Supplementary Material

Unconscious numerical priming despite interocular suppression

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Supplementary Methods

Display

Participants viewed a CRT display (resolution = 800×600, 14' Sony Multiscan 110ES for which a look-up table linearized output luminance) at a distance of 50cm through a mirror stereoscope that displayed different images to corresponding regions of each retina. Textured black and white bars (0.5° width) were placed binocularly 3° on either side of the fixation point in order to facilitate binocular fusion. Stimuli were generated using the Cogent toolbox (www.vislab.ucl.ac.uk/Cogent/) for MATLAB (Mathworks Inc).

Assessment of departure from chance in Enumeration of invisible prime set

Within each participant, the binomial cumulative distribution was used to assess the statistical significance of the accuracy of enumeration of the invisible prime set (rating = 0). With *n* being the number of trials and three possible alternative answers, the probability of arriving at the correct target number at least *k* times by chance was calculated as follows:

$$P(k) = \sum_{i=k}^{n} \binom{n}{i} \times \left(\tfrac{1}{3}\right)^{i} \times \left(\tfrac{2}{3}\right)^{n-i}$$

If the probability thus calculated was less than 5%, then that participant's performance had departed significantly from chance.

Randomization of suppressed stimulus size

The sizes of the suppressed Gabor patches were randomized in such way as to minimize any relation between size and total surface area. For numerosity 3, the diameter of the Gabor patches were sampled from a uniform distribution with mean 0.9 degree (range: 0..8-1.1). For numerosity 2, the diameter of the Gabor patches were sampled from a uniform distribution with mean 1.1 degree (range: 0.9-1.3). For numerosity 1, the diameter of the Gabor patch was sampled from a uniform distribution with mean 1.55 degree (range: 1.2-1.9). These values were chosen to assure that, on average, the total surface area covered by 3 stimuli (i.e. $3\times\pi\times0.9/2\times0.9/2$) was not different from that covered by 2 stimuli (i.e. $2\times\pi\times1.1/2\times11/2$) nor from that of one stimulus (i.e. $1\times\pi\times1.55/2\times1.55/2$). Yet, this randomization with overlapping tails ensured that the size of individual stimuli could not inform the subject about the number of suppressed items. Within each trial, all suppressed Gabor patches had the same size.

Exclusion criteria

In experiment 2, we first excluded participants for whom the frequency of trials where the prime was rated invisible was less than either of the other two rating levels. This led to exclusion of two participants, presumably due to ineffective continuous flash suppression. We then selected trials for further analysis that were rated zero for prime visibility (indicating that the participant was not aware of the prime) and elicited correct responses to the target within 1500ms. Two further participants were excluded on this basis due to reaction times consistently exceeding 1500ms (i.e. rejection of more than 50% trials).

In experiment 3, applying the same inclusion and exclusion criteria as Experiment 2, data from five participants were excluded from the analysis (ineffective CFS for three participants slow RT for two others).

In experiments 4 & 5 data from three participants (ineffective CFS for two participants and slow reaction times for another) were excluded from the analysis.

Experiments 4 and 5: details of design and procedure

In Experiment 4, the task was identical to Experiment 2 (see Figure 1). Each participant completed 12 blocks of 60 trials. Participants completed one practice block before the main experiment. Prime set contrast and duration were reduced (see Stimuli section in General Methods) to enhance the depth of suppression (Tsuchiya et al., 2006). On 40% of the trials, the prime set was presented binocularly and thus was visible. Trials with monocular and binocular primes were randomly interleaved. In Experiment 5, the stimulus sequence was identical to Experiment 4 but participants were asked to enumerate the prime set and rate its visibility. This experiment provided a strict control for prime visibility by employing identical stimuli and the same observers as Experiment 4. Analysis of data was identical to Experiment 1. Each participant completed 8 blocks of 60 trials. The order of the two experiments was counter-balanced across participants.

Supplementary Results

Experiment 2: priming effect is not accounted for by change of target numerosity across distance.

It is conceivable that these effects might relate to the specific target numerosity rather than the more abstract concept of distance between prime and target. As pointed out above, different levels of target-prime distance correspond to specific target quantities. For example, a target/prime distance of -1 comprises trials where target quantity was either one (and prime set was two) or two (and prime set was three); whereas a difference of +1 comprises trials where target quantity was two (and prime set one) and three (and prime set two). Thus, it is possible that the effect of target/prime distance on reaction time may be confounded by the effects of changes in reaction time to different target numerosities.

We therefore conducted two additional analyses. Within each participant and for each level of target-prime distance, we calculated the baseline RT by only considering the zero-prime trials in which target quantity corresponded to the specific target-prime distance. For example, for target/prime -1, we calculated the baseline by selecting all zero-prime trials where target quantity was either 1 or 2. Conversely, for target/prime +1, we selected all zero-prime trials where target quantity was either 2 or 3. Thus, baseline was defined specifically for each level of target-prime distance. Any effects of reaction time specific to target quantity should not be detected in this way as the baseline and the t-p distance of interest correspond to identical target numerosities. Group level analyses replicated the same results as obtained by a common zero-prime ($F(4,64) = 10.36$, $p < 0.0001$; One-sample t-test comparison with zero; for target/prime = -2, $t(16)=3.67$; $p = 0.002$; for target/prime = -1, $t(16) = 2.09$; $p = 0.052$; for target/prime = 0, $t(16)= -2.395$; $p = 0.03$; for target/prime = 1, $t(16) = -2.20$; $p = 0.042$; for target/prime = 2, $t(16) = -2.48$; $p = 0.024$). Note that for target/prime identity, the results of the original and corrected analysis are identical since this includes all target quantities. Furthermore, the results also showed that in the no-prime condition, reaction times to 1, 2 or 3 target items did not differ significantly ($F(2,32) = 1.78$, $p > 0.1$). Therefore, we calculated the baseline reaction time by collapsing across the target set numerosities in all the correctly enumerated no-prime trials.

Experiment 2: Directional selectivity of the distance effects

The priming effect depended on target/prime distance. For prime sets greater than the target set, enumeration judgment was slowed relative to no-prime baseline: for distance -2, $t(16)=3.03$; $p = 0.008$; for distance -1, $t(16) = 3.42$; $p = 0.003$) all tests using one-sample *t*-test comparison with zero. For prime sets equal to or smaller than the target set, enumeration judgment was speeded relative to no-prime baseline (One-sample *t*-test comparison with zero; for target identical to prime $t(16)= -2.395$; $p = 0.03$; for distance 1, $t(16) = -2.40$; $p = 0.03$; for distance 2, $t(16) = 2.27$; $p = 0.04$). Analysis of performance accuracy showed that participants were consistently and similarly accurate and near ceiling across all levels of target/prime distance (accuracy range: 94-98%; one way ANOVA, $F(4,64)=1.47$, $p > 0.2$. Analysis of performance accuracy showed a pattern similar to that obtained in Experiment 2

Direct comparison of Experiment 2 & 3

To compare the results of experiments 2 and 3 directly, RTs were normalised as z-scores relative to the no-prime baseline condition. For each participant, the mean RT from the no-prime condition was subtracted from the mean RTs at each level of target/prime distance, and divided by the standard deviation for the no-prime condition. We then performed a 2 x 5 ANOVA on Z scores with Experiment as one factor (2 levels) and target/prime distance as another factor (5 levels). An independent comparison of baseline no-prime conditions across the two experiments did not show any significant difference. The main effect of target/prime distance was significant ($F(4,112) = 5.73$, $p < 0.001$), while neither the main effect of Experiment $F(1,28) = 0.026$, $p > 0.8$ nor the interaction between the two factors ($F(4,112) = 0.132$, $p > 0.9$) were significant.

Experiment 4: Directional selectivity of the distance effects

The priming effect depended on target/prime distance: for negative target/prime distances, RTs were slowed relative to the zero-prime baseline (for distance = -2, $t(15)=2.26$; $p = 0.03$; for distance = -1, $t(15) = -0.11$; $p = 0.9$; One-sample *t*-test comparison with zero) whereas for positive target/prime distances, RTs were faster relative to baseline (for distance = 0, $t(15)= -3.55$; $p = 0.003$; for distance = +1, $t(15) = -2.49$; $p = 0.025$; for distance = +2, $t(15) = -0.45$; $p = 0.6$).

Experiment 2, 3 and 4: the effect of absolute distance.

In both Experiments 2 and 4, compared to no-prime baseline, enumeration RT was faster for identical prime and target numbers. For higher absolute distances, the enumeration RT increased relative to no-prime condition (One-way ANOVA, Experiment 2: $F(2,32) = 6.43$; $p= 0.004$; Experiment 4: $F(2,30) = 6.53$; $p= 0.005$). Thus, although the priming effects were in opposite directions for positive and negative distances, because of their asymmetric magnitude (e.g. compare t-p = -2 to t-p = 2 in Figure 2B), when collapsed together a net positive priming effect (i.e. interference) is obtained at large distances. In Experiment 3, on the other hand, the effect of absolute distance on priming effect was not significant (One-way ANOVA, Experiment 2: $F(2,24) = 0.81$; $p= 0.4$).

Experiment 4: Plotting RTs for conscious priming effects

In Experiment 4, with monocular invisible primes, participants' phenomenal experience was identical for non-zero and zero primes and therefore, the zero-prime trial served as proper baseline for measuring the priming effect. With visible primes, however, the phenomenal experience of the stimulus sequence was radically different for non-zero and zero-prime trials. For example, the appearance of the prime (irrespective of its magnitude) could act as an alerting signal informing the participant about the imminent appearance of the target set. We observed that this was indeed the case and RTs were generally faster under conscious prime conditions. We therefore decided that in the conscious prime condition, the priming effect was best demonstrated by the RTs themselves as depicted in Figure 3B.

Supplementary Discussion

The recent reports of asymmetric distance-dependent numerical priming such as those reported here as well as by others (Roggeman et al., 2007;Turconi et al., 2006;Van Opstal et al., 2008) point to the possibility of the existence of multiple cognitive processes underlying numerical judgments.

For example, one possible multiple-stage interpretation of the asymmetric effects reported here is that targets of different numerosity may be differentially susceptible to priming. If the prime quantity were to be integrated in the decision process involving enumeration of the target, then having 3 items in the target set may leave little room for priming; on the other hand, enumeration of 1 target may be more strongly affected by more numerous primes. Thus, integration of unconscious prime information in the enumeration decision may depend on a 2-stage process that takes prime information into account only when the target numerosity is less than maximal. Such interpretation predicts an interference effect for negative distances, which is, admittedly, confirmed by the data. However, this account does not predict any priming effect, and certainly no facilitation, for zero (identity priming) and positive distances which the data show repeatedly. It will be intriguing for future work to probe the contribution of such mechanisms to the subliminal priming effects we observed.

A recent study that employed brief conscious primes in a number naming task showed that non-symbolic primes increased reaction times (relative to prime = target condition) with target enumeration only when prime set was smaller than the target set (Roggeman et al., 2007). Primes larger than targets did not affect naming time. Moreover, larger symbolic (digit) primes also appeared to slow dot number naming. Thus, the general pattern of the results reported in this earlier study of conscious primes is not the same as the pattern we found in the present study for unconscious (Experiments 2, 3 and 4; Figures 2B & 2C and Figure 3A) as well as conscious (Experiment 4; Figure 3B) primes. There were several important differences between the two studies that complicate comparison: dichoptic versus conventional presentation of the stimuli, direct enumeration by manual response versus number naming by verbal response, and extended (at least 1000ms) versus brief (<100ms) prime display time. Moreover, this previous work employed numbers up to five, whereas we used only up to three and hence within the subitizing range. It is possible that priming effects for numbers beyond the subitizing range may be different from within it: if one has to count the dots, then attention is on the stimulus for longer and the process of extracting numerosity may be different. Further investigations are needed to clarify the role of each of these factors in the differences delineated by the two studies.

Reference List

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