45 The effect of social stress on the behaviour and physiology of monkeys

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Various endocrine changes associated with submissive behaviour have been shown to occur in monkeys forced into a subordinate role, similar to previous findings with rodents. In the male vervet monkey submissive behaviour is associated with a change from blue to white in the colour of the scrotal skin, due to an alteration in the optical properties of the dermal collagen. This paper summarises a study carried out to determine whether the change is mediated by any of the hormonal changes known to be associated with the social stress of acute submission.

Shortly before I joined the Newcastle Department in 1971, as a direct result of a theoretical paper comparing some aspects of human psychopathology with the behavioural correlates of social submission in baboons (Price, 1967), my attention was drawn to a monkey which, in addition to manifesting baboon-like behavioural correlates of submission, also underwent a conspicuous physiological change in the form of a change in the colour of its scrotal skin. This monkey, a guenon usually called the vervet monkey, was, and as far as I know still is, the only primate, and probably the only mammal, to undergo an observable physiological change during social submission. It seemed, therefore, a suitable experimental animal to study the physiology of submission in animals as a model of some forms of psychopathology (such as depression and anxiety) in man. In this paper I shall review some relevant studies on the vervet monkey, and then summarise some work carried out with colleagues at Newcastle and subsequently at the Clinical Research Centre. But first I would like to make a provisional classification of submission, as it is obvious that, in human beings at least, submission is only occasionally associated with psychopathology.

Classification of submission

Submission may be acute or chronic. Acute submission following defeat in an agonistic encounter I shall call *acute catathetic submission*, using the term catathetic (Price, in press) to indicate that the submitting individual has been "put down" by another individual (the winner). *Acute adulatory submission* is associated with positive affect on the part of the submitting individual and often with over-valuation of the individual submitted to. *Acute benign submission* may be said to occur when an individual submits without either fight or adulation.

Chronic submission takes the form of subordinate rank in group-living species and exclusion from territory in territorial species. Chronic submission may be *catathetic* (maintained by repeated catathetic or 'putting down' signals), *adulatory* or *benign*. We should also recognise a further category of *chronic reluctant submission*, characterised by envy of the privileges enjoyed by those of higher rank, and actual or potential challenge of the rank order; the manifestation of this state is likely to elicit an aggressive (catathetic) response from the dominant individual who is challenged, so that there is a blurring between catathetic and reluctant submission, when it is difficult to tell, or in systemic terms impossible to tell, whether the catathetic behaviour of the dominant individual is spontaneous or a response to reluctance manifested by the subordinate.

Submission and psychopathology

Here I am concerned only with acute and chronic catathetic submission and with chronic reluctant submission. These are the states in which human experience can recognise at least two potentially pathogenic aspects of submission: the sight of others enjoying privileges which are denied one, and the receipt of punishment (catathetic signals) from a dominant person. These were identified by Galen as the two "passions of the soul": he recognised them in his own behaviour, both his envy of physicians who paraded the streets in carriages finer than his own, and his tendency to throw his quill at his slave when he was irritated.

The vervet monkey

Vervet monkeys live in groups of about 20 animals, and except in the arid fringes of their East African habitat the groups contain more than one adult male. Brain (1965) reported as follows on the social structure of the group:

> "The day-to-day pattern of life of any individual monkey in the troop is determined by its position in the social order and by the temperament of any monkeys to which it is subordinate. A casual observer of the captive troop, or of a free-ranging one, might conclude that aggression between individuals is random and unpredictable; this is in fact far from the case and, as soon as the observer is sufficiently familiar with the individual monkeys to be able to recognise them, the existing order of social dominance will immediately become apparent to him."
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> "It is abundantly clear that initial establishment of dominance of one monkey over another is not a matter of physical strength nor of size, but rather by a recognition of specific attributes . . . Among vervets the most important attributes are most probably confidence and imperturbability; these characteristics make possible the steady, level gaze of a dominant primate . . .. This steadiness of gaze is a well-marked characteristic of the most dominant monkeys in the troop, but is noticeably lacking in those individuals near the bottom of the social order."
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> "Adult male vervets are characterised by the almost luminous blueness of their scrotal sacs; this colour has clear social significance and could probably be described as a status symbol; the intensity of the blueness is certainly variable and may well be related to the general state of well-being of the animal and its level of dominance."

The most marked changes in scrotal colour occur when a male falls in the dominance hierarchy. In such a case the scrotum may change from a brilliant blue to a "putty-white colour" over the course of seven to fourteen days. The colour change is associated with a behavioural change which the authors describe as "demoralisation" and "loss of self-confidence", and there is a marked inhibition of aggressive behaviour. For instance, when a monkey named Robert fell from the third position in Brain's captive group, "after a week he had lost all social status and did not retaliate when attacked singly by any of the lowest-ranking monkeys."

Normally, aggressive behaviour among vervets takes the form of threat or pursuit without biting (Gartlan & Brain, 1968). When biting does occur it is usually on the tail, or takes the form of nips around the knees and ankles which usually do not penetrate the skin. The animals are very sensitive to these attacks and may die after them, even though no real injury has been received. In captivity the biting may be more severe, particularly when a stranger is introduced into the troop. Brain (1965) describes the introduction of a stranger as follows:

> "On coming into contact with the new individual, the first reaction of the other male members of the troop was to examine the blue scrotum with the greatest diligence. Eventually, this prolonged scrutiny annoyed the new monkey who became aggressive. Had he been allowed to fight one member of the troop at a time, he would probably soon have achieved a high ranking position, as he showed clear attributes of a dominant individual. This never occurred, however, and the first signs of aggression precipitated a full-scale attack by the whole troop. Within a few days he was completely demoralised and shortly after removal from the cage, died of the injuries he had received. It was particularly noticeable that when this monkey was first placed with the troop, its scrotum was the most brilliant blue colour. As the animal lost confidence as a result of repeated attacks by the troop, the colour faded away to a pale powder-blue hue."

It is not yet known whether the colour change is reversible. Brain (1969) writes: "Concerning the relationship of the colour change to dominance: I was able to observe that the brightness of the colour faded as the male lost status, but I was never able to re-instate a male in the hierarchy, so was not able to demonstrate that the brilliance could be restored. Once a vervet becomes subordinate, it seems extremely difficult to restore its confidence".

Subsequent work on the social behaviour of the vervet monkey has confirmed the observations of Brain & Gartlan, but unfortunately the St Kitts vervet, on which most of the work has been done (McGuire *et al*, 1983) lacks the blue scrotal skin characteristic of the species.

The vervet monkey is a member of a genus which is remarkable for its multicoloured facial and perineal displays (Kingdon, 1980) and apart from the talapoin monkey it is the only member of the genus which lives in multi-male groups (Melnick & Pearl, 1987). It is also the only multi-male-group-living monkey of the cercopithecine family in which the female shows no perineal swelling or colour change at oestrus (Melnick & Pearl, 1987). Therefore it is possible that the genital skin hydration reaction, which in many cercopithecines mediates sexual change in the female, has in this monkey come to mediate social rank change in the male; and that, as in the other monkeys oestrogen prepares both the brain for sexual behaviour and the body for signals of sexual receptivity, in the vervet monkey some hormonal agent prepares both the brain for submissive behaviour and the body for submissive signalling. It was this possibility which provided the motivation for the work which I will now describe.

The blue skin

Three male and two female vervet monkeys (*Cercopithecus aethiops pygerythrus*) were purchased from Animal Suppliers Ltd and the skin was examined by colleagues from the dermatology department of the University of Newcastle upon Tyne (Price *et al*, 1976).

The scrotal skin of the males was a vivid blue colour. The skin of the abdominal wall had a pale blue colour and this extended along the medial aspects of the upper arms and legs. The adult female showed a blue colouration which was most marked on the outer surfaces of the labia majora. In this area the colour was a dark blue without the vivid quality of the scrotal skin. A female infant born in captivity showed a similar dark blue colouration of the labia majora.

The bright blue colouration of the male scrotum was clearly visible from the front and side whether the male was sitting or standing. By contrast, the blue colouration of the female genitalia was not observed in any of the usual postures of the animal. The scrotal colouration was thus a very conspicuous feature of the male, which accords with the suggestion that it acts as a signal to other members of the species (Struhsaker, 1967). Apart from the scrotum which has little hair, the blue colour of the skin elsewhere was largely obscured by fur.

Transillumination

It seemed possible that, as in other species, the blue colour would be due to the preferential scattering of short wave-lengths (Tyndall effect) above a layer of pigment (Fox & Vevers, 1960). This was supported by the findings on transillumination: when a bright light was shone through a fold of scrotal skin a reticulate pattern of brown patches (similar to the colour of melanin) was seen against a homogeneous red background.

Histological examination

Both epidermis and upper dermis were free of pigment, but in the mid and lower dermis there were dense deposits of melanin, situated in cells which had the histological and electron microscopical appearances of melanocytes.

The white skin

The effect of tissue fluid on skin colour

Intradermal injection of saline and other colourless fluids immediately blanched the skin at the site of the bleb, the colour returning as the bleb was absorbed.

Removing tissue fluid by compressing the skin with an artery forceps for a few seconds gave a consistent response, the skin under the forceps taking on a deep blue colour. It was noticeable that this colour had none of the vivid quality of the normal scrotum; it was like the normal colour of the female labia but more intense. On each side of the deep blue colour under the forceps there were lines of pallor due to the tissue fluid which had been expressed sideways by the forceps.

These experiments suggested that colour change could be mediated *artificially* by altering the distribution of tissue fluid in the dermis above the melanin. However, it was not yet clear whether the *natural* occurrence of pallor was also associated with change in interstitial fluid. During the nine months of observation the intensity of the scrotal colour varied spontaneously from a dark blue to a bright blue to a vivid turquoise blue to a pale whitish colour. The whitish colour was always most marked in the upper anterior scrotum above the penis. Regardless of the degree of whiteness, the same intense dark blue could always be restored by compression of the scrotal skin applied for a few seconds with forceps. The pallor returned as the tissue fluid diffused back. The idea that the pallor was due to masking of the blue colour by accumulation of tissue fluid and was not due to a change in melanin was confirmed by histological and electron microscopic examination; the normal pale and blue scrotal skins and the deep blue skin elicited from the former by fluid expression showed no obvious difference in the number of melanocytes nor in the number of pigment granules and their dispersal. The only difference noted concerned the extracellular compartment; in the deep blue skin the melanocytes appeared closer to each other whereas in the pale skin they were separated by wide gaps.

Electrical stimulation *in vitro*

Application of electrical current to male or female blue skin (placed on blotting paper and soaked in physiological saline) abolished the blue colour and left the dermis translucent except for the melanin network. The female skin returned to its normal blue colour in about 30 minutes, but in the bright blue male skin the affected areas turned white in roughly the same time.

A cathode was applied to the skin (anodal stimulation was ineffective) and pulses of 3 milliseconds duration at a rate of 100 per second were applied at an intensity of 5–10 milliwatts for durations of ½ to 4 minutes. After 30 seconds brown circular areas appeared under the electrode and these increased in number until the whole area was brown. *By transmitted light* the affected area was seen as a white circular patch against the usual pink background; in other words, the dermis (apart from the melanin network) had become translucent. In the female skin the pink colour (complementary to the Tyndall blue) returned in about 30 minutes, but in the male the affected area became opaque.

The effect of ionic environment

Pieces of excised scrotal skin kept in physiological saline solution maintained their blue colour. Transferred to normal hydrochloric acid or sodium hydroxide for one minute the pieces of skin became black (translucent except for the melanin deposits). Transfer from the acid solution to a saturated salt solution caused an instantaneous change to white; further transfer to the alkaline solution caused a return of the black colour. Transfer of the black skin from the alkaline solution to a saturated salt solution caused a deep blue colour to develop over the course of one minute. This colour was stable in physiological saline, but the skin can be turned black again by immersion in either acid or alkaline solution.

These manipulations demonstrate that the vervet scrotal skin has the capacity to exist in states which render it blue or white or black to the human eye, and that it can be changed from one state to another by simple changes in the ionic environment.

The colour change

Changes in interstitial fluid content of the skin could be due to hormonal, neural or mechanical mechanisms. A dependent oedema due to inertia or other mechanical causes seemed unlikely because it was the superior aspects of the scrotum which showed the greatest spontaneous fluctuations of fluid content during the months of observation. A neural mechanism could not be excluded, but seemed unlikely due to the time course of the colour change (a matter of days). Of the various hormonal possibilities, the most likely were androgens and corticosteroids which are known to be reduced and increased, respectively, during social stress (Bernstein *et al*, 1983), and oestrogens, which are already known to cause hydration of genital skin in the female of some primate species (Hrdy & Whitten, 1987).

Androgenic hormones

Two males with somewhat pale scrotal sacs were given extra androgen to see if the blue colour could be enhanced. One was given methyltestosterone 5 mg orally daily for three weeks, the other testosterone propionate 2 mg i.m. daily for two weeks; neither showed any change in colour. One male was subjected to bilateral orchidectomy, followed four months later by bilateral adrenalectomy, in the expectation that the removal of androgen might induce hydration. However, the reverse occurred, and the genital skin became a darker blue with less apparent interstitial fluid, tending towards the condition of the adult female skin. This suggests that the hydration of male genital skin occurs in two stages: first, at puberty, there is a slight hydration mediated by androgenic hormones which switches the colour from dark blue to the turquoise blue characteristic of the adult male; then, associated with catathetic submission, and mediated by another hormone, there is the potential for a quantitatively greater (and perhaps qualitatively different) hydration which switches the colour from turquoise blue to pale blue and white.

Stress hormones

In other species the physiological changes associated with acute catathetic submission, apart from reduction of androgenic secretion and increase in prolactin, are almost entirely due to increased activity of the pituitary/adrenocortical axis.

It seemed very likely that the skin colour change would also turn out to be secondary to an increase in circulating glucocorticoids. However, administration of the ACTH analogue Synachthen Depot 0.5 mg i.m. daily for 12 days in one animal, and dexamethasone 0.5 mg orally daily for three weeks in another, were without definite influence on skin colour. If anything, the skin was bluer after the steroid. Prolactin in a dosage of 3 mg i.m. daily for three weeks and the mineralocorticoid aldosterone 0.25 mg by intraperitoneal injection daily for four weeks were also without effect.

In some states of social stress there is chronic adrenomedullary overactivity but unfortunately we were not able to reproduce this condition artificially. Single injections of adrenaline, sufficient to cause marked tachycardia, were without effect on scrotal colour.

Female sex hormones

Apart from the induction of inflammation by locally acting agents, the only hormones known to cause skin hydration are oestrogens. These sometimes cause a generalised dermal oedema in women during pregnancy, and they are responsible for the enormous genital skin swellings of some primate species during oestrus (Hrdy & Whitten, 1987). It seemed likely that the vervet scrotal skin would be sensitive to oestrogen, either because oestrogens might be important in the physiology of the male of this species (as they are, for instance, in the stallion), or because, even after the evolution of another hormonal trigger, the tissue might retain an atavistic sensitivity to oestrogen. However, ethinyloestradiol in a dosage range from 0.1 mg orally to 50 mg i.m. daily for four weeks, with or without the addition of the progestogen norethisterone acetate (5 mg daily), had no effect. The sex skin of the female was also insensitive to administered oestrogen.

Discussion

The vervet scrotal skin is a remarkable organ. The optical properties of its dermal collagen can be rapidly and reversibly altered between three conditions:

(a) all light is reflected giving a white colour
(b) no light is reflected, giving a black colour
(c) only short wavelengths are reflected, giving a blue colour

Only a small proportion of this capacity for signalling is actually used in nature. The black colour does not occur at all. The change from blue to white can be rapid or slow, but only the slow change occurs. The change from white to blue has not been observed. Nevertheless, even with this modest use of its potential, this piece of skin is unique as the only instance in which a signal depends on a change in the optical properties of the particles responsible for a Tyndall blue. Tyndall blues are widespread among fish, amphibia and reptiles, and it is an odd coincidence that loss of blue colouration is often a sign of social submission, as in the rainbow lizard (Greenberg & Crews, 1983). But the mechanism is quite different: the reptilian loss of blue is due to a migration of melanin-containing cells over the layer of guanine crystals responsible for the differential refraction (Fox & Vevers, 1960), and therefore the change in lizards is always from blue to brown rather than blue to white. Tyndall blues are rare in mammals, occurring in the blue of blue eyes, the Mongolian spot, in certain pathological pigmentations of the dermis and in discrete patches on the skin of Old World monkeys. The vervet scrotal skin is the only instance in which loss of the blue colour constitutes a signal.

Further uniqueness lies in the fact that this is the only primate submission signal (except possibly blushing) which involves a physiological change. Other submission signals consist of posture, movement or vocalisation which are under higher nervous control and may be used for deception. Therefore the vervet is not only a model which offers a lead into the physiology of submission, but also an example of theoretical interest in the behavioural ecology of signalling.

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