J. Physiol. (1971), **212**, *pp.* 321–335
With 5 text-figures
Printed in Great Britain

RELATION OF CARDIOVASCULAR CHANGES IN FIGHTING TO EMOTION AND EXERCISE*

By D. B. ADAMS, G. BACCELLI, G. MANCIA AND A. ZANCHETTI

From the Istituto di Ricerche Cardiovascolari, Università di Milano, Via Francesco Sforza 35, Milano 20122, Italy

(*Received 13 May 1970*)

SUMMARY

1. To obtain evidence on the relative importance of exercise and emotion in the cardiovascular changes of fighting in the cat, the changes during fighting were compared with changes during a mild non-emotional exercise (walking on a treadmill at low speed), and during confrontation without fighting (preparation for fighting), an emotional condition accompanied by no or very little motor activity.

2. The direction of change of all variables we measured, iliac and mesenteric flows and conductances, total peripheral conductance, heart rate, cardiac output and blood pressure, was similar in both fighting and exercise.

3. Some of the cardiovascular manifestations of preparation for fighting were very different from those of motor activity. These were iliac vasoconstriction, a fall in cardiac output, and often a strong bradycardia, all of these changes being in the opposite direction to changes during exercise and fighting.

4. It is suggested that the changes during preparation for fighting represent the cardiovascular manifestations of an emotional state, and that during fighting these manifestations are superseded and masked by changes due to motor activity.

INTRODUCTION

We have previously reported the results of a study of cardiovascular changes during naturally elicited fighting behaviour in the cat (Adams, Baccelli, Mancia & Zanchetti, 1969). Fighting was found to be associated with tachycardia, increased cardiac output, little change in arterial blood pressure, an over-all vasodilatation due to a conspicuous vasodilatation

* The experiments described in this paper were conducted in Italy.

in active muscles partly compensated by visceral vasoconstriction and by vasoconstriction in inactive muscles. However, fighting is a mixture of an emotional state and of exercise, and the question naturally arose whether the cardiovascular changes we had observed were primarily representative of the emotional component of fighting or of its exercise component.

This basic question could not be answered without further experimentation. On one hand, most of the evidence concerning the cardiovascular action of exercise has been obtained in man (Bevegård & Shepherd, 1967) and is not immediately referable to laboratory animals. Work on the dog (Herrick, Grindley, Baldes & Mann, 1940; Barger, Richards, Metcalfe & Günther, 1956; Leusen, Demeester & Bouckaert, 1958; Rushmer, 1959; Donald & Shepherd, 1964) has generally been limited to recording of a single cardiovascular variable at a time, and has sometimes been performed during strenuous exercise (which is unavoidably emotional) or in rather unphysiological conditions. On the other hand, little is known of the cardiovascular manifestations of an emotional behaviour accompanied by no or very little motor activity. Furthermore, because of the multiplicity of emotions, each of which might be associated with a different cardiovascular pattern, an ideal experimental situation would be to isolate the emotional state proper of fighting from any motor component.

With these considerations in mind, we thought that the best way to answer the question on the relative importance of exercise and emotion in the cardiovascular changes of fighting, was to compare these changes on one hand with those occurring in the same cats during a mild non-emotional exercise (walking on a treadmill at low speed), and on the other hand with those observed when the cats could foresee an imminent attack and were prepared for fighting (in the event the attack was prevented and fighting did not take place, a condition henceforth called preparation for fighting).

METHODS

Our experimental set-up for studying fighting behaviour in unanaesthetized cats has already been described (Adams *et al.* 1969). Briefly, fighting was elicited as a natural response to an attack launched by another cat, which was electrically stimulated through electrodes chronically implanted in a portion of the mid-brain from which attack could be evoked at will. The two cats, the attacking cat and the subject of the recording experiment, remained on opposite sides of a partitioned cage between trials, and there was fighting whenever the partition was raised. The brain-stimulated attacking cat was moved towards the other cat, and the latter responded with hissing and striking. As soon as the subject responded with hissing and striking the attacking cat was withdrawn, the partition was lowered and the trial was terminated. Trials of two kinds were analysed: one, called supportive fighting, was performed when the cat supported itself on all four limbs and used both fore- and hind limbs for fighting; the other, called non-supportive fighting, occurred when the

cat was attacked while spontaneously lying on one side, so that it used only forelimbs for striking, the hind limbs remaining inactive throughout. All trials during which the animal changed position from lying to standing were discarded.

The cardiovascular changes of preparation for fighting could be seen in the interval between the moment that the partition was opened and the moment that the subject responded with hissing and striking to the attack of the brain-stimulated cat. Some changes began even before the opening of the partition in response to the noise made while the attack cat was grasped to prepare for the trial. To see these changes more clearly and to follow their time course, other trials were performed in which the same procedure was used up to the point of moving the attack cat towards the subject cat, but then no stimulation was given, no attack took place, and the subject simply flinched, retracted its ears, dilated the pupils, and watched the attack cat closely. These trials of confrontation without fighting we have called trials of preparation for fighting. These trials were alternated with fighting trials in a random order, so that the cats could not learn whether a real attack was going to take place or not.

The 'non-emotional' exercise consisted of walking on a treadmill at a rate of 10 m/min for 30 sec. The cat was standing before the trial was begun, and an episode was initiated when the treadmill was turned on and the cat began immediately to walk. In this way postural changes induced by the beginning of the walking were reduced to a minimum. We took great care to prevent the cat from having an emotional reaction to the treadmill or its movement. Each cat was subjected to prolonged training before recording trials were started. A very mild exercise was purposefully selected in order to avoid the emotional components inescapable in strenuous exercise in spite of training.

The following cardiovascular measurements were continuously made in all cats before, during and after each of the three experimental behaviours described above. Cardiac output, superior mesenteric flow and external iliac flow were obtained from electromagnetic flow-probes (Statham) chronically implanted on the ascending aorta, superior mesenteric artery and left external iliac artery, at least 1 week before recording sessions. The instantaneous flow records were electronically integrated at 2 sec intervals. Heart rate was recorded by cardiotachography. Mean arterial pressure was obtained from a catheter implanted in the right femoral artery. Total peripheral, superior mesenteric, and external iliac conductances were computed for each 2 sec interval by dividing flow by mean pressure. As will be seen later, the very small changes in blood pressure invariably observed in the present experiments made it safe to use flow-to-pressure ratios as an index of active changes in vascular diameter. In addition to the direct cardiovascular measurements, electromyograms from two electrode plates positioned on dorsal and ventral muscles of the left thigh (i.e. the same leg the flow of which was monitored) and from two needle electrodes in cervical muscles were recorded on a twelve channel Grass P7 polygraph. Further technical details, as well as reasons for preferring conductance to its inverse resistance, as an index of vascular diameter changes, have been reported in a previous paper (Adams *et al.* 1969).

When iliac blood flow had to be recorded after blocking blood flow to the ipsilateral paw, the paw was placed in a rubber sleeve of suitable diameter, closed on the distal end, the proximal end being sealed with tape to the skin of the leg above the ankle. The sleeve was connected through tubing to an air pump which could produce an air pressure greater than the systolic blood pressure simultaneously recorded from the contralateral femoral artery of the cat. Air pressure inside this occlusion cuff was directly measured by a second Statham pressure transducer and also recorded on the polygraph. Occlusion of the hind paw circulation was started 10–15 sec before a trial, and interrupted 20–30 sec after the trial was terminated. No

animal was seen to experience pain, probably because occlusion was always short-lasting.

The data reported in this paper come from five cats. In a sixth cat, only iliac blood flow and arterial pressure were recorded. At least six trials were recorded in each of five cats during supportive fighting, non-supportive fighting and during the behaviour of preparation for fighting. Several trials of more prolonged fighting were also performed in four cats. In four cats trials were recorded with the cuff on the left hind paw but no pressure inside, and then repeated with sufficient pressure to occlude hind paw circulation. Six trials of either type were performed during the behaviour of preparation for fighting. Six trials of exercise on the treadmill were recorded in three cats only.

The pattern and time course of the cardiovascular changes which occurred during each behaviour were remarkably constant from trial to trial within each cat and experimental condition. Thus it was possible meaningfully to average the data from many trials (usually six) of the same type in each cat, using as a fixed point in time the first striking movement of the attacked cat for fighting behaviour, opening of the cage partition for the behaviour of preparation for fighting, and the first hind limb movement on turning on the treadmill for exercise. Statistical analysis was carried out by analysis of variance with two-way classification according to Snedecor & Cochran (1967), by comparing values of a given 2 sec interval during each behaviour with base line values obtained from 2 sec intervals randomly selected from a 30 sec period of quiet resting immediately before the trial. Data for analysis were fed into an electronic desk-top computer Olivetti Programma 101.

RESULTS

Preparation for fighting

Preparatory changes for fighting behaviour, contrary to suggestions in the literature, were different in direction from those of supportive fighting. In the typical example reproduced in Fig. 1, there was a marked bradycardia, instead of the tachycardia usual in fighting, a fall in cardiac output instead of an increase, and the iliac blood flow and conductance were markedly decreased, rather than increased as in fighting.

Direction, extent and consistency of the preparatory cardiovascular changes can be more clearly assessed from the graphs in the left column of Figs. 2 and 3, where percentage changes are reported as means of six episodes for each cat. Figs. 2 and 3 also provide statistical information on the significance of the changes. To provide a convenient comparison, the cardiovascular changes measured during six episodes of supportive fighting are reported in the middle column of Figs. 2 and 3. In two cats there was a remarkable bradycardia, which was significant in both animals, while in a third cat (G) a milder bradycardia was observed, which however fell short of statistical significance. Significant tachycardia occurred in one cat only. Cardiac output decreased significantly in four cats, even in that which showed increased heart rate. Mean blood pressure decreased slightly in four cats (the decrease being significant in three of them), and significantly increased, though by few mm Hg, in one animal. There was a decrease in

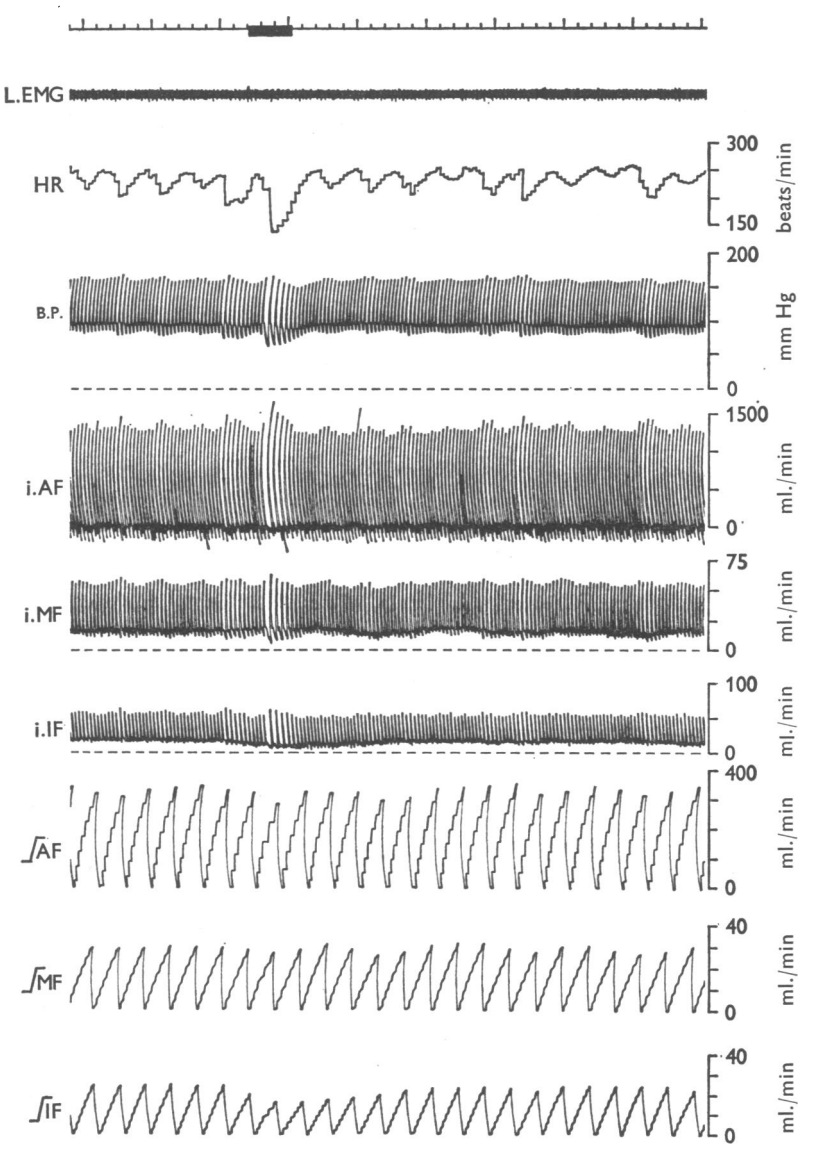

Fig. 1. Trial of preparation for fighting in cat M. In this Figure as well as in Fig. 5: L.EMG, electromyogram of the left hind limb; HR, heart rate; B.P., blood pressure; i. AF, instantaneous flow through the ascending aorta; i. MF, instantaneous flow through the superior mesenteric artery; i. IF, instantaneous flow through the left external iliac artery; ∫AF, ∫MF, ∫IF, 2 sec integrations of the above flows. On top, time in 1 and 5 sec, and event marker for raising the cage partition.

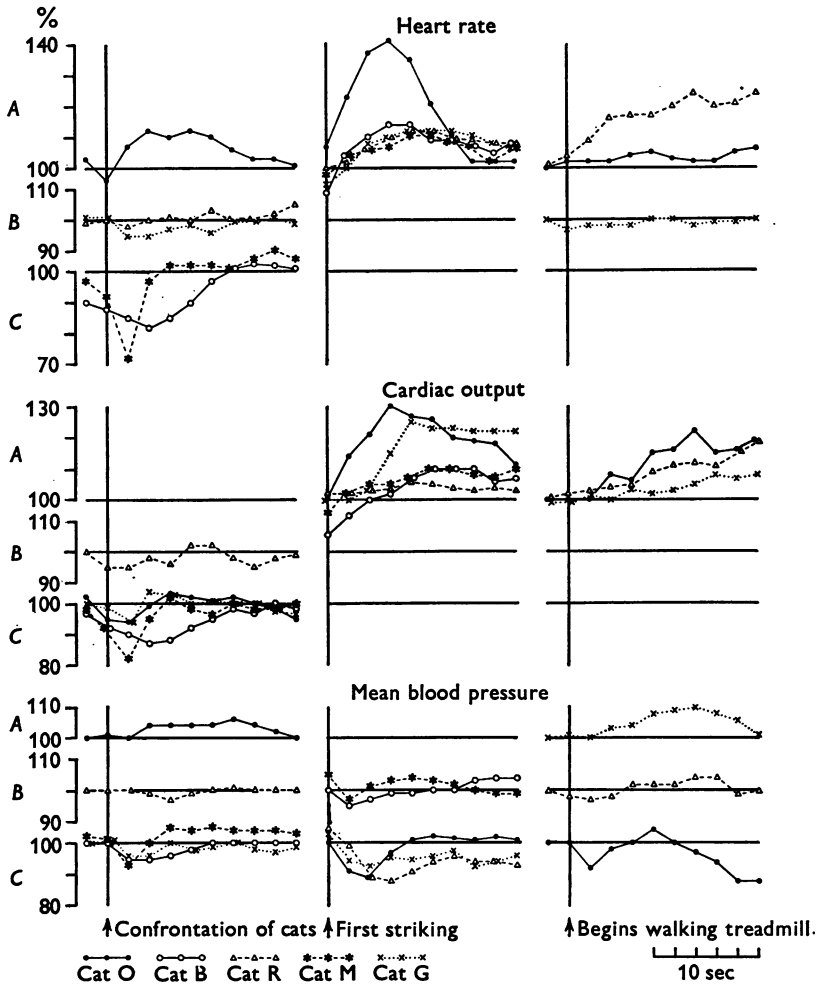

Fig. 2. Percentage changes in heart rate, cardiac output and mean blood pressure during trials of preparation for fighting (left column), supportive fighting (middle column) and exercise on the treadmill (right column). In each column vertical lines indicate: confrontation of cats (left), first striking of the attacked cat (middle) and beginning of walking on the treadmill (right). Data from five cats, identified by symbols indicated in the Figure. Each symbol is mean of 2 sec measurements from six trials. For each variable curves have been drawn on three separate rows, *A*: for significant increases ($P < 0{\cdot}05$) over base line values. *B*: for no significant changes ($P > 0{\cdot}05$) in either direction, *C*: for significant decreases ($P < 0{\cdot}05$). Base line values from the 30 sec period previous to each trial.

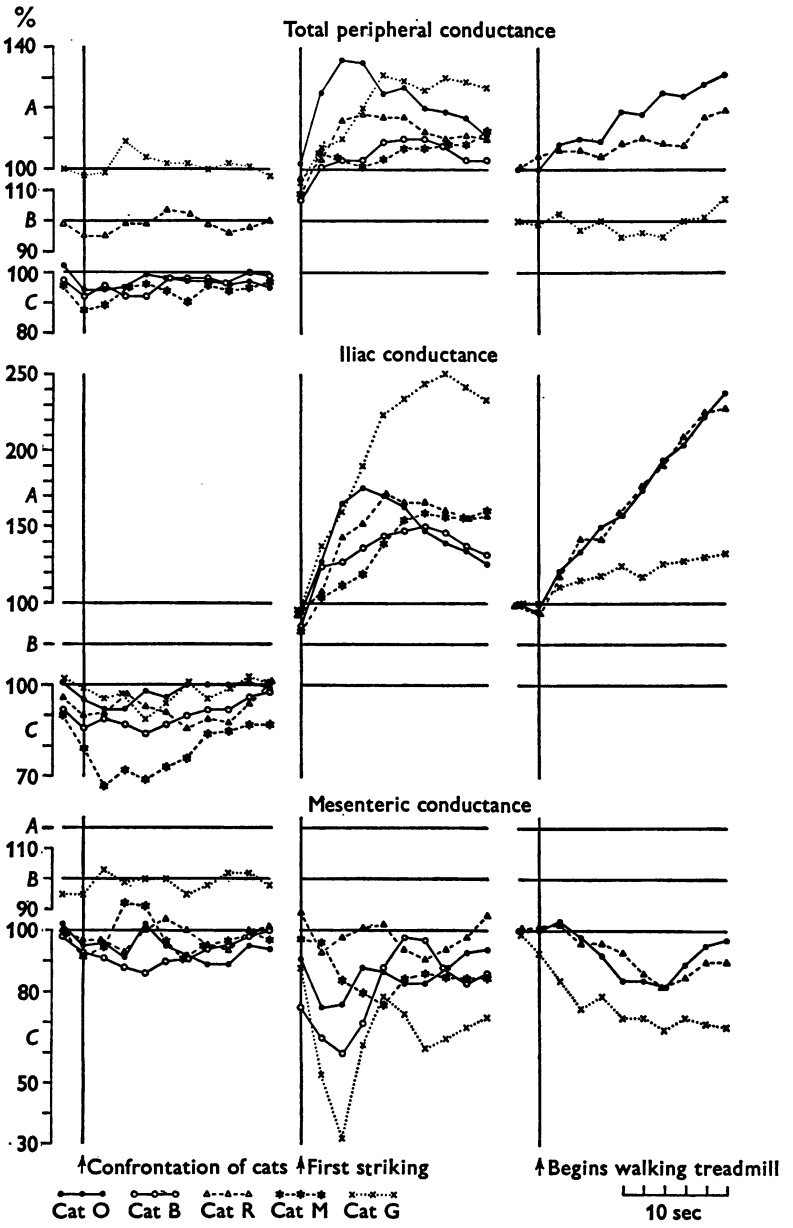

Fig. 3. Percentage changes in total peripheral conductance, iliac conductance and mesenteric conductance during trials of preparation for fighting (left column), supportive fighting (middle column) and exercise on the treadmill (right column). Other explanations as in Fig. 2.

total peripheral conductance in four cats, which was significant in three; a small increase in conductance was seen in one cat only. Iliac conductance invariably and significantly decreased in all cats, the change being indicative for the entire population. Finally, mesenteric conductance fell significantly in four cats, and remained unchanged in one. Changes in a similar direction as those observed during the trials of preparation for fighting could also be seen in all cats in the few seconds preceding the striking response in fighting trials. These changes, soon superseded by those produced by fighting behaviour, are reflected in the displaced base line wherefrom manifestations start, as shown in the middle column of Figs. 2 and 3 (first values at the left, on the vertical line).

When cardiovascular changes occurring during preparation for fighting and during supportive fighting are compared, as in the two first columns of Figs. 2 and 3, it is immediately evident that the two main differences concerned the cardiac output and the iliac conductance. In all cats these were consistently affected in the opposite direction. On the other hand, the heart rate response was a constant increase during fighting, and had a more variable direction during preparation, bradycardia being the most common though not the only kind of response observed. A slight initial fall in blood pressure and mesenteric vasoconstriction were the only changes that were regularly similar in direction during preparation for fighting and supportive fighting. The preparatory pressure changes, however, were obviously different in mechanism from those during fighting. During fighting the fall in pressure was associated with an increased total peripheral conductance and muscle vasodilatation. During preparation for fighting the fall was instead associated with a fall in cardiac output somewhat larger than the concomitant decrease in peripheral conductance.

Was the iliac vasoconstriction a true muscle vasoconstriction, or was it due to the cutaneous component of the vascular bed of the external iliac artery? In order to remove as much of the skin component as possible, we performed an additional experiment, the results of which are shown in Fig. 4. As it is known that sympathetic control of skin blood flow is mainly limited to the paw (Ström, 1950), six trials of preparation for fighting were carried out after the blood flow to the left paw (i.e. ipsilaterally to the iliac flowmeter) had been eliminated by enclosing the paw in a suitable occlusion cuff and raising the air pressure inside the cuff above systolic arterial pressure (for more details see Methods). The percentage decrease in iliac conductance was unaltered by this procedure, as was also shown by analysis of variance (F 1·12, d.f. 1, 5, $P > 0{\cdot}3$). Thus it appears that the decrease in iliac conductance truly represents muscle vasoconstriction.

Treadmill exercise

Cardiovascular changes measured in three cats during treadmill exercise are reported as means of six episodes for each cat in the right column of Figs. 2 and 3. Data in the middle column of both Figures provide comparison with changes during supportive fighting. Tracings from a trial of treadmill exercise are reproduced in Fig. 5.

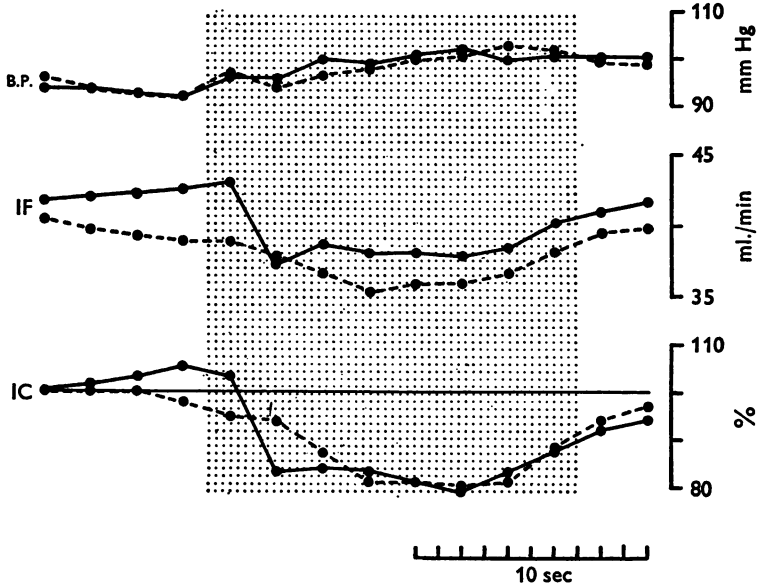

Fig. 4. Changes in blood pressure (B.P.), iliac flow (IF) and iliac conductance (IC) in cat MA during trials of preparation for fighting with hind paw circulation included (continuous line) or excluded by means of a pressure cuff (interrupted line). Each symbol is mean of six trials in either condition. B.P. and IF expressed in absolute values, IC in percentage of base line. Shaded area indicates period of confrontation without fighting.

It will be seen that exercise changed cardiovascular variables in a direction similar to that during supportive fighting. Heart rate increased significantly in two cats, and remained unchanged in the third. Cardiac output augmented significantly in all three cats. The change in blood pressure was variable in the different animals: there was a small significant increase in one, a significant decrease in another, and no change in a third animal. Total peripheral conductance increased significantly in two cats, while there was no change in the other. Iliac conductance increased and mesenteric conductance decreased in all cats. Both changes were significant in each cat. In both fighting and exercise total peripheral conductance increased in parallel with the increase in external iliac conductance. Thus, for instance, cat G, which was the only cat without an increase

in total peripheral conductance on the treadmill, also had the lowest increase in iliac conductance, perhaps because its base line iliac flow was already relatively high before the beginning of exercise.

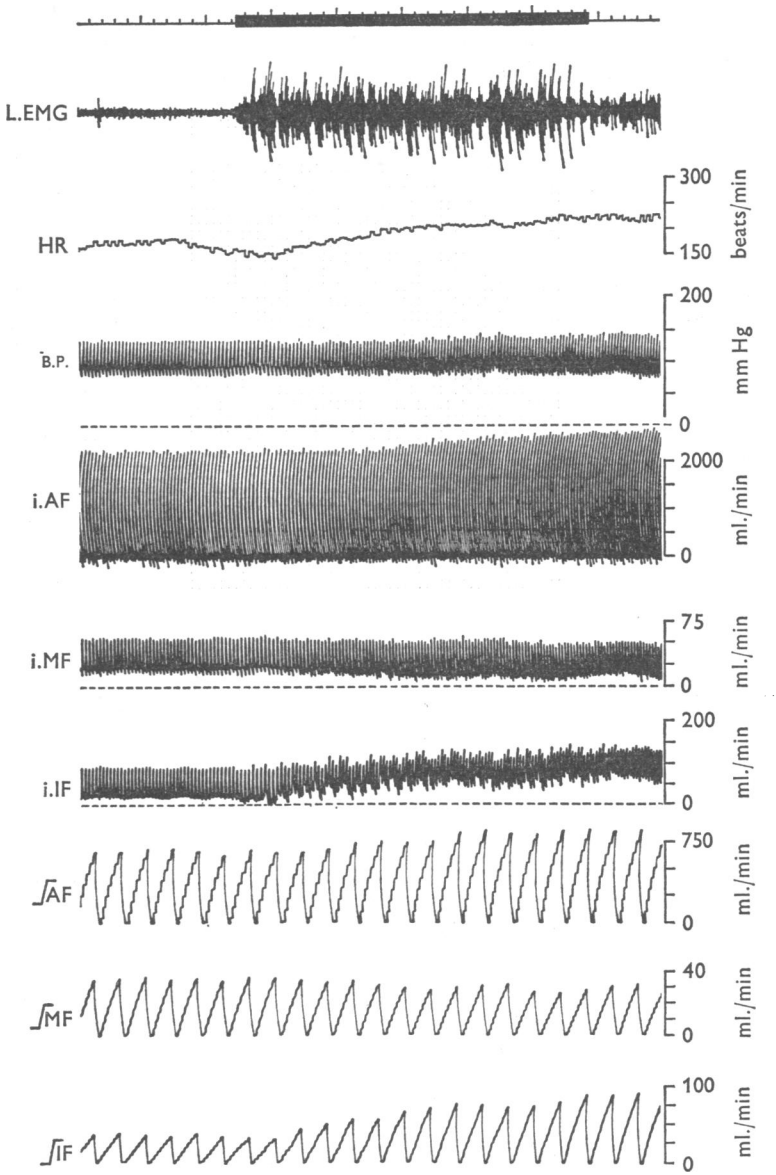

Fig. 5. Trial of exercise in cat R. Event marker on the top indicates duration of walking on the treadmill (at 10 m/min). All other symbols as in Fig. 1.

Although fighting and treadmill exercise changed cardiovascular functions in the same direction, the patterns were not identical. In general, the changes were initially stronger in fighting and then returned to base line after the end of the fighting. In treadmill exercise they were initially milder, but then continued to change in an approximately linear way as the walking continued, with the exception of blood pressure (which was variably affected in the different cats) and of mesenteric vasoconstriction, which often reached a peak some time before the exercise ended. It seems reasonable that all differences in the time course of the cardiovascular changes were due simply to the different strength and duration of the two behaviours chosen for comparison.

Short- and long-lasting fighting behaviour

In the trials reported in the middle column of Figs. 2 and 3, episodes of supportive fighting were generally kept short in duration (2–10 sec), because the short flurry of striking movements made the time course of the episodes remarkably constant from trial to trial, and made it possible to average the data from many trials. However, to provide a better comparison with longer-lasting trials of treadmill exercise, fighting episodes of longer duration (up to 20–30 sec) have also been studied. The direction of changes was similar for all variables both in short- and long-lasting fighting. There were, however, quantitative differences. The iliac vasodilatation, total peripheral conductance, and cardiac output all continued to increase during the long fighting to levels well above those occurring in shorter episodes. Heart rate and mesenteric vasoconstriction, instead, quickly reached peaks in the longer fighting similar to those of shorter trials, and did not increase further. Blood pressure changes during long-lasting fighting episodes were also similar to those during shorter trials, but complicated by the multiplication of striking motions by the cat, causing rather regular fluctuations in the blood pressure record simultaneous with movements. These small but consistent changes in blood pressure are not movement artifacts, since they are reflected in the independently obtained flow channels, and may be caused, at least in part, by mechanical pressures such as increased muscle tension associated with the striking.

Fighting and exercise without hind limb participation

Further analogies between the cardiovascular changes of fighting and exercise have been sought by comparing trials of fighting in which the hind limbs do not participate, with a kind of unemotional exercise limited to the anterior part of the body. In this type of fighting (non-supportive fighting) the animal lay on its side, hissed, and struck with the forelimbs

only, and did not use the hind limbs, the electromyographic activity of which was minimally changed during fighting. An unemotional exercise limited to head and forelimbs occurred whenever the cats spontaneously groomed the head with the forelimb while lying down on one side: the hind limbs remained immobile. The cardiovascular changes during non-supportive fighting have already been reported in detail elsewhere (Adams *et al.* 1969), the peculiar feature being a decreased blood flow and a vasoconstriction in the iliac bed, instead of the constant iliac vasodilatation seen in supportive fighting when the hind limbs move. Likewise, the large iliac vasodilatation always observed in the active hind limbs during treadmill exercise was substituted by vasoconstriction in the inactive hind limbs during the exercise of grooming.

DISCUSSION

Is there a cardiovascular pattern peculiar to fighting behaviour? Our results show that the major cardiovascular events during fighting behaviour are indistinguishable from those of a strong and violent activity, and need not be attributed to an emotional aspect of the behaviour. Indeed, the direction of change of all of the variables we measured (iliac and mesenteric flows and conductances, total peripheral conductance, heart rate, cardiac output and blood pressure) was similar in both behaviours. A similar vasoconstriction was also observed in inactive limbs both during non-supportive fighting and in the exercise of grooming, conforming to the change observed in non-exercising muscles during human exercise (Bevegård & Shepherd, 1966; Blair, Glover & Roddie, 1961). Though it cannot be ruled out that the mechanisms of the cardiovascular changes during fighting and during exercise are partly different, the changes themselves are surprisingly similar in the two conditions.

Details of the cardiovascular patterns were different, but did not seem to be attributable simply to an emotional component present in fighting and absent in exercise. Indeed, quantitative differences between the two circulatory responses could easily be expected, since the exercise and fighting manoeuvres could not be matched as far as oxygen consumption (and therefore muscular activity) was concerned, and comparison between the two cardiovascular patterns must be qualitative only.

Is there a cardiovascular pattern peculiar to emotion? Even if we conclude that the cardiovascular pattern of fighting is the same as that of any other strong motor activity involving the same musculature, we may still think that there are cardiovascular consequences of emotional behaviour, and that they are either identical to those produced by motion or basically different but superseded and masked by changes due to the motor activity

itself. Our data for the changes preparatory to fighting clearly support the latter hypothesis. Indeed, the cardiovascular manifestations of this behaviour are very different from those of motor activity, be it associated or not with emotion. There are iliac vasoconstriction, a fall in cardiac output, and often a strong bradycardia, all of these changes being in the opposite direction from those changes during exercise and supportive fighting.

Our observation that preparation for fighting is associated with iliac vasoconstriction, and that this is a muscle, not purely skin, vasoconstriction, seems to contradict the conclusions of Abrahams, Hilton & Zbrożyna (1964) who found that cholinergic sympathetic dilatation of muscle vessels occurs when 'alerting' was induced by various sensory stimuli. It is disputable, however, whether this condition is correctly interpreted, as done by Abrahams *et al.* (1964), as preparation for the defence reaction, and whether it may be compared with the behaviour we have studied. A muscle vasodilatation, presumed to be largely cholinergic because reduced by atropine, has been recently described by Bolme & Novotny (1969) in dogs during a conditioned response to painful stimulation. It is unknown, however, how far uncontrolled movement might have contributed to this vasodilatation, and is equally uncertain, even according to Bolme & Novotny, whether the vasodilatation is really related to the emotional background of the conditioned reflex. In any case, our data neither support nor refute the concept (Folkow, Heymans & Neil, 1965) that muscle cholinergic vasodilatation may occur in normal unanaesthetized animals in emotional or unemotional conditions different from those we have studied in our experimental model.

The hypothesis that the cardiovascular pattern observed during preparation for fighting represents the circulatory manifestations of emotion, or at least of some quality of emotion, assumes that the behaviour of preparation for fighting may be defined as an emotional response. The flinching, ear retraction, pupil dilatation, and what we may assume to be the 'feeling' of the cat that an attack is imminent, leave little doubt that this is an emotional behaviour. We have described the care we have taken in order to prevent the cats from learning whether a real attack was going to follow or not, and there is therefore no reason to doubt that all trials appeared initially as equally harmful to the subject cats. Though we are not ready to commit ourselves to define precisely the emotional feeling during preparation for fighting, were it rage or fright or a mixture of both, it is only reasonable to surmise that it was of the same quality as the emotion occurring in the other trials in which violent fighting was elicited.

Of course, although the purpose of the present experiments was simply that of dissociating the circulatory manifestations of the emotion proper

of fighting from those of exercise, it would be desirable to compare the preparation for fighting with some other emotional response, since different cardiovascular patterns may underlie different emotional states. Since it appears that the circulatory consequences of motor activity can mask changes due to emotional states, it is necessary that the procedure be one without overt movement or great increase in isometric muscle tone. An emotional condition of considerably longer duration than that of short confrontations without fighting would also be desirable as an experimental model, as its cardiovascular manifestations might be more marked, or partly different, from those described here.

In conclusion, our results suggest that cardiovascular changes during an active emotional behaviour, such as fighting, are not qualitatively dissimilar at first glance from those during non-emotional behaviour employing a similar muscular response, and differences must be sought at the level of mechanisms involved, if there are any differences at all. On the other hand, a clear distinction must be made between the changes occurring during motor activity and the changes while the cat is preparing for the motor activity of fighting. It is suggested that the latter changes might represent the cardiovascular manifestations of the emotional quality underlying fighting behaviour.

This study was supported by the Air Force Office of Scientific Research, through the European Office of Aerospace Research (OAR) United States Air Force, under Grant AF EOAR 67-41, and by Consiglio Nazionale delle Ricerche.

Dr Adams was postgraduate Fellow of the Public Health Service from Yale University.

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