Effects of red light and loud noise on the rate at which monkeys sample the sensory environment

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Abstract. Monkeys, given the opportunity to move between two featureless chambers, 'sample' first one, then the other in a way which reflects a Poisson decision process. The rate of sampling is higher in red light than in blue and in loud noise than in quietness. We suggest that monkeys 'tune' their sampling rate to the *a priori* probability of change in the environment.

1 Introduction

Earlier research on the reactions of monkeys to red and blue light led us to conclude that "at a behavioural level the most that can safely be said from this series of experiments is that monkeys 'do things faster' in red light than in blue" (Humphrey and Keeble 1977). The new experiment reported here allows us to be more specific about what it means to "do things faster". We found grounds in the earlier experiments for rejecting any account in terms simply of changes in motor activity and suggested instead that "this phenomenon may reflect an influence of colour on the passage of subjective time". We now believe that the right way to interpret the monkeys' behaviour is in terms of the rate at which they attempt to 'sample' the sensory environment. Sampling rate (as defined by this experiment) goes up in red light as compared to blue. But it is also affected by factors other than colour; for example it goes up in noisy conditions as compared to quiet ones. We are led to suggest that monkeys 'tune' their sampling rate to the probability of change in their environment—and that red light is one among several influences which may lead them to expect more rapid change.

The experiment grew out of a surprising observation. In the course of setting up an experiment on sensory preference we designed the apparatus shown in figure 1. The monkeys were given the choice of sitting in one or the other of two chambers whose illumination and noise levels could be varied. The chambers were connected by a short tunnel through which the monkeys could pass freely to and fro.
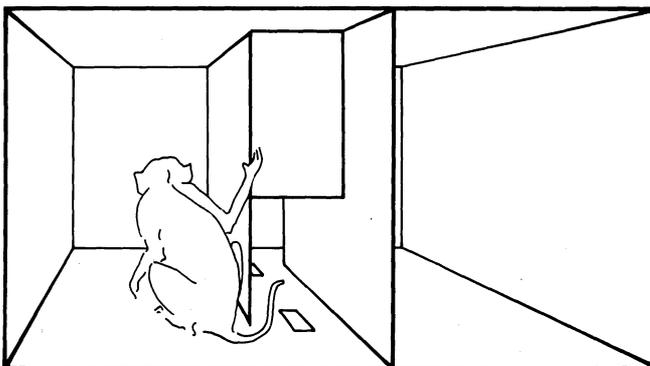

Figure 1.

We thought that if the two chambers differed in their sensory characteristics the monkeys might exhibit a decisive preference, choosing to spend extended periods in one side rather than the other. But we found it was not so. Whatever the characteristics of the two chambers the monkeys vacillated endlessly: they would sit for say 5 s in one side, then up and move to the other side for say 10 s, then back to the first side, and so on ..., alternating perhaps ten times a minute. This was true both when the two chambers were very different (so that the monkeys might have been expected to stay on one side because they preferred it) and when they were exactly the same (so that the monkeys might have been expected to stay on one side because there was no point in moving). If the monkeys did exhibit a preference it was evident only insofar as the *average* time for which they would stay put in one chamber depended on the illumination and noise levels; but this time—the average 'bout' length—was never anything but brief.

To an observer, watching on closed-circuit television, the monkeys' behaviour was intriguing and not easily explicable. There seemed to be nothing stereotyped or mechanical in the way they moved between the chambers, nor were they wandering about aimlessly and accidentally entering the tunnel; rather, every move appeared to be intentional—the monkeys would be sitting apparently contentedly, then suddenly they would become alert, glance around, and take off quickly through the tunnel to the other side.

We soon lost interest in studying preference as such and began to ask questions about the detailed timing of the monkeys' decisions to change sides. The bout lengths were by no means constant: on some occasions the monkeys would leave the chamber within a second or two of entering, on others they would sit for 5, 10, 20, or even 40 s. What was the statistical distribution of these bout lengths? What, if any, simple parameter defined the distribution? How did this parameter—which might be said to describe the 'tempo' of the monkeys' movements—change as a function of illumination and noise level?

Being no longer primarily concerned with preference, we kept the situation simple for the monkeys (and ourselves) by making the two chambers identical. Every one of the monkeys' moves could then be interpreted as a decision purely to change sides, uncomplicated by any possible 'liking' for one chamber over the other. We looked separately at the effects of colour and noise. In experiment 1 both chambers were illuminated with either red light or blue light, while the noise level was set at 68 dB; in experiment 2 both chambers were illuminated with white light, while the noise level was set at either 60 dB or 90 dB.

2 Experimental
2.1 *Apparatus and procedure*
The apparatus (ground plan shown in figure 2) was designed to create two spatially identical chambers, there being nothing in the internal layout which would enable the monkey to tell them apart (and so perhaps show a 'position preference'). Each chamber measured 45 cm wide × 80 cm deep × 60 cm high; the tunnel had a lower, 25 cm, ceiling, so that while the monkey could pass through easily on all fours it could not sit down or turn around once it was inside. The position of the tunnel ensured that the monkey could not see the space it was entering until it was almost through.

Noise, from a white-noise generator, was provided by loudspeakers in the roof of each chamber. When the two loudspeakers were set to the same level the sound density was approximately uniform throughout the testing apparatus. The noise level was measured with a Dawe sound-level meter with 'A-weighting'. Some indication of the subjective loudness of the levels used in the experiments is given by the Dawe handbook: 60 dB—a quiet office; 68 dB—a large shop; 90 dB—inside a tube train.

The far wall of each chamber was made of ground Perspex. These walls were back-illuminated by two slide projectors. The rest of the inside of the apparatus was painted matt black. The colour of the illumination was determined by Kodak Wratten filters in the projectors (red filter 25, blue filter 38A). The brightness level, measured at the Perspex wall, was adjusted to $1 \cdot 2$ log-footlamberts for the human eye (which has approximately the same spectral sensitivity as that of the rhesus monkey).

Passage of the monkey through the tunnel was detected by capacity sensors in the floor. Each bout was timed from the point at which the monkey entered the chamber to the point when, having left it, it entered the other one. The distribution of bout lengths was automatically recorded by solid-state logic modules in the form of a 'survivorship curve', using 5 s bins. Since it took the monkeys on average $2 \cdot 0$ s to pass completely through the tunnel, the origin of the survivorship curves was deemed to be not at 0 but at 2 s.

Two television cameras, mounted against fish-eye lenses in the walls, allowed the experimenter to monitor the monkeys' behaviour in the chambers.

At the beginning of each testing session the monkey was introduced into one chamber or the other through a door in the side wall. Recording began immediately after the first move through the tunnel. The testing session lasted for 300 s.

The monkeys were tested in the morning and in the afternoon, 5 days a week. In experiment 1 they were tested ten times with red light and ten times with blue; in experiment 2 they were tested ten times with 60 dB noise and ten times with 90 dB noise. Stimulus conditions, time of day, and the chamber the monkeys started in were arranged in a balanced design.
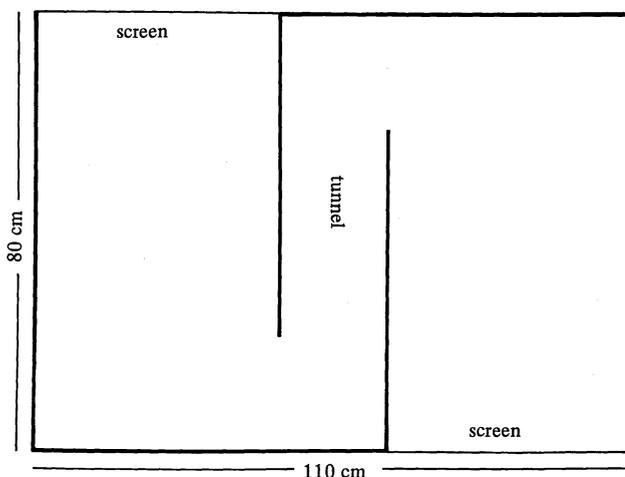

Figure 2. Plan of the testing apparatus (to scale).

2.2 *Subjects*

The subjects were seven young male rhesus monkeys (*Macaca mulatta*). Four of them had taken part previously in experiments with coloured light (Humphrey and Keeble 1977) but they had had no experience which might have been expected to bias the results of the present study. All the subjects were thoroughly familiar with the testing situation, having taken part in a series of pilot studies involving similar apparatus.

3 Results and interpretation

The results of experiment 1 (showing the effect of colour) are given in figure 3a, and of experiment 2 (showing the effect of noise) in figure 3b. The data are presented in the form of log 'survivorship curves' in which the proportion of bouts which lasted at least t s is plotted on a log scale on the ordinate against t on the abscissa. Each figure shows the mean for all seven monkeys; because the ordinate has a log scale the mean is represented by the geometric rather than the arithmetic mean of the individual monkeys' data.

The shape of these curves is remarkable: they clearly approximate straight lines. Admittedly these are averaged data, but inspection of the results from the individual monkeys shows that they all followed the same linear pattern.

Let us consider first what these straight lines signify, before discussing the influence of colour and noise. A straight line on a log survivorship curve implies that the individual bout lengths conform to a Poisson distribution: the probability that a bout, which has already lasted for time t, will be terminated between time t and $t + \delta t$ is constant and independent of t. For example the probability that the monkey, having stayed for 25 s, will leave before 30 s is exactly the same as the probability that the monkey, having stayed for only 5 s, will leave before 10 s. Such a distribution is characterised by its 'half-life', which is equal to the time within which half the surviving bouts may be expected to be terminated. The half-life is inversely proportional to the slope of the straight line.

The meaning of this kind of distribution may be explained by a simple model. Suppose that every h s the monkey were to toss a coin: if the coin comes down heads the monkey moves, if it comes down tails the monkey stays where it is—and h s later tosses the coin again. Then sometimes the monkey will move after the first toss, but sometimes it will wait for several tosses before doing so. If each coin toss— and thus each decision to move or stay—is genuinely independent of all earlier ones, the bout lengths will be distributed according to a Poisson distribution. On the assumption that at each toss there is a 50% chance of the coin coming down heads or tails, then h will be the half-life of the distribution.
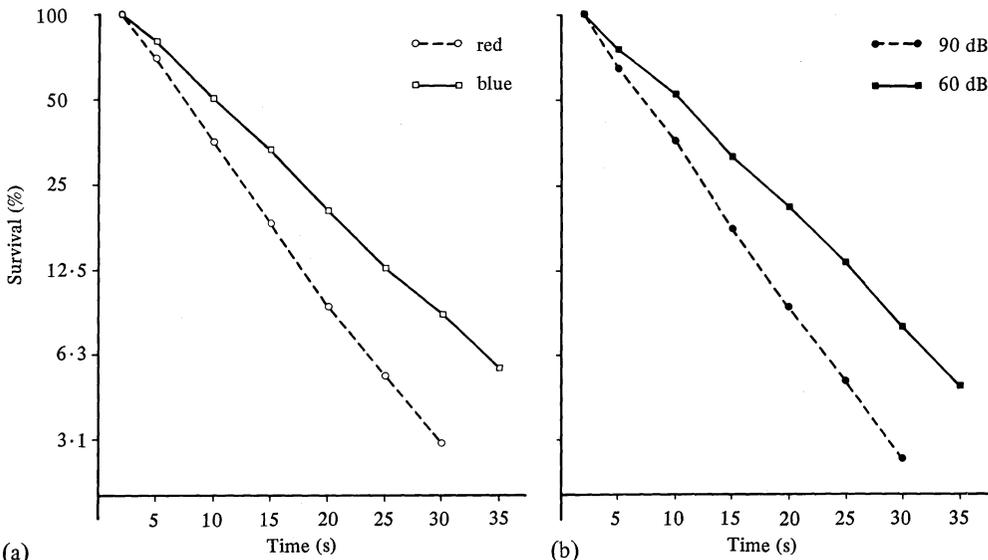

Figure 3. Log survivorship curves for bouts in (a) red light and blue light (68 dB noise); (b) 90 dB and 60 dB noise (white light).

What figure 3 shows is that the slopes of the survivorship curves—and thus the half-lives of the distributions—change as a function of colour and noise. In experiment 1 the approximate half-lives of the mean distributions were $5 \cdot 5$ s in red light and $7 \cdot 9$ s in blue light; in experiment 2 they were $5 \cdot 2$ s in 90 dB noise and $7 \cdot 8$ s in 60 dB noise. All seven individual monkeys reacted to colour and noise in the same way (half-life in red $<$ half-life in blue; half-life in 90 dB $<$ half-life in 60 dB), giving a significance to each result of $p < 0 \cdot 01$.

4 Discussion

These results could be 'explained', in the same way that we explained the results of our last series of experiments (Humphrey and Keeble 1977), in terms of an influence of the sensory environment on the passage of subjective time. Thus it might be suggested that monkeys have a subjective clock which not only runs faster in red light than in blue but also—on the evidence of the present study—runs faster in 90 dB noise than in 60 dB noise. The trouble with this explanation is that it does not really get to grips with the behavioural phenomenon: it explains the effects of colour and noise on a pattern of behaviour which itself remains unexplained. Just what were the monkeys about when they moved back and forth between the chambers?

No one who observed the monkeys could have thought that they were merely indulging in aimless motor activity. Each of their moves looked purposeful. Yet, since the two chambers were identical, no obvious purpose was in fact achieved by moving. Can the monkeys have gone on shuttling to and fro in the vain expectation that *next* time there might be something different about the other chamber?

Look at the Necker Cube in figure 4. You see it first this way round, then that way, then this way again. Your mind is never satisfied that it has reached the right interpretation. No matter that you have already seen both aspects of the cube a dozen times, you go on vainly 'sampling' each of the possible alternatives. So, perhaps, with the monkeys in the testing apparatus: able to be in only one place at one time, they could never be *sure* that they were not missing something in the other chamber—and every so often the urge came over them to check on it.

In the real world such periodic checks would have a clear function. The real world, unlike the testing apparatus, cannot be counted on to remain stable over time. Things which are out of sight are out of ken and if a monkey is to keep itself informed it must continually sample hidden bits of its environment. Such sampling may sometimes amount to no more than a glance over the shoulder, sometimes a
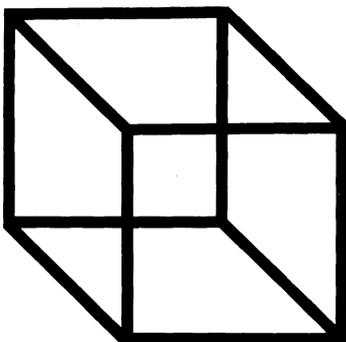

Figure 4. Necker Cube. Note that a recent attempt to characterise the probability distribution of temporal fluctuations in the perception of this figure concludes that "the underlying process may be described by a simple Poisson model" (De Marco et al 1977).

peep behind a tree, a hand thrust into a bush, the turning of a stone. But whatever form the sampling takes we may expect that monkeys are biologically adapted to conduct it both methodically and economically. No monkey can afford either to spend all its time collecting information or, for that matter, to be slack about it; the sensible strategy, as every human ethological observer knows, is to space out successive observations in a way which yields maximum information for least effort. This means (i) generating an appropriate statistical distribution of intervals between observations, (ii) choosing an appropriate mean sampling frequency.

We suggest that a Poisson distribution, containing a semirandom assortment of intersample intervals, may represent an efficient strategy for detecting some of the short-term changes in addition to most of the longer-term changes in an unpredictable environment. And, further, we suggest that, given this distribution, the mean sampling frequency (which is inversely proportional to the half-life) ought to be tuned to the *a priori* probability of change in the environment.

Let us explain this last suggestion and relate it to the results of the experiment. Although all environments may be unstable, some are more unstable than others. In the kind of world that monkeys naturally live in, the probability of significant change must vary both with general factors such as the time of day, the weather, the season and also with more specific ones such as the social situation, the threat of predators, the nature of the immediate habitat, etc. Some of these factors will be associated with particular kinds of background sensory stimulation—sounds, colours, temperature, atmospheric pressure, etc. We propose, in the light of our experimental results, that red light presages more rapid change than blue, and loud noise more rapid change than quietness.

Although these proposals about noise and colour are *post hoc*, they make good sense.

Colour. Red is associated with dusk and dawn (when predators are active), with fire, with blood, with oestrous swellings, with ripe fruits, with stinging insects, and a host of other natural 'signs' (see Humphrey 1976). Blue is associated with the midday sky—and very little else.

Noise. Loud noise is associated with thunderstorms, falling trees, approaching elephants, screams of anger or fear, etc. Quietness is associated with quietness.

No wonder, therefore, that monkeys might be more alert to change in a red and/or a noisy environment than in a blue and/or a quiet one. It is not that their subjective clocks go faster under the former conditions, but that the world itself does.

References
De Marco A, Penengo P, Trabucco A, Borsellino A, Carlini F, Riani M, Tuccio M T, 1977 "Stochastic models and fluctuations in reversal time of ambiguous figures" *Perception* **6** 645–656
Humphrey N K, 1976 "The colour currency of Nature" in *Colour for Architecture* Eds T Porter, B Mikellides (London: Studio Vista) pp 95–98
Humphrey N K, Keeble G R, 1977 "Do monkeys' subjective clocks run faster in red light than in blue?" *Perception* **6** 7–14

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