Fig. 3 The estimated peak (acrophase) of the circadian rhythms in one-target (+), three-target (○) and five-target (●) SAM performance, and in body temperature (▲), on successive light/dark cycles. The shaded areas represent the dark period, the solid bars the periods of wakefulness, and the open bars the periods of sleep. *a* Shows the results from subject 269, and *b* the results from subject 272.

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Added noise restores recognizability of coarse quantized images

M. Concetta Morrone, David C. Burr & John Ross

Department of Psychology, University of Western Australia, Nedlands, Western Australia 6009, Australia

When a portrait is coarsely quantized into blocks, the block structure hides the face, although lower spatial frequencies of the original image sufficient by themselves for recognition are preserved. Recognition can be recovered by blurring the image, or otherwise attenuating the spurious higher spatial frequency components[1,2]. Harmon and Julesz[2] claim that high spatial frequencies introduced by quantized blocking mask the lower spatial frequencies which convey information about the face, preventing recognition. Here we show that recognition can be enhanced, without decreasing the amplitude of these spurious higher frequencies, by adding further high-frequency noise to the quantized image. This result is clearly at odds with a theory of high-frequency (or critical band) masking. We suggest that the added noise mutes mechanisms which would otherwise impose a block structure on the image, allowing the alternative perceptual organization of the hidden face to reemerge.

A detail of Leonardo's 'Mona Lisa' was digitized into 256 × 256 pixels, using a flying spot scanning system made up of a Cromemco microcomputer, an oscilloscope (Hewlett Packard 1335A), a lens and a photometer (Spectra Pritchard 1980A). The digitized file was transferred to a larger computer (PDP-11/44) which performed all the necessary mathematical manipulations. Processed files were transferred back to the Cromemco, which displayed the resultant images on a variable persistance oscilloscope (Hewlett Packard 1335A). Figure 1*a* shows an unmanipulated version of the picture to give an indication of the image quality of the system.

The 256 × 256 pixel picture was next reduced to 16 × 16 blocks, by setting all the elements in each block of 16 × 16 pixels to a uniform luminance equal to the mean luminance of the elements of that block (Fig. 1*b*). Technically, the effect of this quantization is to remove the high spatial frequencies of the original picture and replace them with spurious high spatial frequencies associated with the block structure of the new image. Lower frequencies sampled above the Nyquist rate are left relatively intact.

As Harmon and Julesz[2] report, recognition can be recovered by attenuating the spurious high spatial frequencies, either by screwing up the eyes, by defocusing, by reducing the image size, contrast or luminance (to a point where vision can no longer resolve the higher frequencies) or by filtering. Figure 1*c* shows a low pass version of the quantized image: the face looks blurred, but is more recognizable than the image from which it is derived (Fig. 1*b*).

The original explanation for the failure to perceive faces after coarse quantization was that spectrally adjacent higher frequencies introduced by the quantization process mask the lower frequencies which convey information about the face, an idea which is supported by experiments demonstrating critical band masking both in vision[3] and in hearing[4]. Appealing though this notion is[5], however, the idea of the high-frequency components masking the low-frequency components becomes less credible when their relative power is considered. Figure 2 shows that the spectrum of high spatial frequencies of the blocked portrait is meagre in comparison with that of the lows, both in amplitude and in spread of orientations. It is difficult to conceive how these high spatial frequency components are capable of corrupting the image beyond recognition.

Fig. 1 *a*, The face of Leonardo's 'Mona Lisa' after it had been digitized into 256 × 256 pixels (256 grey levels), Fourier transformed, back-transformed and photographed from an oscilloscope using a time exposure technique. *b*, Coarse quantized version of *a*, produced by setting all the elements within each block of 16 × 16 pixels to a uniform luminance equal to the mean luminance of the elements within that block. *c*, Low pass version of *b*, produced by removing all frequencies of period less than 1.5 times the block size. *d*, The blocked portrait with superimposed high-frequency noise (see Fig. 2).
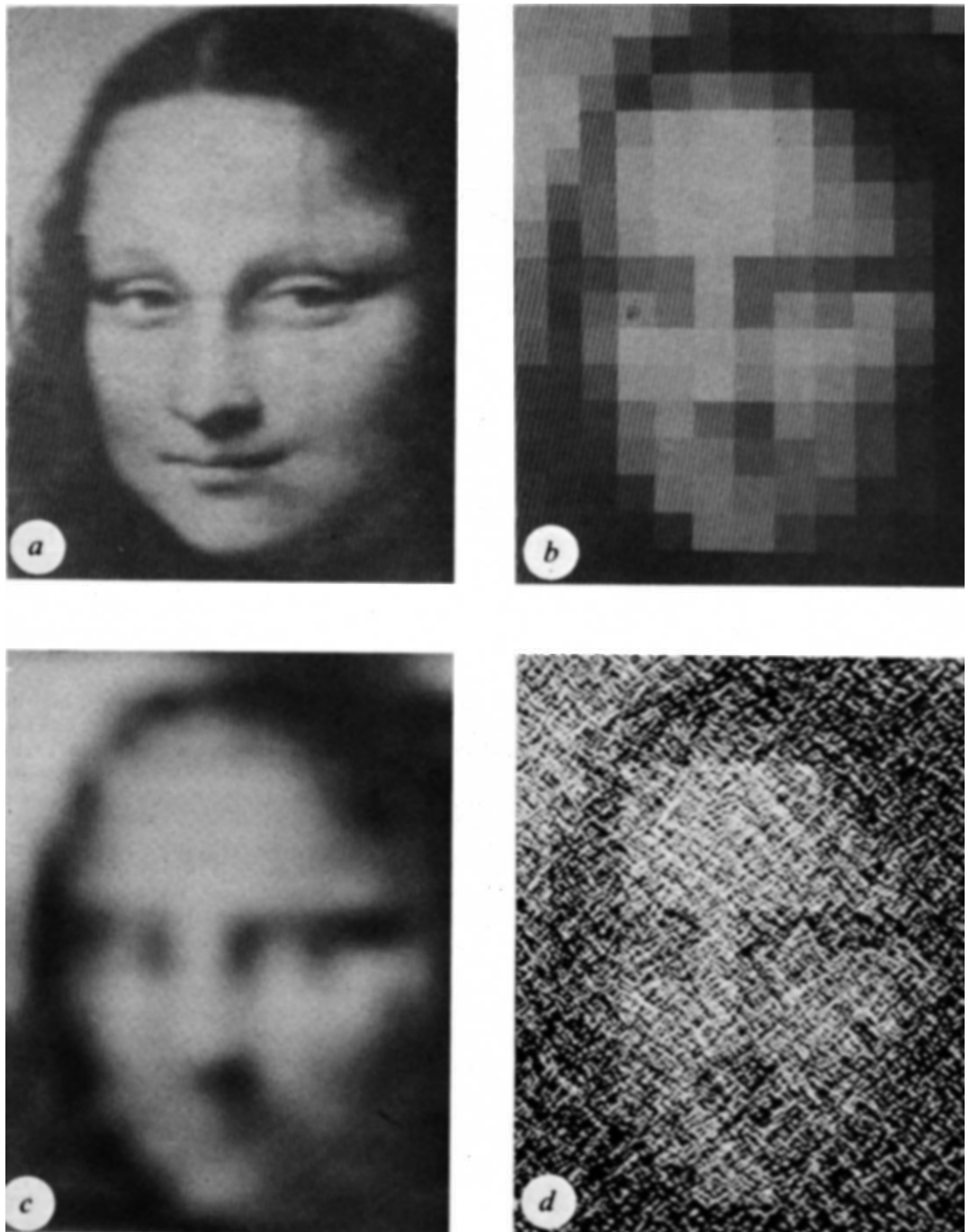
We tested Harmon and Julesz's theory by adding further high-frequency noise to the quantized Mona Lisa. This noise comprised only high spatial frequencies (higher than one and a half times the block frequency) and had energy everywhere except within 22.5° of the horizontal and vertical meridians, where the energy of the high-frequency components of the quantized image lies. Thus, it increased the power and spread of the high frequencies without physically interfering with the edges of the block structure, or reducing amplitude by phase cancellation. If the masking theory[2] were correct, this barrage of added noise could be expected only to contaminate the picture further.

Figure 1*d* shows the result. Rather than impeding recognition, added high-frequency noise significantly enhances it. Although the edges are still visible on scrutiny, the noise destroys the block structure of the quantized picture, allowing Leonardo's Gioconda to reemerge. Several observers have claimed that the quantized picture with added noise is of a higher quality than the low pass filtered version (Fig. 1*c*), rather like a pointillist version of the original.

This curious result suggests that the effect of the noise is to destroy the configuration introduced by blocking. One possible mechanism emerges on considering the physiological effect of visual noise. Simple cells in cat cortex do not respond to two-dimensional visual noise[6]. Burr *et al.*[7,8] have claimed that the silence of simple cells results from inhibition by surrounding cortical cells of different orientation preference, which is supported by the fact that simple cells respond well to one-dimensional visual noise which is mathematically contained within the two-dimensional noise to which they fail to respond. Simple cells prefer isolated one-dimensional stimuli—lines, edges, gratings or noise. This preference for one-dimensional stimuli led Burr *et al.*[7,8] to suggest that simple cells may be specialized to signal the contours or boundaries of objects, which are locally one-dimensional. It is conceivable that in human vision there may also exist mechanisms similar to simple cells in cat cortex which
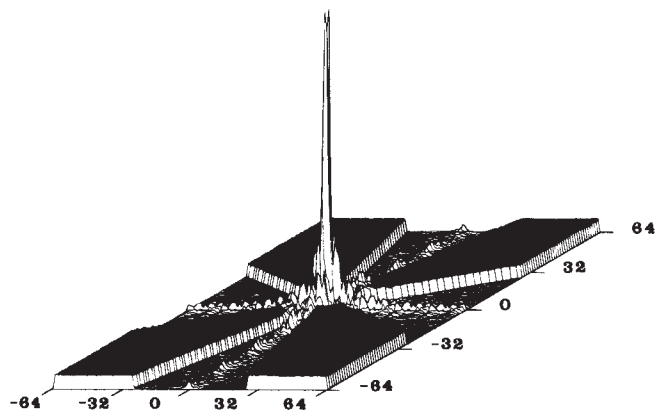
Fig. 2 Spectral representation of the image in Fig. 1d with mean luminance set to zero. Spatial frequency is indicated on the abscissae of the base plane (in cycles per picture height) and amplitude is represented along the ordinate. The high peaks in the centre are the low-frequency components of the original image. The ripples along the meridians are the spurious high-frequency components introduced by coarse quantization (giving rise to the block structure of Fig. 1b). The elevated and shaded 'cross' formation is the transform of the added high-frequency orientation band-limited noise. This noise contains no low-frequency energy, and none within 22.5° of the horizontal and vertical meridians, but is flat elsewhere.

are similarly susceptible to inhibitory control, and which may form part of a more general set of structuring mechanisms, serving to disentangle objects from their background.

In the block portrait of Fig. 1b, the clearest one-dimensional structures are the outlines of the blocks themselves. Structuring mechanisms of appropriate spatial frequency and orientation tuning (analogous to simple cells) will form the sketchlines of the framework within which the portrait is perceived. Adding noise of all orientations except that of the blocks will generate inhibition of the output of the structuring mechanisms tuned to high frequencies, weakening the block organization and allowing the alternative 'Mona Lisa' organization to take over. She too has contours which, for short runs at least, are more or less one-dimensional. These contours should excite structuring mechanisms of lower spatial frequency tuning (uninhibited by the high-frequency noise), which dictate the alternative perceptual organization of the portrait (which was presumably previously overridden by the high-frequency response).

As the noise in Fig. 1d contains no energy within 22.5° of that of the spurious high frequencies (Fig. 2), it should not mask these frequencies (in the sense that it raises their threshold), as classical masking is small[9] at 22.5° (although 22.5° may be within the range of complicated phenomena such as disadaptation[10]). Thus, we are not suggesting that the added noise makes the spurious high-frequency components of the blocked figure invisible and thereby unmasks the low-frequency components. Rather, we assert that the added noise destroys the propensity to organize the image according to its spurious high-frequency structure, by inhibiting the mechanisms which create that organization.

This is not to say that the particular noise used in Fig. 1d is the only stimulus which will restore recognition. White random noise and various grid patterns will all do the job, to a greater or lesser extent. So also will jumbling the phase of the spurious components introduced by blocking. It is possible that in these conditions, other mechanisms, such as masking, may play a part in restoration of recognition.

Other types of explanation than those in terms of inhibition and masking also deserve more consideration than we have yet given them. For example, we have not speculated about interactions between energy in different spatial frequency bands, nor about the effect on the alignment of zero crossings[11] of added noise and other stimuli. Further work along these lines is in progress.

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Quantification of Ca²⁺-activated K⁺ channels under hormonal control in pig pancreas acinar cells

Y. Maruyama, O. H. Petersen*, P. Flanagan & G. T. Pearson

MRC Secretory Control Research Group, The Physiological Laboratory, University of Liverpool, PO Box 147, Brownlow Hill, Liverpool L69 3BX, UK

Ca^{2+}- and voltage-activated K^+ channels are found in many electrically excitable cells and have an important role in regulating electrical activity[1-4]. Recently, the large K^+ channel has been found in the baso-lateral plasma membranes of salivary gland acinar cells, where it may be important in the regulation of salt transport[5]. Using patch-clamp methods[6,7] to record single-channel currents from excised fragments of baso-lateral acinar cell membranes in combination with current recordings from isolated single acinar cells and two- and three-cell clusters, we have now for the first time characterized the K^+ channels quantitatively. In pig pancreatic acini there are 25–60 K^+ channels per cell with a maximal single channel conductance of about 200 pS. We have quantified the relationship between internal ionized Ca^{2+} concentration ($[Ca^{2+}]_i$) membrane potential and open-state probability (p) of the K^+ channel. By comparing curves obtained from excised patches relating membrane potential to p, at different levels of $[Ca^{2+}]_i$, with similar curves obtained from intact cells, $[Ca^{2+}]_i$ in resting acinar cells was found to be between 10^{-8} and 10^{-7} M. In microelectrode experiments acetylcholine (ACh), gastrin–cholecystokinin (CCK) as well as bombesin peptides evoked Ca^{2+}-dependent opening of the K^+ conductance pathway, resulting in membrane hyperpolarization. The large K^+ channel, which is under strict dual control by internal Ca^{2+} and voltage, may provide a crucial link between hormone-evoked increase in internal Ca^{2+} concentration and the resulting NaCl-rich fluid secretion[5,8].

Figure 1A shows a series of single-channel current recordings from an excised patch in quasi-physiological conditions: that is, the extracellular solution was in contact with the outside of the patch membrane (pipette solution) and intracellular solution was on the inside of the plasma membrane (bath solution). When the ionized Ca^{2+} concentration in the bath ($[Ca^{2+}]_i$) was kept at 10^{-8} M there were only few and brief unitary outward currents at negative membrane potentials. Depolarizing the membrane patch increased the frequency of channel opening events. At membrane potentials of 30–40 mV, the one channel present in the patch was almost constantly open except for very brief moments of closure. These results are very similar to those obtained when recording from electrically isolated patches *in situ* (not shown). The single-channel current-voltage (i/V) relationship is shown in Fig. 1B (circles). Reversal of outward to inward current was not observed, but it is clear that the null potential is more negative than −40 mV. In this case the only ion with a negative equilibrium potential is K^+ ($E_K = -82$ mV), as there is no Cl^- gradient.

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* To whom reprint requests should be addressed.