characteristic of normal experimental settings; however, once it has been established that contrast modulates priming effects, this should be a cause for concern even when higher levels of contrast are employed. Note that although the contrast is measured by registering the luminance of the print and the screen background, the actually perceived contrast is largely affected by the ambient light in the experimental room. Recent measures from our laboratory showed, for example, that identical screen settings yielded contrasts levels of 0.5 and 0.11 in a dark room but 0.37 and 0.08 in a lighted room. Again, the impact of ambient room lighting on contrast levels seemed discontinuous; it was apparent with brighter ambient light but less so with dimmer light.

Whether this should be a cause for concern for researchers, is not a simple question. In a recent study, Rastle and Brysbaert (2006) provided an illuminating meta-analysis of masked phonological priming effects reported in dozens of studies. In their analysis they have outlined a series of experimental factors that could account for the excessive variability of results, factors related to task demands, experimental conditions, and structure of stimuli. Our results suggest that even if all of these factors are well-controlled, print luminance could also determine the rejection of the null hypothesis when brief exposure durations are employed. Considering, for example, the results of Experiment 2, the difference between 8 ms and 33 ms of priming obtained within the same exposure duration, but with different luminance levels, is in all probability the difference between reporting significant or insignificant effects. Given the relatively small size of average masked phonological priming effects reported by Rastle and Brysbaert (2006), it is possible that variations in contrast or print luminance may tilt the balance between rejecting the null hypothesis or not. Thus, it seems that employing all-or-none designs, which are aimed at examining whether or not priming can be obtained at a brief SOA is futile without considering the luminance of the print. Unfortunately, researchers seldom report the luminance employed in their experimental setting, nor do they report screen contrast, room luminance, or procedures for dark adaptation. Moreover, very little is known about the energy scales in which priming is affected by luminance during visual word recognition. This could be one source of the present controversies regarding the time course of phonological computation.

Within the context of practical relevance to laboratory experiments, we should emphasize that luminance is not necessarily relevant to all priming experiments. If researchers are simply concerned with *relative* effect sizes within various experimental conditions, when the absolute value of exposure duration is not a theoretical construct, then luminance may not matter. Thus, studies monitoring the relative impact of orthographic, phonological, semantic, or morphological similarity at a given SOA may not be affected by parameters related to print luminance. Our conclusions concern the explicit study of the time course of activation where the SOA between prime and target is taken to reflect the absolute time course of processing.

The findings of the present study suggest that SOA on its own does not reveal the absolute time course of cognitive processing. Instead, more refined measures should be applied for examining fast computation. These should be based on measuring *energy*, computed by simultaneously considering exposure duration and print luminance. Our experiments reveal

that luminance affects priming in a complex manner. Since the impact of luminance on perception in a given exposure duration is a U shaped function (e.g., Hadani, Meiri, & Guri, 1984), the linear combinations of luminance and exposure duration will have a differential effect on priming, depending on the specific luminance and exposure duration parameters employed. In both Experiment 1 and 2, whether luminance was interchangeable with SOA depended on the overall level of energy, and the different levels of luminance modulated priming to a different extent, in the two exposure durations. Why Bloch's law applies only to the higher energy levels remains an open question. It seems clear that extensive parametric research is needed to accurately map the possible interactions of luminance and SOA in psycholinguistic experiments. The present study is but an initial step in this direction.

Interestingly, from a historical perspective, the impact of luminance on word recognition had been the focus of extensive research in the early days of visual perception research, some 3 or 4 decades ago. For example, Sperling (1971) specifically demonstrated that total stimulus duration does not necessarily predict response accuracy, since stimulus visibility is a major factor as well. Similarly, the classical studies by Turvey and his colleagues (Turvey 1973; Michaels & Turvey, 1979) showed unequivocally that effects of masking interact with luminance conditions. Hence, researchers concerned with the processing of linguistic codes should not forget that linguistic processes initiated by the visual presentation of a printed word, are necessarily constrained by the characteristics of our visual system.

APPENDIX A

RGB values for the levels of luminance employed in Experiment 1-3.

luminance (in mcd/m^2)	Experiment 1		
	R	G	B
1	58	55	45
2	69	66	54
4	85	81	67
8	107	102	84
16	156	149	123

luminance (in mcd/m^2)	Experiment 2		
	R	G	B
1	45	52	53
2	60	62	63
4	76	77	77
8	97	97	97
16	123	124	123

luminance (in mcd/m^2)	Experiment 3		
	R	G	B
1	54	57	57
32	167	167	167
40	182	182	182

APPENDIX B

Reaction times, percent errors, (Sds), for all experimental cells in experiment 1, and ANOVA details.

Energy Level		identity		control	
WORDS	SOA	20	40	20	40
1		520 2.3% (70)	510 2.7% (61)	527 3.7% (69)	525 4.5% (57)
2		521 4.0% (63)	504 3.3% (65)	541 6.8% (67)	541 7.1% (68)
3		517 3.8% (65)	503 3.8% (66)	546 5.7% (62)	558 9.7% (60)
4		508 2.4% (70)	490 3.7% (60)	567 8.7% (65)	557 7.7% (61)
NONWORDS	SOA	20	40	20	40
1		596 3.7% (80)	583 6.9% (79)	594 5.4% (80)	584 6.1% (82)
2		588 4.3% (78)	586 5.2% (87)	587 6.1% (79)	582 6.1% (82)
3		586 6.3% (80)	576 6.8% (84)	596 4.5% (77)	593 5.6% (84)
4		586 5.6% (80)	572 4.3% (76)	600 5.1% (79)	590 3.7% (87)

		source	df	sum of square	mean square	F value	p value	minF'	df
words	by Subjects	energy	3	160025.267	53341.756	32.586	0.000	18.155	3,453
		error	165	270093.742	1636.932				
		SOA	1	23334.965	23334.965	19.187	0.000	8.928	1,224
		error	55	66891.753	1216.214				
		SOA*energy	3	6854.153	2284.718	1.942	0.125	1.035	3,523
		error	165	194.157.522	1176.712				
	by Items	energy	3	177859.701	59286.567	40.996	0.000		
		error	440	636305.544	1446.149				
		SOA	1	24147.226	24147.226	16.698	0.000		
		error	440	636305.544	1446.149				
		SOA*energy	3	9606.099	3202.033	2.214	0.086		
		error	440	636305.544	1446.149				
nonwords	by Subjects	energy	3	31944.063	10648.021	5.663	0.001	2.313	3,533
		error	165	310269.479	1880.421				
		SOA	1	902.582	902.582	0.503	0.481	0.120	1,248
		error	55	98768.765	1795.796				
		SOA*energy	3	1562.194	520.731	0.316	0.814	0.219	3,557
		error	165	271750.536	1646.973				
	by Items	energy	3	28491.072	9497.024	3.910	0.009		
		error	440	1068643.617	2428.735				
		SOA	1	384.300	384.300	0.158	0.691		
		error	440	1068643.617	2428.735				
		SOA*energy	3	5213.337	1737.779	0.716	0.543		
		error	440	1068643.617	2428.735				

Reaction times, percent errors, (SDs), for all experimental cells in experiment 2 and ANOVA details.

Energy Level		identity		control	
WORDS	SOA	20	40	20	40
1		611 2.2% (60)	603 2.2% (63)	625 4.2% (58)	642 4.8% (56)
2		620 2.9% (68)	606 1.9% (69)	627 4.5% (66)	635 4.3% (52)

Energy Level		identity		control	
NONWORDS SOA	3	597 2.0% (57)	599 2.6% (56)	630 3.4% (70)	638 8.5% (55)
	4	582 3.1% (59)	581 1.4% (65)	613 2.8% (63)	621 3.3% (59)
	20		40	20	40
1	1	684 2.4% (73)	695 3.3% (77)	686 2.0% (67)	696 3.6% (73)
	2	672 2.7% (69)	679 2.9% (78)	680 3.7% (74)	687 3.1% (67)
	3	680 3.6% (72)	665 3.1% (71)	684 2.8% (74)	670 2.3% (73)
	4	683 3.1% (78)	658 2.4% (73)	682 3.7% (68)	665 1.9% (66)

		source	df	sum of square	mean square	F value	p value	minF	df
words	by Subjects	energy	3	24078.494	8026.165	4.145	0.007	1.834	3,535
		error	165	319495.978	1936.339				
		SOA	1	27615.167	27615.167	18.505	0.000	7.699	1,294
		error	55	82076.492	1492.300				
		SOA*energy	3	6887.976	2295.992	1.720	0.165	0.433	3,589
		error	165	220227.653	1334.713				
	by Items	energy	3	24926.659	8308.886	3.290	0.021		
		error	440	1111328.850	2525.747				
		SOA	1	33301.646	33301.646	13.185	0.000		
		error	440	1111328.850	2525.747				
		SOA*energy	3	4386.044	1462.015	0.579	0.629		
		error	440	1111328.850	2525.747				
nonwords	by Subjects	energy	3	2350.764	783.588	0.308	0.820	0.148	3,502
		error	165	419772.020	2544.073				
		SOA	1	431.191	431.191	0.251	0.618	0.158	1,287
		error	55	94386.441	1716.117				
		SOA*energy	3	1693.815	564.605	0.255	0.858	0.101	3,530
		error	165	365453.748	2214.871				
	by Items	energy	3	2409.014	803.005	0.285	0.837		
		error	440	1241521.528	2821.640				
		SOA	1	1206.651	1206.651	0.428	0.513		
		error	440	1241521.528	2821.640				
		SOA*energy	3	1404.540	468.180	0.166	0.919		
		error	440	1241521.528	2821.640				

Reaction times, percent errors, (SDs) for all experimental cells in experiment 3, and ANOVA details

Contrast Level		identity		control	
WORDS		20	40	20	40
low		579 1.4% (55)	573 2.8% (68)	587 2.2% (57)	595 4.3% (47)
	high	572 3.1% (56)	557 2.2% (65)	588 2.9% (47)	596 5.2% (48)
NONWORDS		20	40	20	40
low		633 3.3% (60)	613 2.8% (60)	637 4.0% (66)	630 3.4% (69)
	high	624 4.3% (67)	613 4.2% (66)	634 2.2% (71)	622 2.8% (65)

		source	df	sum of square	mean square	F value	p value	minF'	df
words	by Subjects	contrast	1	4342.783	4342.783	10.705	0.003	2.595	1,471
		error	27	10953.687	405.692				
		SOA	1	9804.886	9804.886	6.916	0.014	3.621	1,363
		error	27	38280.485	1417.796				
		SOA*contrast	1	444.527	444.527	0.634	0.433	0.280	1,455
		error	27	18927.323	701.012				
	by Items	contrast	1	21537.143	21537.143	3.426	0.065		
		error	444	2791554.444	6287.285				
		SOA	1	47781.302	47781.302	7.600	0.006		
		error	444	2791554.444	6287.285				
		SOA*contrast	1	3141.892	3141.892	0.500	0.480		
		error	444	2791554.444	6287.285				
nonwords	by Subjects	contrast	1	53.956	53.956	0.078	0.782	0.068	1,427
		error	27	18608.244	689.194				
		SOA	1	1027.587	1027.587	1.548	0.224	0.483	1,431
		error	27	17927.698	663.989				
		SOA*contrast	1	1521.429	1521.429	2.082	0.161	0.770	1,419
		error	27	19732.636	730.838				
	by Items	contrast	1	2303.350	2303.350	0.509	0.476		
		error	444	2011170.992	4529.664				
		SOA	1	3181.239	3181.239	0.702	0.402		
		error	444	2011170.992	4529.664				
		SOA*contrast	1	5533.383	5533.383	1.222	0.270		
		error	444	2011170.992	4529.664				

References

- Berent I, Perfetti CA. Roses are reezes: The two cycles of phonological assembly in English. *Psychological Review* 1995;102:146–184.
- Brysbaert M. Prelexical phonological coding of visual words in Dutch: Automatic after all. *Memory & Cognition* 2001;29:765–773.
- Boudelaa, S.; Marslen-Wilson, W. The time-course of morphological, phonological and semantic processes in reading Modern Standard Arabic; Proceedings of the Twenty Third Annual Meeting of the Cognitive Science Society Edinburgh; Scotland. 2001. p. 138-143.
- Coltheart M, Rastle K, Perry C, Langdon R, Zeigler J. A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review* 2001;108:204–256. [PubMed: 11212628]DRC
- Di Lollo V, von Muhlenen A, Enns JT, Bridgeman B. Decoupling stimulus duration from brightness in metacontrast masking: Data and models. *Journal of Experimental Psychology: Human Perception and Performance* 2004;30:733–745. [PubMed: 15301621]
- Dominguez A, Segui J, Cueto F. The time course of inflexional morphological priming. *Linguistics* 2002;40:235–259.
- Hadani I, Meiri AZ, Guri M. The effect of exposure duration and luminance on the 3-dot hyperacuity task. *Vision Research* 1984;24:871–874. [PubMed: 6474843]
- Ferrand L, Grainger J. Phonology and orthography in visual word recognition: Evidence from masked nonword priming. *The Quarterly Journal of Experimental Psychology* 1992;45A:353–372. [PubMed: 1308733]
- Ferrand L, Grainger J. The time course of orthographic and phonological code activation in early phases of visual word recognition. *Bulletin of the Psychonomic Society* 1993;31:119–122.
- Ferrand L, Grainger J. Effects of orthography are independent of phonology in masked form priming. *The Quarterly Journal of Experimental Psychology* 1994;47A:365–382. [PubMed: 8036269]
- Forster, KI. Form-priming with masked primes: The best-match hypothesis. In: Coltheart, M., editor. *Attention & Performance XII*. Lawrence Erlbaum; Hillsdale, N.J.: 1987. p. 127-146.
- Forster KI. The pros and cons of masked priming. *Journal of Psycholinguistic Research* 1998;27:203–233. [PubMed: 9561785]

- Forster KI, Davis C. Repetition priming and frequency attenuation in lexical access. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 1984;10:680–698.
- Frost R. Phonological computation and missing vowels: Mapping lexical involvement in reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 1995;21:398–408.
- Frost R. Towards a strong phonological theory of visual word recognition: True issues and false trails. *Psychological Bulletin* 1998;123:71–99. [PubMed: 9461854]
- Frost R, Forster KI, Deutsch A. What can we learn from the morphology of Hebrew: A masked priming investigation of morphological representation. *Journal of Experimental Psychology: Learning Memory, & Cognition* 1997;23:829–856.
- Frost R, Ahissar M, Gottesman R, Tayeb S. Are phonological effects fragile? The effect of luminance and exposure duration on form priming and phonological Priming. *Journal of Memory and Language* 2003;48:346–358.
- Grainger J, Ferrand L. Masked orthographic and phonological priming in visual word recognition and naming: Cross-task comparisons. *Journal of Memory and Language* 1996;35:623–647.
- Hood, DC.; Finkelstein, MA. Sensitivity to light. In: Boff, K.; Kaufman, L.; Thomas, J., editors. *Handbook of Perception and Human Performance*. 1. Wiley-Interscience; New York: 1986. p. 5.1-5.66.
- Jacobs AM, Grainger J, Ferrand L. The incremental priming technique: A method for determining within-condition priming effects. *Perception & Psychophysics* 1995;57:1101–1110. [PubMed: 8539086]
- Lukatela G, Frost S, Turvey MT. Phonological priming by masked nonword primes in the lexical decision task. *Journal of memory and Language* 1998;39:666–683.
- Lukatela G, Turvey MT. Visual access is initially phonological: 1. Evidence from associative priming by words, homophones, and pseudohomophones. *Journal of Experimental Psychology: General* 1994a;123:107–128. [PubMed: 8014609]
- Lukatela G, Turvey MT. Visual access is initially phonological: 2. Evidence from associative priming by homophones and pseudohomophones. *Journal of Experimental Psychology: General* 1994b; 123:331–353. [PubMed: 7996120]
- Michaels CF, Turvey MT. Central sources of visual masking: Indexing structures supporting seeing at a single brief glance. *Psychological Research* 1979;41:1–61.
- Perfetti CA, Bell LC, Delaney SM. Automatic (prelexical) phonetic activation in silent word reading: Evidence from backward masking. *Journal of Memory and Language* 1988;27:59–70.
- Rastle K, Brysbaert M. Masked phonological priming effects in English: are they real? Do they matter? *Cognitive Psychology* 2006;53:97–145. [PubMed: 16554045]
- Sperling G. Information retrieval from two rapidly consecutive stimuli: A new analysis. *Perception and Psychophysics* 1971;9:89–91.
- Tan LH, Perfetti CA. Phonological and associative inhibition in the early stages of English word identification: Evidence from backward masking. *Journal of Experimental Psychology: Human Perception and Performance* 1999;25:59–69.
- Turvey MT. On peripheral and central processes in vision: Inferences from an information-processing analysis of masking with patterned stimuli. *Psychological Review* 1973;80:1–52. [PubMed: 4689202]
- Van Orden GC, Pennington BF, Stone GO. Word identification in reading and the promise of subsymbolic psycholinguistics. *Psychological Review* 1990;97:488–522. [PubMed: 2247539]
- Verstaen A, Humphreys GW, Olson A, d'Ydewalle G. Are phonemic effects in backward masking evidence for automatic prelexical phonemic activation in visual word recognition? *Journal of Memory and Language* 1995;34:335–356.

Figure 1. Identity priming effects obtained for words and nonwords at increasing levels of luminance and at the two levels of SOA, in experiment 1.

Figure 2.
Identity priming effects obtained for words and nonwords at increasing levels of luminance and at the two levels of SOA, in Experiment 2.

Figure 3.
Identity priming effects obtained for words and nonwords at increasing levels of contrast and at the two levels of SOA, in Experiment 3.

Table 1

Exposure durations and luminance measures used to determine the four levels of energy of Experiment 1.

Energy Level	Short Exposure High-Luminance	Long Exposure Low-Luminance	Total Energy
1	20 ms $\times$ 2 cd/m ²	40 ms $\times$ 1 cd/m ²	40
2	20 ms $\times$ 4 cd/m ²	40 ms $\times$ 2 cd/m ²	80
3	20 ms $\times$ 8 cd/m ²	40 ms $\times$ 4 cd/m ²	160
4	20 ms $\times$ 16 cd/m ²	40 ms $\times$ 8 cd/m ²	320