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New type of perceptual suppression during dynamic ocular accommodation

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When viewing natural scenes saccadic eye movements are used to position retinal images of interest on the fovea, while vergence eye movements act to minimise retinal disparity and maintain a single binocular view of the target. Despite these disruptions to the retinal image, we perceive a stable visual world due to suppression of the magnocellular visual pathway which processes low spatial frequency target details [1]. Retinal image clarity is maintained by the mechanism of accommodation, which changes ocular power to produce sharp retinal images of objects at different viewing distances [2]. During abrupt dynamic changes in accommodation, visual suppression seems to occur as image degradation is rarely reported. Here, we report direct psychophysical evidence that visual suppression during dynamic accommodation really does occur. This suppression is selective for luminance modulated patterns of higher spatial frequencies, implying that the suppression is occurring in the parvocellular visual pathway, which carries colour and fine detail information.

Dynamic accommodation responses have a dual-mode behaviour comprising of an initial fast response, followed by a slower component [3,4]. The initial fast component provides a pre-programmed accommodation response, which is ballistic in nature and proportional to the level of retinal image blur. This fast component accounts for the majority of the response amplitude and produces abrupt changes in accommodation response level required to form clear retinal images. The slow component completes the abrupt change in accommodation and employs continuous feedback control to refine the response. Visual suppression is therefore likely to occur during the fast component of the accommodation response, which does not rely upon visual feedback control.

Using an adaptive staircase procedure and a two-alternative forced choice method, monocular contrast thresholds for detecting brief (43 ms) luminance modulated gratings of 1, 4 and 9 cycles per degree (cpd) presented at 1 m distance were measured during dynamic far-to-near accommodation responses (1 m to 0.33 m) at predetermined time markers after accommodation stimulus onset (see Figure 1 and Supplemental Data available on-line with this issue). Recorded accommodation responses were used to calculate the magnitude of retinal image defocus occurring at each time marker (Figure 1). Contrast thresholds were also measured during steady-state accommodation responses at viewing distances equal to the amount of defocus present in the dynamic conditions at each time marker.

As expected, contrast sensitivity (the reciprocal of contrast threshold) in both dynamic and steady-state accommodation conditions was reduced as a function of stimuli defocus to a greater extent at higher spatial frequencies (Figure 2) [5]. Multiple comparisons (t-tests using a Bonferroni correction) between contrast sensitivities in dynamic (Figure 2, open symbols) and steady-state (Figure 2, filled symbols) conditions revealed that contrast sensitivities for gratings of 1 cpd were not significantly different. Dynamic conditions reduced significantly ($P < 0.05$) the contrast sensitivity for 4 cpd gratings only for one subject (MD), while contrast sensitivities for 9 cpd gratings were significantly ($P < 0.05$) reduced for all subjects during the fast phase of the dynamic accommodation response (Figure 2 arrows; see Supplemental data).

To counterbalance accommodation direction and exclude possible reductions in retinal image contrast during the fast component of the dynamic accommodation response we measured contrast sensitivity to brief gratings of 6 ms duration and 4 degree diameter presented at 1 m viewing distance during far-to-near and near-to-far accommodation (Supplemental Data, control experiment 1). We found a significant reduction in sensitivity during the fast phase of far-to-near accommodation (Supplemental Figure S1a) and a lack of suppression during near-to-far accommodation (Supplemental Figure S1b). This finding suggests, that high spatial frequency information relating to the starting point of the accommodation response is selectively suppressed, with information about the end point being maintained. Based on this prediction, high spatial frequency gratings displayed at a near viewing distance (0.33 m) would be suppressed only during the fast phase of near-to-far accommodation responses but not during far-to-near accommodation responses. This was confirmed by subsequent results (Supplemental Data, control experiment1, Figure S1c and d).

Further control experiments examined whether bias in the direction of defocus (the visual stimulus getting more blurred...
eye movements do not influence sensitivity to high spatial frequency patterns (Supplemental Data, control experiment 3). The spatial-frequency selective nature of the observed suppression during dynamic accommodation makes it unlikely that our results can be explained by attentional mechanisms. Furthermore, we found that contrast sensitivity to 9 cpd gratings, measured during steady-state accommodation to a fixation target at a 0.67m viewing distance, did not change in the presence of an attentional cue (Supplemental Data, control experiment 4).

Our results demonstrate the existence of contrast sensitivity suppression for higher spatial frequencies which cannot be explained by optical factors. The use of a brief test stimulus makes it unlikely that eye movements can account for this visual suppression. Rather, the suppression can be attributed to a central neural mechanism such as the parvocellular visual pathway which processes stimuli of higher spatial frequencies. We intend to explore this proposition further by examining the effect of dynamic accommodation on the sensitivity to iso-luminant, chromatically-modulated patterns in the presence of luminance noise, which activate selectively the parvocellular pathway [6].

Research has shown that contrast sensitivity is reduced selectively for low spatial frequency stimuli during saccadic eye movements [1], vergence eye movements [7] and eyelid blinks [8]. These results were accounted for by suppression of the magnocellular visual pathway, which assists the visual system by selecting only relevant visual information [9] to maintain a stable perceptual environment. The parvocellular visual pathway mediates the perception of high spatial frequency details, and therefore relies upon accurate ocular accommodation to minimise retinal image blur. High spatial frequency stimuli produce a strong and sustained masking effect [10] which could affect visual perception during accommodation. The selective parvocellular visual pathway suppression identified in this study, during the fast phase of the accommodation response, would restrict the unwanted information about high spatial frequency patterns in the visual scene at starting and intermediate (see control experiment 2) positions of the accommodation target. This would alleviate any masking effect of these patterns on the accommodation target at the final destination and improve its clarity during the final slow phase of the accommodation response. Thus, in addition to the suppression of coarse object information during ocular movements, visual suppression during dynamic accommodation responses may play an important role in our perception of a stable and clear three-dimensional visual world. Our findings may have impact upon development of computational models of visual perception in everyday visual environments.

**Figure 2. Contrast sensitivity.**
Contrast sensitivity for detecting gratings of (A) 1, (B) 4 and (C) 9 cycles per degree (cpd) in steady-state (filled symbols) and dynamic (open symbols) conditions as a function of defocus of the test stimulus. Error bars denote 95% confidence intervals. Error bars are smaller than symbols when not visible. Arrows show that contrast sensitivities in steady-state and dynamic conditions are significantly different (P < 0.05, multiple comparisons using t-tests and a Bonferroni correction).

during the dynamic accommodation response), vergence eye movements in the occluded eye or attentional mechanisms were responsible for the reduced sensitivity at high spatial frequencies (Supplemental Data, control experiments 2–4). The results show that accommodative suppression still occurs when the visual stimulus gets clearer over the target presentation time during far-to-near accommodation (Supplemental Data, control experiment 2) and that vergence