

moderately low pH and high total aluminium levels. A detailed understanding of aluminium chemistry is essential to enable the effect of aluminium on the development of indigenous fish to be evaluated.

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1. Schofield, C. L. *Proc. Conf. Emerging Environmental Problems, Acid Precipitation*, 76–87 (US Environmental Protection Agency, 1976).
2. Davis, R. B., Smith, M. O., Bailey, J. H. & Norton, S. A. *Verh. int. Verein. theor. angew. Limnol.* **20**, 532–537 (1978).

3. Johnson, N. M. *Science* **204**, 497–499 (1979).
4. Dickson, W. *Verh. int. Verein. theor. angew. Limnol.* **20**, 851–856 (1978).
5. Cronan, C. S. & Schofield, C. L. *Science* **204**, 304–305 (1979).
6. Schofield, C. L. & Trojnar, J. R. *Proc. Conf. Polluted Rain* (Plenum, New York, in the press).
7. Smith, R. W. *Advances in Chemistry*, Ser. 106, 250–279 (Am. Chem. Soc., Washington DC, 1972).
8. Driscoll, C. T. thesis, Cornell University (1980).
9. Hem, J. D. *US geol. Surv. Wat. Supply Pap.* 1827-B (1968).
10. Robertson, C. E. & Hem, J. D. *US geol. Surv. Wat. Supply Pap.* 1827-C (1969).
11. Lind, C. J. & Hem, J. D. *US geol. Surv. Wat. Supply Pap.* 1827-G (1975).
12. Burrows, W. D. *CRC Crit. Rev. Environ. Control*, 167–216 (1977).
13. Pagenkopf, G. K., Russo, R. C. & Thursten, R. V. *J. Fish Res. Bd Can.* **31**, 362–465 (1974).
14. Giesey, J. P. Jr., Leversee, G. J. & Williams, D. R. *Wat. Res.* **11**, 1013–1020 (1977).

## Motion smear

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It is well known that the visual system summates signals over time, about 120 ms in daylight<sup>1,2</sup>. Although this summation has the obvious advantage of enhancing visual sensitivity, it creates the potential problem of motion smear when viewing moving targets, whose images are also summated over time<sup>3</sup>. Here I report some measurements which reveal that provided the moving target is exposed for long enough to elicit a clear sensation of motion, the amount of smear is far less than may be expected. This suggests that the visual mechanisms which signal motion are also responsible for signalling a clear unsmear perception of the target in motion.

In addition to the threshold measurements of temporal summation it is also well established that super-threshold stimulation leads to a sensation which persists in vision for some time after the termination of the stimulus<sup>4</sup>, again, for about 120 ms in daylight<sup>5,6</sup>. Perhaps the most direct measurements of the duration of this persistence were made by Ross and Hogben<sup>7</sup> with dynamic random dot patterns, continuous sequences of brief flashes of light displayed at random positions on an oscilloscope face. Although only one dot is physically imaged on the

retina at any one time, an observer sees not just one, but a whole screen full of dots, in fact, all those that were displayed during the previous 120 ms. Clearly, under these circumstances, the neural sensations greatly outlast the duration of the visual stimulus.

This fact is of little consequence when viewing a stationary scene, but for moving targets, it poses the problem of motion smear. Objects travelling at even moderate speed cover a perceptible distance in 120 ms. If the same rules of visible persistence apply for moving scenes as for random dot patterns, we may expect moving objects to seem smeared and elongated in the direction of motion. This is illustrated by the photograph of Fig. 1, which was taken with a 125-ms shutter speed. Although the buildings all have good definition and contrast, the images of the people walking in the foreground are smeared beyond recognition. However, in natural viewing conditions, the images of moving objects always appear sharp and clearly defined, certainly very different from Fig. 1. Only very rapid image motion creates perceptible smear. Admittedly, with free viewing, the eyes will pursue a target of interest, but this does not solve the general problem, as it in turn introduces retinal motion of the background. What, then, are the mechanisms of vision that prevent motion smear?

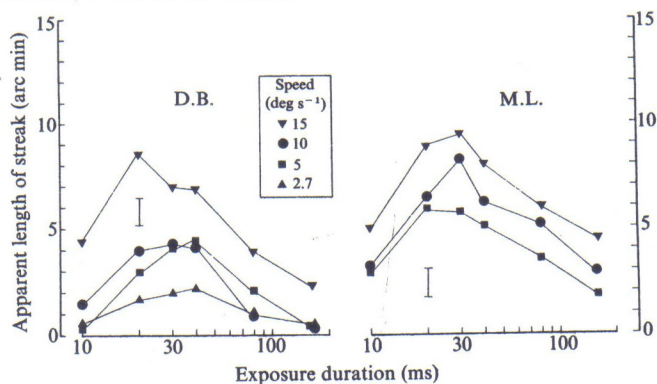
Although this problem is fundamental to the understanding of dynamic visual perception, it has received surprisingly little attention. Many measurements have been made on the effect of image motion on acuity<sup>8,9</sup>, but these do not necessarily reflect the more subjective perceptual qualities of smear or apparent elongation. Two investigations which do bear on this question report that the clarity and veridical perception of a target in



**Fig 1** Vision through a 125-ms temporal window. Although much evidence suggest that the visual system integrates light for 125 ms, our every day perceptions differ markedly from a photograph taken with this integration period (shutter speed).

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**Fig. 2** The apparent length of the motion streak of dots moving along a constant linear trajectory, as a function of exposure duration. For durations of up to  $\sim 30$  ms, the apparent length increases with increasing duration, as may be expected were light to be integrated over this period. However, at durations of longer than 30 ms, the apparent length decreases with increasing durations—the further the dots travel, the shorter they appear. The error bars each represent 2 standard errors, averaged over all conditions.

motion are enhanced by the prior and post exposure in locations at either end of the motion sequence<sup>10,11</sup>. Here I show that even without pre- and post-viewing of stationary targets (which, given the filtering properties of vision, alters the effective visual velocity<sup>12</sup>), the amount of apparent elongation or smear is far less than might be expected on the basis of visual persistence<sup>7</sup>.

With a simple matching technique, I have measured motion smear as a function of the duration of exposure to the motion sequence. The measurements were made by matching the length of a short stationary line to the apparent length of dots in an array of motion, using a multiple interleaved staircase procedure under computer supervision<sup>13</sup>. The observer saw a short sequence of moving dots, immediately followed by a continuously visible stationary line. By pressing the appropriate button, he indicated which of the two stimuli seemed to be longer. Depending on his response, the length of the line was either incremented or decremented on the next trial of that condition. The apparent length, taken as the mean of the previous 15 trials, was measured separately three times to give a rough estimate of measurement error. The stimulus pattern was an array of 100 dots in random locations, intensified on an oscilloscope face (p15 phosphor) to a contrast 100 times their visibility threshold against a uniform background luminance of  $30 \text{ cd m}^{-2}$ . The dots were caused to move by displacing them successively at 5-ms intervals between each brief (4  $\mu\text{s}$ ) intensification, on some trials to the left and on some to the right, the two directions being presented in random order. Short presentations of unpredictable direction of motion precluded the possibility of pursuit eye movements<sup>14</sup>. The screen was vignettted down to a  $5^\circ$  diameter circle by a mask of the same mean luminance placed outside the observer's field of focus, so that the dots faded smoothly out of view. Measurements are reported for two observers, D.B. and M.L., but the effect has been verified qualitatively with many observers, and indeed, can be readily verified by anyone with access to basic visual display facilities.

The results are shown in Fig. 2. Dots exposed for long durations, which travel over a larger retinal region, may be expected to seem more elongated than those exposed only briefly. Indeed, if all the light impinging on the retina were seen simultaneously, as with the dynamic random dot patterns, the perceived length of the streak should be equal to the distance covered by the moving dot. However, this is far from being the case. At short durations (up to 20–30 ms) the amount of motion smear does increase with duration, but at longer durations, the perceived length actually decreases with duration—the further the dots travel, the shorter they seem. Whereas with brief presentation times one sees an array of almost stationary line segments, at longer durations the stimuli are unquestionably small dots in motion, with no hint of elongation along their

trajectory, except when moving at the fastest speed,  $15 \text{ deg s}^{-1}$ . However, even at this speed the apparent length was only 2 or 4 arc min (for D.B. and M.L.), compared with the 100 arc min the spot traverses during the 120 ms of 'visual persistence'.

Not only was there less elongation of the dots, but also the sensation of motion became much stronger at longer durations. All the stimuli seemed to move to some extent, but with brief exposure times the sensation was quite weak. The non-occurrence of motion smear seems to be linked to the perception of smooth motion. Only when the motion seemed smooth and realistic was the target seen as a small, sharp, unsmearred dot. This suggests, that, contrary to the currently favoured idea of separate analysis of pattern and motion<sup>15,16</sup>, the mechanisms of vision specialised to detect motion are also responsible for the analysis of the spatial form of the target in motion. Brief glimpses of a motion sequence fail to activate these mechanisms, activating instead mechanisms which, like a camera of long exposure, signal motion smear. A more detailed account, explaining these and other similar results in terms of the known spatial and temporal tuning properties of visual mechanisms, is in preparation.

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1. Graham, C. H. & Margaria, R. *Am. J. Physiol.* **113**, 299 (1935).
2. Barlow, H. B. *J. Physiol., Lond.* **141**, 337 (1958).
3. Burr, D. C. thesis, Univ. Cambridge (1979).
4. Newton, I. *Opticks*, 347 (1730, reprinted Dover, New York, 1952).
5. Effron, R. *Neuropsychologia* **8**, 57 (1970).
6. Hogben, J. H. & Di Lollo, V. *Vision Res.* **14**, 1059 (1974).
7. Ross, J. & Hogben, J. H. *Vision Res.* **14**, 1195 (1974).
8. DeSilva, H. R. *Br. J. Psychol.* **19**, 268 (1929).
9. Westheimer, G. & McKee, S. *J. opt. Soc. Am.* **65**, 847 (1975).
10. Smith, W. M. & Gulick, W. L. *J. exp. Psychol.* **53**, 145 (1957).
11. Martin, L. in *Handbook of Sensory Physiology* Vol. VII/4 (eds Jameson, D. & Hurvich, L. M.) (Springer, Berlin, 1972).
12. Morgan, M. J. *Vision Res.* **19**, 491 (1979).
13. Cornsweet, T. N. *Am. J. Psychol.* **75**, 483 (1962).
14. Westheimer, G. *Archs Ophthalmol.* **52**, 932 (1954).
15. Tolhurst, D. J. *J. Physiol., Lond.* **231**, 385 (1973).
16. Kulikowski, J. J. & Tolhurst, D. J. *J. Physiol., Lond.* **232**, 149 (1973).

## Mastectomy and mammary glands in reproductive control in the goat

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Little attention has been paid to the role of the mammary glands in reproduction apart from the suppression of reproductive activity during lactation in some species. A hint of greater involvement, however, stems from two observations in the goat. First, Linzell<sup>1</sup> reported that while developing his technique of transplanting mammary glands to other sites in the body in order to gain access to the mammary artery, the incidence of reproductive disturbances (infertility, abortion and apparently inexplicable maternal death at parturition) seemed greater in goats which had lost mammary tissue post-operatively, or which retained only one mammary gland, than in others in the herd and second, the mammary glands may significantly influence the concentration of a hormone in the general circulation<sup>2–5</sup>. Moreover, in some marsupials there is evidence that the mammary glands are involved in the control of reproduction, for example, denervation of the mammary glands during lactation initiates development of the diapausing embryo<sup>6</sup>. In view of the importance of reproductive integration in the artificial control of fertility, we have followed up these clues by investigating the effects of mastectomy in the goat, a species with a seasonal, rather than a lactational, anoestrus. We report here that the oestrous cycle was markedly disturbed by mastectomy and that fertility, and possibly also the length of gestation, seemed to be affected.