SENSORY ORIGINS OF MASKED PRIMING: PRIME-TRAGET CONGRUENCY AND CONGRUENCY BASE RATE ALTER VISUAL TARGET DISCRIMINABILITY

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Abstract

Perceptual priming studies commonly use response latencies and error rates to infer if primes affect motor responses or sensory representations as well. Here, we use signal detection theory (SDT) analysis to address this issue, varying both prime-target congruency and non-sensory context of the task (serial presentation order and base rates of congruent and incongruent trials). Participants pressed a respective key, promptly deciding whether or not the target square had gaps in its outline. In a trial, two other stimuli were presented prior to the target: either a congruent or an incongruent prime (same/different square, respectively) and a mask (square with dashed outline). In between-subject designs, we varied the frequency of congruent and incongruent trials in the series (1:1, 1:3, and 3:1) and serial order of their presentation (either frequent or infrequent - congruent or incongruent - trials were more, or equally, likely to occur at the series outset). The results indicate (1) a reliable priming of target discriminability (i.e., enhanced congruent trials), (2) a congruency × base rate interaction for discriminability, such that frequent incongruent trials abolish discriminability priming, but (3) no priming for decision/response criteria. We conclude that with masked priming of visual identification, both sensory (prime-target congruency) and non-sensory variables (base rates of congruent and incongruent trials) modulate target discriminability, affecting sensory representations, rather than decision criteria and/or response tendencies.

Studies of perceptual priming, unlike research on higher-order forms of priming (for example, memory, semantic, and other cognitive priming effects; e.g., Schacter and Buckner, 1998), have sought to determine if primes directly affect motor/response (executive) components of performance or sensory representations as well. Much work has argued that perceptual priming, as measured commonly by response latencies and error rates for congruent and incongruent trials (i.e., trials with either matching or non-matching prime and target, respectively), heavily relies on concurrent motor responses (e.g., Eimer & Schlaghecken, 2003). Some authors suggest, however, that perceptual priming can be nonmotor and occur also for sensory/mental representations (e.g., Mattler, 2003). One straightforward way to

address the issue of whether perceptual priming relates to sensory or decisional/response processing is to use signal detection analysis that provides for separate measures of sensory discriminability and response (decision) criteria (Green & Swets, 1966; Macmillan & Creelman, 2005). Surprisingly, in recent years perceptual priming has been investigated using primarily response latencies and error rates while the signal detection theory (SDT) measures have long been available (cf. Farah, 1989; Norris, 1995).

Here, we use SDT analysis to examine if varying both sensory (the prime-target congruency) and non-sensory variables (the frequency/base rate of congruent and incongruent trials and their serial order of presentation) selectively affects visual target discriminability and/or decision (response) bias in a typical three-stimulus masked priming paradigm. We employed a visual identification task with the prime, mask, and target presented consecutively in a trial. Participants responded with a respective key, promptly deciding whether or not the target square had gaps in its outline. We hypothesized that if, on the one hand, perceptual priming occurs for sensory representations, then congruent prime-target trials (e.g., gap prime/gap target) would result in a greater discriminability of gap/no-gap targets than incongruent prime-target trials (gap prime/no-gap target). On the other hand, if priming is restricted solely to response tendencies, then the base rate of congruent and incongruent trials and their serial presentation order would specifically modulate the participants' decision criteria.

Method

Participants

Seven separate groups of 8 volunteer participants each (46 female and ten male; age range, 17-47 years; mean, 26 years) took part in the study. They had normal or corrected vision, were right-handed, unaware of the aim of the research, and run individually.

Stimuli, procedure, and generation of presentation series

We used three consecutive stimuli presented on a trial: a prime, a mask, and a target; each was represented as an bright-outline square of the same dimensions. Two distinct kinds of squares served both as the prime and target stimuli. One square had an intact outline (side, 32 mm [80 pixels, 3 pixels thick], or 0.046° viewed from an observation distance of 70 cm; a *no-gap* stimulus type), and the other was created by removing a 35-pixel part of the outline in the middle of the square's both vertical sides (a *gap* stimulus type). Using the two-side gaps avoided likely contamination of left/right responses with an asymmetrical (e.g., left/right-hand located) relevant target feature. The mask was a square with the dashed outline (alternating 5-pixel gaps and lines). The stimuli were presented on a 17-in. monitor (refresh rate, 75 Hz) driven by the Matlab Psychophysics Toolbox extensions for Microsoft Windows (Brainard, 1997; Pelli, 1997), running on a Pentium-4 PC. The duration of a screen frame was 13.3 msec.

Four different types of trials were built by using the *gap* and *no-gap* squares: two congruent trial types (with the matched prime and target: *gap/gap*, *no gap/no gap*) and two incongruent types (with the non-matched prime and target: *gap/no gap, no gap/gap*). The proportion of distinct trials within each trial type was always equal (e.g., gap/gap and no gap/no gap for congruent trials, 1:1) and balanced throughout the experiments. A total of 200 congruent and incongruent trials were presented in a series with different base rates and orders of presentation. Specifically, in a between-subject design of seven experimental conditions (Table 1), we varied the frequency/base rate of congruent and incongruent trials in the series

Table 1. Summary of the experimental conditions (in brackets, the number of distinct trials).

Cond. No.	Cong. / Incong. Base Rate	Trial Randomization	Frequent Outset Trials
1	1 : 1 (100c : 100i)	biased	congruent
2	1 : 1 (100c : 100i)	biased	incongruent
3	3 : 1 (150c : 50i)	biased	incongruent
4	1 : 3 (50c : 150i)	biased	congruent
5	3 : 1 (150c : 50i)	standard	congruent
6	1 : 3 (50c : 150i)	standard	incongruent
7	1 : 1 (100c : 100i)	standard	none

(1:1, 1:3, and 3:1) and serial order of their presentation (either frequent or infrequent, congruent or incongruent, trials were more, or equally, likely to occur at the series outset). In order to manipulate the serial presentation order, we used either standard (computer-assisted) or biased randomization of trials. The biased presentation series were created using a modified version of the algorithm described in detail elsewhere (Sokolov, Reissner, & Pavlova, 2004). In brief, with standard randomization of equal-frequent congruent and incongruent trials (condition 7), both types of trials were equally likely to occur at the beginning (outset) of the series. With standard randomization of the series with unequal-frequent trials, on overall frequent (either congruent, condition 5, or incongruent, condition 6) trials were more likely to occur at the series outset. By contrast, with biased randomization of unequal-frequent trials, on overall *in*frequent (either incongruent, condition 3, or congruent, condition 4) trials mainly occurred at the series outset. Similarly, with biased randomization of equal-frequent trials (conditions 1 and 2), either congruent or incongruent ones, respectively, were more likely to do so, merely mimicking the difference in overall frequency. Two distinct presentation series per condition were used in order to control for any series effects. The experiments were conducted in a dimly-lit room. The participants viewed the stimuli with both eyes; a head-and-chinrest ensured stable observation distance.

The series started automatically after the participant's entering information about sex and age and confirming the understanding of the on-screen instructions. A trial began with a fixation cross in the middle of the screen shown for 505 msec (38 frames). After that, three stimuli were consecutively presented: a prime (duration, 26.6 msec), the mask (79.8 msec), and a target (106.4 msec); thus, the prime-target SOA was 106.4 msec including the intermediate mask. Participants had to make speeded responses with their left or right index finger depending on whether or not the target square had gaps in its outline. The two *Control* keys on the PC keyboard were labelled as *gap* or *no gap*. The label positions were counterbalanced between participants. No information about trial probabilities or any familiarization trials were given to the participants prior to the experiment; no online feedback was provided regarding the participant's performance. After a short break at the end of the session, participants completed a supplementary Priming Identification Procedure (PIP; 40 congruent and 40 incongruent trials presented randomly with the task to judge the masked-prime identity) that served for assessment of the visibility of primes in the main experiment.

Results

The results indicate a strong, reliable priming effect of prime-target congruency on visual target discriminability: the congruent trials with matching prime and target stimuli yield much better gap/no gap discriminability than the incongruent trials with non-matching prime and

target. The outcome of a mixed three-way repeated measures ANOVA performed on individual measures of discriminability, *d'*, in the conditions 3-6 (with different-frequent trials) and factors Type of Trial (congruent/incongruent), Serial Order (mainly congruent/incongruent trials presented at the series outset), and Frequency (frequent congruent/incongruent trials) reveals a highly significant main effect of Type of Trial on discriminability [F (1;28) = 35.057, $p < .0001$]. This is also true for equal-frequent congruent and incongruent trials in conditions 1 and 2 (mixed two-way repeated measures ANOVA with factors Type of Trial and Serial Order; F (1;14) = 12.100, $p < .004$; Figure 1), and in condition 7 (repeated measures ANOVA with factor Type of Trial; F (1;7) = 17.269, $p < .004$; not shown). No main effects of either serial presentation order or frequency of congruent and incongruent trials on discriminability are found in either analysis.

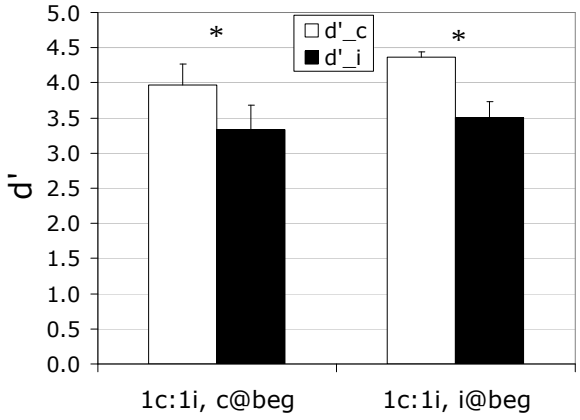

Figure 1. Mean visual target discriminability (*d'*) for the equal-frequent congruent, *white*, and incongruent trials, *black* bars, in the series with either mainly congruent or incongruent trials presented at the beginning (outset) of the series (conditions 1, *c@beg*, and 2, *i@beg*). Each bar is a group mean for eight participants ± 1 SEM. Asterisks indicate a reliable priming of target discriminability ($p < .004$).

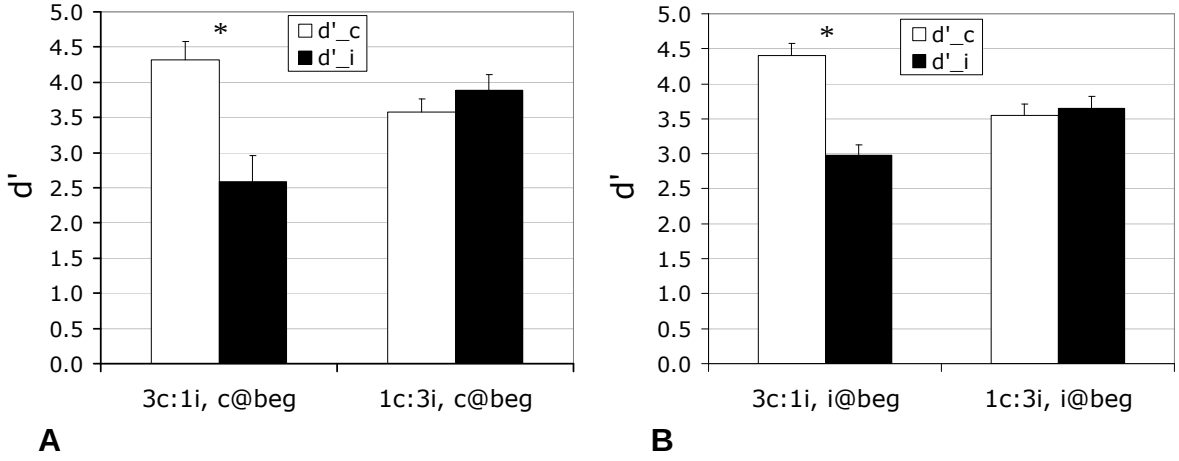

Figure 2. Mean target discriminability (*d'*) for the different-frequent congruent, *white*, and incongruent trials, *black* bars, in the series with either mainly congruent or incongruent trials presented at the series outset: ***A***, conditions 4 (*1c:3i*) and 5 (*3c:1i*), both *c@beg*; ***B***, conditions 3 (*3c:1i*) and 6 (*1c:3i*), both *i@beg*. Each bar is a group mean for eight participants ± 1 SEM. Note a strong Type of Trial by Frequency interaction ($p < .0001$) due to an augmented priming effect with frequent congruent trials and an abolished priming effect with frequent incongruent trials.

Notably, neither main effects of the three factors, nor their interactions occur whatsoever for decision criteria.

Most important, however, while on overall frequent congruent trials augment priming effect for discriminability compared to the respective conditions with equal-frequent trials (cf. Figures 1 and 2; conditions 5 versus 1, $t(7) = 3.29$, $p < .01$, and conditions 3 versus 2, $t(7) = 2.26$, $p < .06$), on overall frequent incongruent trials completely abolish the priming effect, giving rise to target discriminability that is now comparable to that for congruent trials (Figure 2a,b; *right*). The results of the above mixed three-way repeated measures ANOVA support this observation, indicating a highly significant Type of Trial by Frequency interaction [$F(1;28) = 59.460$, $p < .0001$]. Moreover, the strong interactions repeatedly occur when comparing corresponding pairs of conditions with variable frequency of distinct trials (Figure 2a,b; mixed two-way repeated measures ANOVA; conditions 4 and 5, $F(1;14) = 38.890$; conditions 3 and 6, 21.757; conditions 5 and 6, 23.988; and conditions 3 and 4, 40.448, all $p < .0001$). Although the visibility of masked prime as assessed by PIP was above chance (across conditions, average $d' = 1.165$; percentage correct, 67.63%; $p < .05$), there were clear priming effects as well.

Discussion

The present findings show a strong congruency and a striking congruency by frequency priming effect for visual target discriminability in the absense of any effects of these sensory and non-sensory variables on decision/response bias. In the SDT framework, this suggests that on overall, congruent prime and target result in sensory representations for the *gap* and *no-gap* targets that are further apart along the gap/no-gap continuum (i.e., are more distinguishable) than those for incongruent prime and target. Furthermore, frequent congruent prime and target increase this separation, augmenting the priming effect, while frequent incongruent prime and target reduce it and, thereby, entirely abolish the priming effect. In the latter case, the *gap*/*no-gap* identification remains comparably good for both congruent and incongruent trials, with a discriminability that is generally lower than discriminability for congruent trials but generally higher than discriminability for incongruent trials in other experimental conditions (Figures 1 and 2). Congruent prime and target, however, do not exhibit an advantage compared to incongruent ones.

Congruency priming effects on target discriminability with masked priming corroborate previous evidence on congruency effects on sensitivity in perceptual priming (e.g., Farah, 1989). This suggests that initial processing of masked primes that share sensory information with the target greatly enhances subsequent target identification, highlighting - in addition to motor component - a substantial sensory, nonmotor component of perceptual priming. The effects of a non-sensory variable (frequency/base rate of congruent and incongruent trials) on sensory representations, as indexed by discriminability and modulated by prime-target congruency, appear unexpected. Rather, one would anticipate a change in decision/response criteria. However, neither congruency, nor both non-sensory factors (frequency and serial presentation order of trials) are found to alter decision/response criteria. Because response criteria refer to covert rather than overt decisions, this result extends the vast evidence on automatic perceptual priming of motor (overt) responding, which is commonly indexed by the response latency and error rate (e.g., Eimer & Schlaghecken, 2003). It remains to be seen how the SDT measures of priming are related to these indices of performance in the present data, which reveals both the serial order and frequency effects on latency and error rate.

One possibility to parsimoniously account for the entire pattern of the present findings is that of selective attention operating on sensory representations (e.g., Mulligan & Hartman, 1996). Specifically, in the series with frequent congruent trials (conditions 3 and 5) the visual system is likely to heavily rely on the prime-target congruency. In this case, the preferential reliance on prime-target congruency would substantially improve discriminability for congruent trials, but it would deteriorate discriminability for incongruent trials compared with the series of equal-frequent trials (conditions 1, 2 and 7). This will lead to much more pronounced priming effects on target discriminability with frequent congruent trials than with equal-frequent trials (cf. Figures 1 and 2ab, *left*). By contrast, with frequent incongruent trials (conditions 4 and 6), the participants may tend to largely ignore the sensory information provided by the prime, making a *gap*/*no gap* decision solely on the basis of available target information as the two targets used in the study were clearly distinguishable. In this case, the sole reliance on target processing is likely to eliminate the priming effects of prime-target congruency, giving rise to comparably moderate target discriminability for both congruent and incongruent trials (Figure 2ab, *right*). Even if one considers SDT merely as a means to summarize the data without the theory's implications as a processing model (e.g., Norris, 1995), this proposal appears to plausibly account for the present data, for example, in a framework of accumulator models of perceptual priming (e.g., Usher & McClelland, 2001).

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