

## THE LOCUS OF COLLINEAR FACILITATION IN TEXTURE PROCESSING: AN EARLY OR LATE CORTICAL SEAT?

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### Abstract

*This study addresses the issue of whether collinear facilitation in texture processing, an effect observed across different visual tasks, rests on centre-surround mechanisms or rather involves certain forms of top-down mediation. A group of nine subjects rated their confidence about the presence/absence of the target on a four-point scale. Backward-masking was used after several learning sessions. The detection performance reached “pop-out” levels at 26-ms presentations. Improvement along sessions occurred in both target-present and target-absent trials. The target-present condition started by associating with higher confidence ratings and lower RTs, although performance was at a lower level than in the target-absent condition. Backward-masking did not disrupt the observed improvements, unlike what happens with non-collinear stimuli. Outcomes suggest that texture processing with collinear elements does depend on feed-forward processes mediating early-level interactions among VI cells.*

The global arrangement of an array of stimulus affects the visibility of a locally embedded target. Typically, the surrounding elements have a deteriorating effect on target's visibility (e.g., masking and crowding effects). However, when the target and the flanker elements are collinearly arranged, enhancement of target's visibility may result instead. Collinear facilitation has been found across different visual tasks. Polat & Sagi (1993) have shown that the detection of a low-contrast Gabor patch can be either enhanced or suppressed when tested with two adjacent high-contrast masking patches. Facilitation prevailed when the local orientation of the masking patches was co-axial with that of the test stimulus and vanished when it was made orthogonal to that of the test (Polat & Sagi, 1994). Similar results were also obtained in a contour integration task (Field, Hayes & Hess, 1993) requiring subjects to detect a path of Gabor patches embedded in randomly oriented patches. When the elements along the path were arranged collinearly, the structure was more salient than when their local orientation was 40-60° off the path. Moreover, reversing the contrast polarity of the Gabor patches in the path made it more difficult to detect (Field, Hayes & Hess, 2000). These facilitation effects obtained with collinear elements may be a demonstration of the "good continuation" and "similarity" principles of perceptual organisation formulated by Gestalt psychologists over 80 years ago.

It was suggested that the facilitation effect due to collinearity relies on excitatory connections from co-axial elements and inhibition from lateral elements ("the association field theory", Field et al. 1993), a process that selectively links local orientation analyzers in enhancing the processing of a region's global structure. Several studies that measured VI neurons activity in both alert and anesthetized monkeys (Kapadia et al. 2000; Nothdurft et al. 1999) provided support for the "association field" theory; facilitation (response enhancement) was found to arise mainly from co-axial interactions, while inhibition (response reduction) appeared to stem from lateral positions.

However, it is an open question whether the facilitatory and inhibitory connections underlying collinear facilitation rest strictly on neural interactions within the primary visual cortex, or whether they involve any form of top-down modulation. This issue is addressed here using a perceptual learning paradigm in a task requiring the subjects to detect a target among collinear distracters on the basis of contrast polarity. Using non-collinear elements, Grieco, Casco & Roncato (2006) showed that accuracy was similar and below threshold, at start, on both target-absent and target-present conditions, and that practice improved performance in the former condition more than in the later. Building on the collinear facilitation effect, different results may be hypothesized for collinearly arranged elements. Specifically: collinear arrangements of the background elements should facilitate the detection of presence/absence of a target right from the first learning session; moreover, learning could be expected to improved performance in the target-present condition by as much as in target-absent trials.

To highlight the locus of learning-related plasticity, the transfer of learning to stimuli where target and background elements switched their respective contrast polarities was evaluated: if improvements achieved during learning are specific to contrast polarity, then no transfer of learning should occur, in accordance with a low level seat of plasticity.

To investigate whether improvements rely on local low-level mechanisms or whether they involve some top-down modulation, a backward-masking paradigm is used after the leaning sessions. The effects of a backward masking pattern on stimulus detection have been proved to depend on the Stimulus Onset Asymmetry (SOA). For SOA below 100 ms, deterioration of the visibility of a stimulus arises from stimulus-masking integration: test and masking stimuli are perceived as forming part of the same pattern. On the other hand, for SOA above 100 ms, deterioration is due to interruption effects. If the analysis of the test stimulus involves recurrent processes, a mask should interrupt the signals that are fed back from higher to lower cortical areas. Contextual modulation for figure-ground displays has actually been shown to modify VI cells response 100-200 ms after stimulus onset. Therefore, if the collinear facilitation involves feedback mechanisms, performance will be disrupted by masking (providing that SOA is above 100 ms).

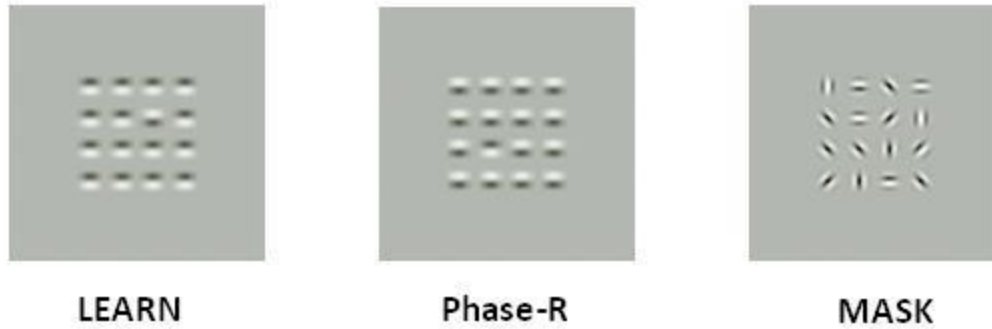
## Method

### *Stimuli*

Stimuli consisted of arrays of 4 x 4 Gabor elements, subtending an area of 6 x 6 deg (at a  $\approx$  70 cm viewing distance). The target was a Gabor patch of 0.8 deg (windowed sine wave with 1 cycle/deg) presented at maximum contrast (100%) among mirror-image elements. The target was present in half the trials, and its position in the array was varied randomly across trials. The learning stimuli (LEARN) and the Phase-R (Phase-Reversed) transfer stimuli for the target-present condition, as well as the masking stimuli, are illustrated in Fig. 1 (respectively left, middle and right panels).

### *Procedure, design and analysis*

Nine subjects took part in the experiment. They were made to rate their confidence about the presence/absence of the target on a four-point scale. Response times were always recorded, and  $d'$  measures of sensitivity, as well as  $c$  measures of response bias, were computed from the responses. The experiment proceeded through blocks of 160 trials corresponding to 2 (target conditions: present/absent)  $\times$  5 (exposure durations: 13-65ms)  $\times$  16 (different target positions).



**Figure 1.** Illustration of the stimuli arrays: *Left panel:* Learning stimulus (target-present). *Middle panel:* Phase-reversed stimulus (target-present). *Right panel:* Masking stimulus.

Each trial started by the presentation of a fixation screen for 1000 ms, which was immediately followed by the test stimulus. After the stimulus offset, a grey screen was displayed and remained visible until the subject's response. A total of 16 to 20 blocks were performed in 4 days. The transfer of learning (T) was evaluated at a 26 ms exposure duration, as the difference between Phase-R performance after and before the learning sessions, normalised to the total improvement during learning.

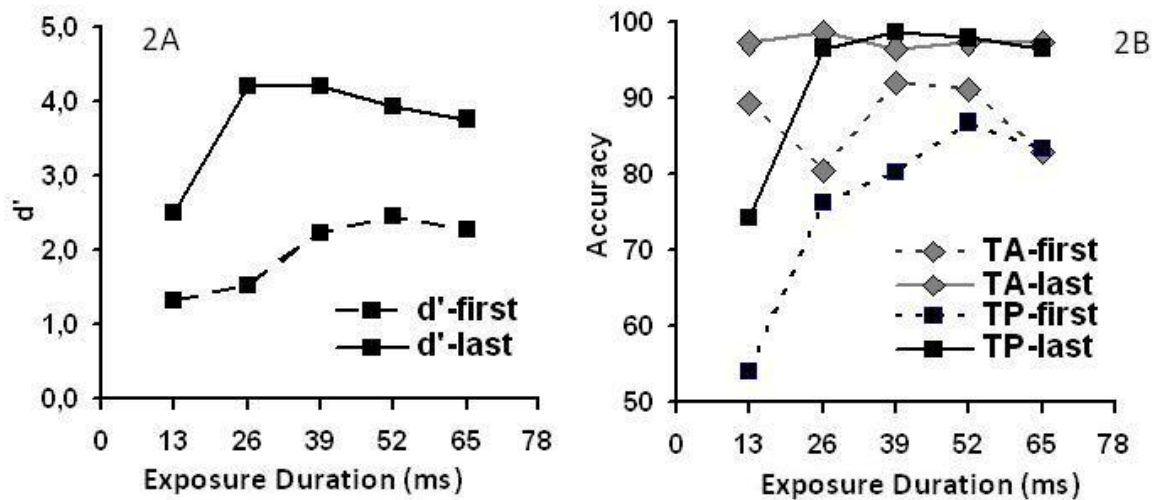
$$T = \frac{(d'_{after} - d'_{before})_{transfer-stimulus}}{(d'_{last} - d'_{first})_{learning\ stimulus}} \quad (1)$$

The effects of the mask on the test-stimulus were evaluated at a 65 ms exposure duration. The masking stimulus appeared either 165 or 315 ms (randomized) after the onset of the test stimulus (LEARN-w-mask165 and LEARN-w-mask315) and lasted for 250 ms.

## Results and Discussion

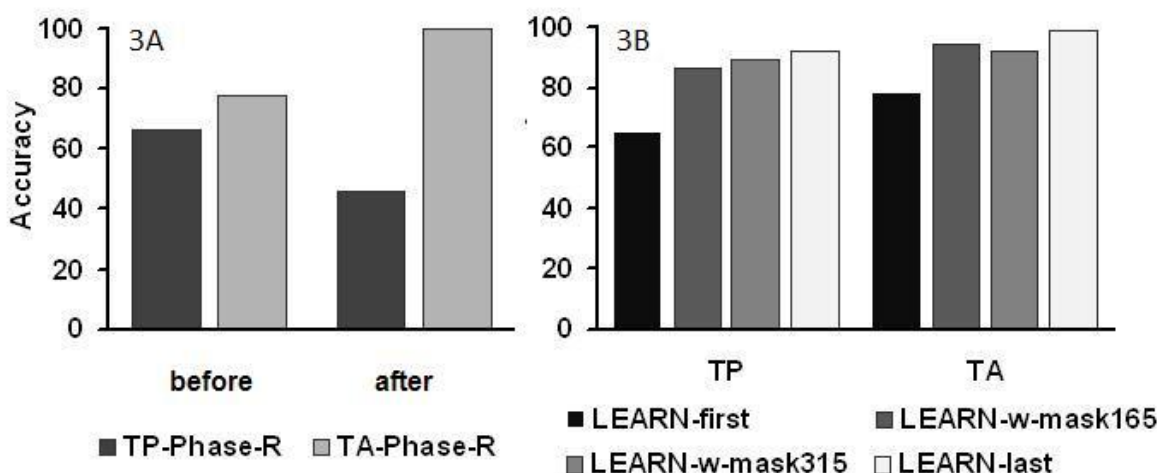
Figure 2 (A and B) plots sensitivity, measured by  $d'$ , and percent of correct responses (both averaged over 9 subjects) in the first and last learning session for both target conditions, as a function of exposure duration. Results show that  $d'$  was at pop out levels ( $d' \geq 1.34$ ) right from the start, and significantly increased during learning ( $p < 0.01$ ). Both target-present (TP) and target-absent (TA) performances ( $p < 0.001$ ) contribute to the overall improvement, which is more in keeping with a perceptual-sensitivity change interpretation than with one calling upon high-levels factors. This interpretation is strengthened by absence of shifts in the response criterion. Accuracy varied as a function of exposure duration in different ways for TP and TA ( $p < 0.001$ ). This difference is actually located at the 13 ms exposure duration, where target detection is severely impaired (compared to the TA performance), and remained after the learning was over, suggesting that limited exposure affects the processing of TP but not of TA. The amount of information caught in a 13 ms window thus appears sufficient to enable efficient processing in TA trials. On the contrary, it appears insufficient to support accurate target detection. Consistent accuracy in TP is on its turn observed from 26 ms onward, and that since the very first learning session.

Fig. 3 (A) displays accuracy values for the transfer stimulus (Phase-R) before and after learning, at 26 ms duration (the duration at which transfer of learning was evaluated) in both target conditions. Learning had a negative effect in the TP condition of Phase-R, where the target had the same contrast polarity as distracters during learning.



**Figure 2.** *Left (2A):* Averaged sensitivity, indexed by  $d'$ , for the learning stimuli, for the first and last learning sessions. *Right (2B):* Accuracy (percentage of correct responses) for both target-present/absent conditions, computed for the first and the last learning sessions.

The scanty overall transfer of learning to Phase-R ( $T=0.21$ ) is actually the mean resultant of very different transfer effects observed for each target condition ( $p < 0.001$ ). Accuracy for the TA condition in Phase-R is at ceiling after learning, while it actually decreases in the TP condition regarding performance before learning. In contrast to what happened with TP, the TA processing during learning was thus totally transferred to Phase-R, regardless of whether the characteristic feature shared by distracters was changed or not. This finding suggests that the mechanisms for processing homogeneous textures are insensible to contrast polarity.



**Figure 3.** *Left (3A):* Accuracy (percentage of correct responses) for Phase-R stimuli computed before and after the learning sessions in both target-present/absent conditions. *Right (3B):* Accuracy for the LEARN stimuli, computed for the first and last learning sessions (LEARN-first, LEARN-last), and for the post-learning sessions with mask presented at different SOA (LEARN-w-mask165, LEARN-w-mask315, and).

To evaluate whether masking disrupted the learning-related improvements, the accuracy of both target conditions in the first and the last learning sessions were compared with accuracy obtained with masking at 165 and 315 ms SOA. The correct percentage of both target conditions for each session (LEARN-first, LEARN-w-mask165, LEARN-w-mask315, and LEARN-last) is displayed in Fig. 3B. LEARN-w-mask at both SOAs differs from LEARN-first ( $p < 0.001$ ) but not from LEARN-last ( $p > 0.05$ ). The results show that performance was not affected by a post-masking presentation, regardless of the SOA (differences between LEARN-w-mask at 165 ms and at 315 ms SOA were not significant), and thus that the mask did not interfere with the improvements. This contrast with results found for non-collinear elements, where learning improvements for the TP condition were disrupted by backward masking with 170 ms SOA (Grieco et al. 2007). The present findings suggest that, unlike non-collinear textures, the processing of textures made up of collinear elements does not involve contextual modulation from higher levels of analysis.

The observed transfer patterns suggest that exclusion of distracters is the mechanism responsible for improvements in the TP condition. The circumstance that these mechanisms were not affected by backward masking suggests further that the inhibition of background elements is based on low level inhibitory mechanisms. This inhibitory interaction between the neural channels may also explain the learning effects on absent trials. In fact, suppression of a cell response to a stimulus presented in its RF, when the same texture falls in the surrounding area, is thought to be the basic mechanism of grouping by similarity (Maffei & Fiorentini, 1976).

Processes operating in TA trials appear capable of handling similarity in presentations as brief as 13 ms, they transfer when contrast polarity is reversed, and they are unaffected by masking. Similarly to the data obtained with non-collinear stimuli, therefore, these results suggest that homogeneous texture displays are processed through feed forward processes.

Although performance in the TA condition was better than in the TP condition, this later associated, at the beginning, with higher confidence ratings ( $p < 0.001$ ) and lower response time ( $p < 0.01$ ). The difference in response times was decreased along learning ( $p < 0.01$ ), but went on being significant. The difference in confidence ratings vanished with practice. Participants thus seemingly started by "guessing" that the target was absent, though accuracy was actually above threshold levels. This is consistent with a dissociation of target-absent processing as measured by objective and by subjective criteria: participants appear to not be aware of what they actually see. Conversely, even if less accurate, participants are more confident when responding that target is present. This could be taken as suggesting that when a different element is embedded among collinear distracters, some early attentive sources get mobilized, probably reducing target-location uncertainty and eliciting conscious experiences. Such an interpretation concurs with the finding that improvement in threshold detection of a Gabor patch when flanked by collinear ones was largely due to a significant reduction in uncertainty (Petrov, Verghese & McKee, 2006). More generally, also, bottom-up mechanisms are known capable of triggering rapid attentional and oculomotor responses to a salient target (Geng & DiQuattro, 2010).

Overall, the present findings show that collinear arrangements of the stimulus ease up the processing of both target conditions. Considering the transfer patterns and the results of masking together, it can be suggested that no recurrent processes are involved in the TP condition. If any top-down mechanisms happen to be at work in collinear facilitation for TP displays, they must be operating on the 'saliency map' or some other early working place, not before 13 ms nor later than 100-140 ms after stimulus onset, the point at which masking might interfere through contextual modulation. The early nature of collinear facilitation was also defended by Sterkin, Yehezkel, Bonne, Norcia, & Polat (2009), who showed that it can

be suppressed by backward masking with 50 ms SOA, i.e., coinciding with the characteristic temporal window of lateral interactions.

For the TA condition, our data supports feed-forward processes, initially without awareness. However, learning in the TA condition appears to have fostered mechanisms allowing for conscious target-absent perception.

As one general implication, consideration should be given to whether the target is embedded on collinearly or non-collinearly arranged elements, since different processes seem to be called upon by each situation. While inhibition of the suppressive surround appears to be mediated by feedback connections from higher cortical areas (Grieco et al. 2007) in non-collinear stimulus, it appears to differently rest on low level mechanisms in collinearly arranged stimulus.

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