sera from the placebo group, whereas one year post-immunization, the average titre of the 50 recaptured seals immunized with the contraceptive vaccine was 25±26% of the reference serum. Contrary to expectation, 7 of 8 females with two or more recaptures had stable or increasing anti-SIZP titres during the three-year monitoring period. This suggests the immunocontraceptive vaccine could be effective for more than three years.

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Illusory motion from shadows

SIR — At least since the time of da Vinci, it has been known that shadows can give a qualitative sense of depth[1,2]. Moving shadows, however, have been ignored as a source of information about the motion of three-dimensional objects in both biological and computational theories of vision. Rather, shadows have been considered a source of ambiguity. We show here that shadows can have a strong influence on the perceived three-dimensional motion of objects. The movement of an object's shadow induces apparent motion in depth of the object, even when the image of the object itself is stationary.

We used a computer graphics animation consisting of a checkerboard with a central square in front of it, and a shadow moving towards and away from the square (Fig. 1). The size of the square was constant over time, thereby setting the three-dimensional motion cues of object expansion and contraction to indicate no motion in depth. The lack of any translatory motion of the square in the image provided further evidence, based on the assumption of a general viewing position, that the square was stationary in three dimensions. Despite the presence of these strong cues, all observers of the animation reported a strong perceptual impression of a square moving in depth.

If the apparent motion is specific to the processing of cast shadows, reducing the likelihood of labelling a region as a shadow should reduce the probability of obtaining the effect. We tested this prediction by measuring how often observers reported seeing the illusion under four different illumination conditions, generated by crossing two pairs of illumination properties: extended or point light source (shadows with penumbrae or sharp edges), and the light source from above or from below (Fig. 2).

Perceived motion was more likely when the shadow had a penumbra or when illumination was from above. The optimal shadow condition (fuzzy shadow below the square) replicated our initial observations, with all 15 observers reporting a perceived motion in depth on initial viewing. The worst shadow condition (sharp shadow above the square) showed the weakest motion induction effect, with only 7 out of 15 observers reporting the effect on initial viewing.

The kind of brain computation suggested by our findings resembles a process in which the visual system seeks a rational interpretation of the image sequence based on knowledge of how images could be formed from objects, their spatial relations, the illumination and viewpoint, together with prior assumptions about the nature of the world[3]. Theoretically, the visual interpretation is ambiguous. The kinematics of the shadow could be due to a light source moving, or to motion of the square itself. The strong apparent motion of the square in depth suggests that the visual system resolves this ambiguity by assumingthat light sources are usually stationary. Previous studies have shown that the perception of shape assumes that illumination is from above[4], and that shadows are dark[5]. Our results show that depth perception takes advantage of the fact that light sources are generally stationary and above, thereby obviating the need for the computational resources required to estimate light source position and motion precisely.

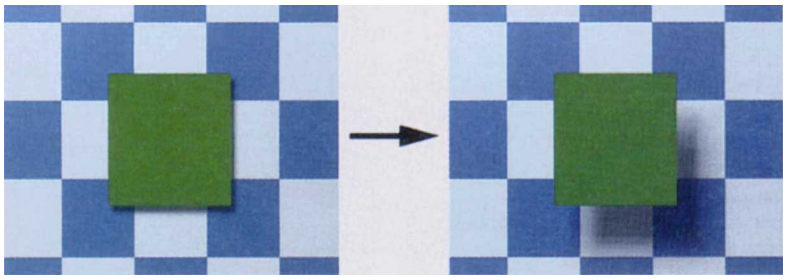

FIG. 1 A central square superimposed over a checkerboard pattern was made to move back and forth directly along the line of sight. The coincidental alignment of motion and viewing direction, combined with the use of orthographic projection, resulted in an image of the square whose size and position did not vary over time. A rectangular light panel illuminated the scene from above and to the left of the square, generating a cast shadow which moved diagonally and whose sharpness decreased as the central patch moved away from the checkerboard. The left and right panels show the first and last frames from a 24-frame sequence which was played forward then backward in a 48-frame loop at 15 frames s^{-1}.

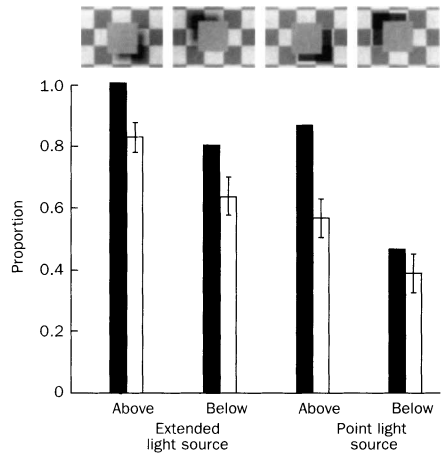

FIG. 2 The proportion of times observers reported the central square patch to be moving in depth for extended and point light sources from above or below. The black bars show the proportion (out of 15) of motion-in-depth judgements reported on first observations only. There is a significant advantage of an extended light over a point source ($z = 2.28$, $P<0.02$), and of light from above as opposed to below ($z = 3.028$, $P<0.002$). The open bars show the proportion of motion-in-depth judgements averaged over repeated observations (240 observations per condition). The error bars show 95% confidence intervals. Sixty observers were tested four times for each illumination condition, giving 16 responses per observer.

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