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CIRCULATORY CHANGES DURING FAINTING AND COMA CAUSED BY OXYGEN LACK

By D. P. ANDERSON, W. J. ALLEN, H. BARCROFT, O. G. EDHOLM and G. W. MANNING[1]
From the Physiological Laboratory, Queen's University, Belfast

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It has recently been found that dilatation of the muscle blood vessels takes place in subjects who faint from loss of blood (Barcroft, Edholm, McMichael & Sharpey-Schafer, 1944; Barcroft & Edholm, 1945). This vasodilatation in muscle causes the acute drop in arterial blood pressure, the cerebral anaemia and the pallor of the skin. Further work was needed to find whether muscle vasodilatation was a constant manifestation of the vaso-vagal syndrome (Lewis, 1932), irrespective of how the syndrome was excited. It was therefore necessary to use some stimulus other than haemorrhage to elicit the fainting reaction. The stimulus chosen was hypoxia. Henderson (1938), Schneider (1918), Ershler, Kossman & White (1942) and Keys, Stapp & Violante (1942) have shown that moderate reduction in the oxygen in the inspired air induces fainting in some subjects. In other subjects hypoxia causes loss of consciousness without fainting, i.e. without the vaso-vagal syndrome. We therefore had an opportunity to study the blood flow in the forearm, which is mainly muscle, in both 'fainters' and 'non-fainters'. Abramson, Landt & Benjamin (1941) and McMichael & Snyder (1943) have investigated the blood flow in the forearm and in the leg during hypoxia, but not during fainting or coma.

Experiments of the effect of hypoxia in 'posthaemorrhagic' subjects are also described, as they throw further light on the nature of the vaso-vagal syndrome.

METHODS

The subjects were healthy men aged 20–30 years. Room temperature was 18–20° C.

The subject lay on a couch with his back supported at an angle of about 45°. Arrangements were completed for recording the blood flow in the left forearm by the Brodie venous occlusion principle, using the Lewis-Grant plethysmograph (Barcroft & Edholm, 1943). Water-bath temperature was 33–34° C. A sphygmomanometer cuff was put on the right arm. The subject was made comfortably warm with blankets.

[1] Squadron Leader, Royal Canadian Air Force.

Pulse, arterial blood pressure, and forearm blood-flow determinations were made at 5 min. intervals. At 15 min. an oxygen mask (R.C.A.F. pattern) was put on and tested to see that it made an airtight fit. The subject breathed air from the room through the mask. At 20 min. air from a cylinder of compressed air was substituted. At 30 min. administration of a low percentage of oxygen in nitrogen was begun. Mixtures containing approximately 10, 8, 7 and 6% oxygen were available. Most experiments began with 8%. During the hypoxia, determinations were made of pulse, blood pressure and forearm blood flow at 3 min. intervals. After each reading the subject was shown a numbered photograph to test his mental condition, and his hands were examined for involuntary movements. After 15 min. of moderate hypoxia, a mixture poorer in oxygen was usually given.

(*a*) In a 'fainter', several determinations of pulse, blood pressure, and forearm blood flow (collecting pressure lowered to 30 mm. Hg) were made at about 1 min. intervals.

(*b*) In a 'non-fainter' hypoxia was continued till there were definite signs of depression of the higher centres; either deep stupor from which he could barely be roused, or total analgesia to pin-prick.

The mask was then taken off, and readings were continued for ½ hr. The subject was questioned about his sensations and his recollection of the photographs.

In the experiments on the posthaemorrhagic hypoxia a 6½ in. sphygmomanometer cuff was placed round each thigh, as high up as possible, and inflated to diastolic pressure at time 0. This procedure dams back blood in the veins of the legs and so produces the equivalent of a large haemorrhage, but not large enough to cause fainting, or only very rarely so (McMichael & Sharpey-Schafer, 1944; Ebert & Stead, 1940). At 15 min. the pressure was raised to 110 mm. Hg, and the mask was put on. At 30 min. 8% oxygen was given. After a faint, the administration of the hypoxic mixture was generally maintained for 15 min. or more. The procedure for a non-fainter was as above. At 60 min. the cuffs were deflated and the mask taken off in those subjects from whom this had not been done before.

RESULTS

There were three fainters and ten non-fainters.

Fainters. Fig. 1 shows typical results. Mask breathing barely altered the pulse, blood pressure or forearm blood flow. 9·8% oxygen was administered. In 2 min. the subject became slightly cyanosed. After 7 min. the pulse rate had risen to 120 beats/min., the blood pressure to 164/83 mm. Hg. The forearm blood flow was 3·1 c.c./100 c.c. forearm/min. Then there was a typical vaso-vagal faint. The subject was very pale. Profuse perspiration broke out. The radial pulse could no longer be felt. Consciousness was lost. The heart rate, measured by auscultation at the apex, had slowed to 56. The blood pressure was 85/75. The forearm blood flow had risen to 10·1 c.c./min., signifying a marked vaso-dilatation in the forearm. Then the mask was taken off. The blood pressure rose, the forearm flow subsided, and within 2 min. the subject was able to answer questions. Bradycardia and slight pallor persisted for many minutes. About 1 hr. after fainting the subject left the room feeling perfectly well.

Similar results were obtained in experiments on two other 'fainters'. During fainting there was an acute fall in blood pressure and an increase in forearm blood flow signifying vasodilatation. Fig. 2 shows the averaged results (peak flows in the other two experiments were 20 and 8·7 c.c.). There is no doubt that vasodilatation in the forearm occurs during hypoxic fainting.

Non-fainters. Fig. 3 shows a typical experiment. Breathing air through the mask caused no significant changes. 4 min. after 8% oxygen was given the subject was cyanosed, the pulse rate had risen to 125 and the blood pressure to 140/80; there was a slight rise in the forearm blood flow. After 10 min. of hypoxia the subject looked distressed, his arms and legs were twitching. He was deeply cyanosed but could still understand what was said to him. The 8%

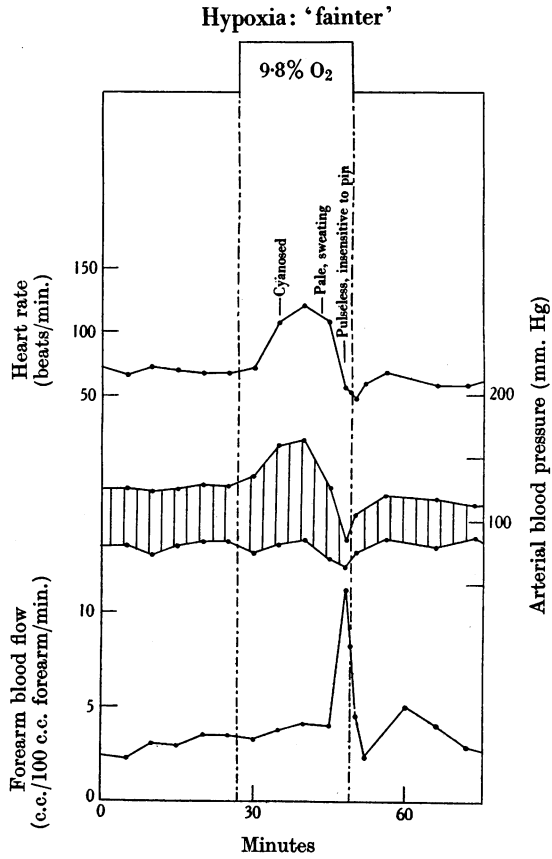

Fig. 1. Typical symptoms and typical changes in heart rate, in arterial blood pressure and in blood flow in the forearm.

oxygen was replaced by 7%. The subject soon lost consciousness and became quite insensitive to pin-prick. The pulse rate (110), high blood pressure (165/85) and rapid forearm flow (8·5 c.c./min.) showed that there was no sign of the vaso-vagal reaction. 2 min. after the mask was taken off the subject's colour was normal. He did not remember the removal of the mask. He had a headache. The pulse, blood pressure and forearm blood flow very quickly returned to normal. 75 min. later he left the room perfectly well except for a slight headache.

Fig. 4 shows the results of nine other experiments on non-fainters. The effect on the forearm blood flow varied from none in Exp. 2 to a sevenfold increase in Exp. 9.

It is noteworthy that involuntary muscular movements preceded coma in every experiment.

Fig. 2 shows the averaged results of the experiments on the non-fainters. It emphasizes the activity of the circulation during depression of the higher centres.

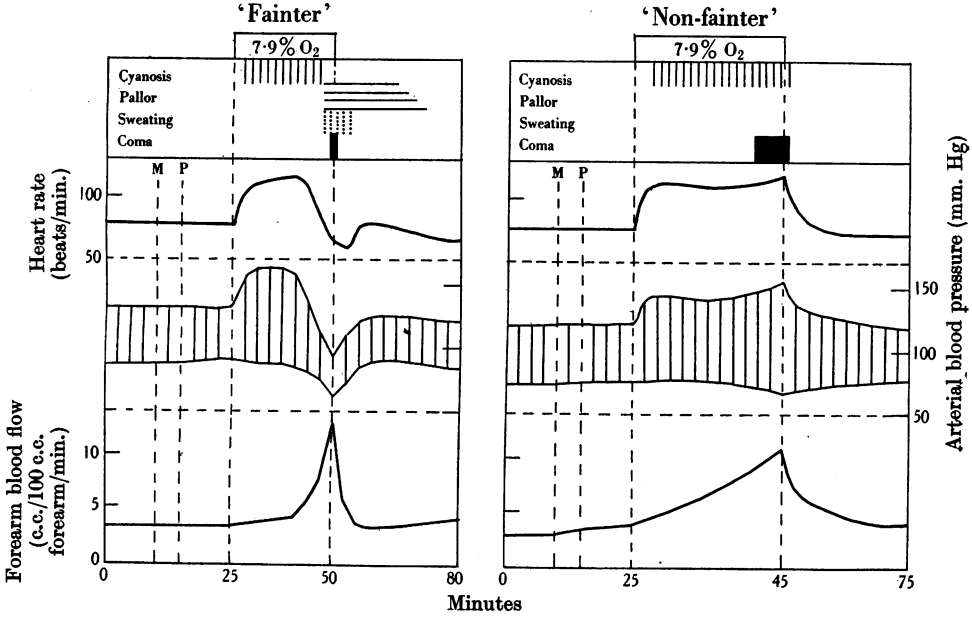

Fig. 2. Averaged results. *M*, mask put on, room air breathed. *P*, air from cylinder of compressed air breathed.

'Posthaemorrhagic' hypoxia. The same thirteen men who acted as subjects for the above experiments also acted for the experiments on the effect of hypoxia during the posthaemorrhagic state.

There was a striking increase in the proportion of 'fainters' to 'non-fainters' as is seen below:

	Fainters	Non-fainters
Hypoxia alone	3	10
'Posthaemorrhagic' hypoxia	10	3

The group of ten posthaemorrhagic fainters included the three subjects who had previously fainted during simple hypoxia.

A remarkable finding was that spontaneous recovery from fainting occurred in six subjects while they were still breathing the oxygen-poor mixture, and while they continued to have the blood dammed back in the legs. Fig. 5 shows

a typical experiment. Soon after beginning to breathe 8·4% oxygen, the subject became slightly cyanosed, the pulse rate rose to 114, and then there was a typical vaso-vagal faint. He became extremely pale and sweated. Consciousness was lost and pricking the skin elicited no response. The heart

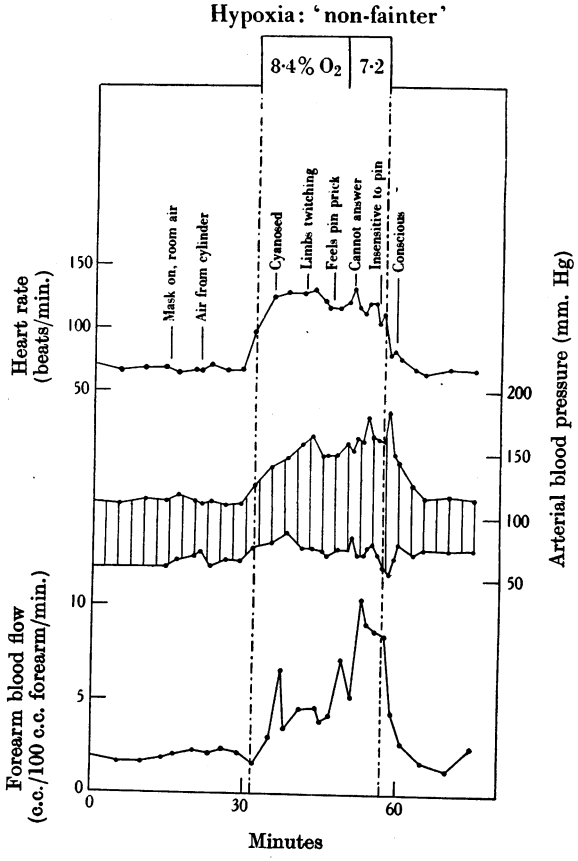

Fig. 3. Typical symptoms and typical changes in the heart rate, in the arterial blood pressure and in the blood flow in the forearm.

rate was 58, the blood pressure was 80/65, and the forearm flow had risen to 7·8 c.c./min. The blood was kept dammed back in the legs and the hypoxia continued. Within 2 or 3 min. the pulse rate and blood pressure started to rise. Spontaneous recovery had begun. 15 min. after fainting the subject had regained consciousness, was able to answer questions and was not distressed. The dilatation in the forearm had, to a large extent, subsided and the pulse rate and blood pressure had recovered their initial values and more.

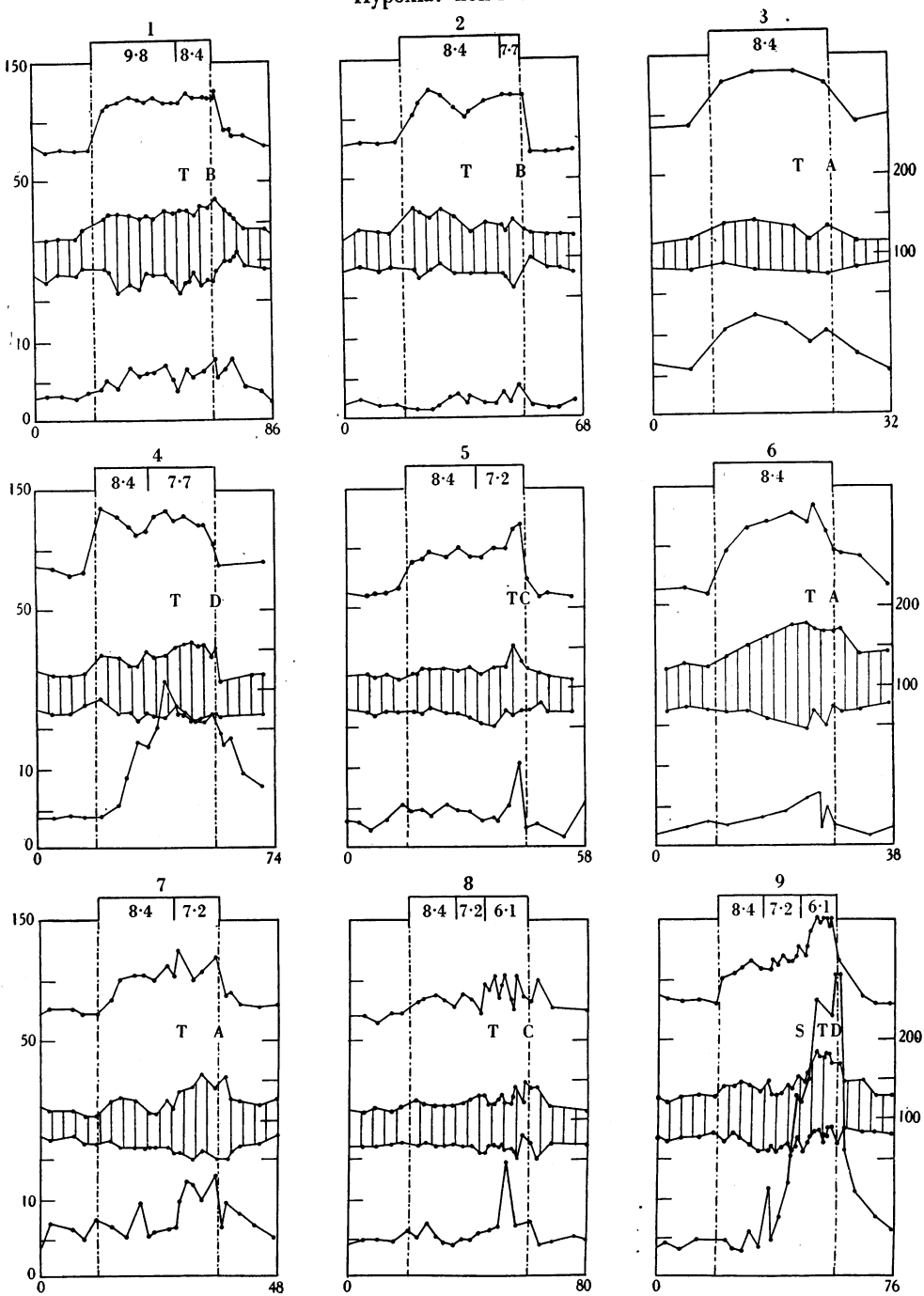

Fig. 4. Upper curve: heart rate, beats/min. Middle curve: arterial blood pressure, mm. Hg. Lower curve: forearm blood flow, c.c./100 c.c. forearm/min. Time in min. Raised portion of upper margin of graph: oxygen poor mixture breathed. The number under the upper margin is the percentage of oxygen. *T*, the onset of involuntary muscular twitches. *S*, the onset of involuntary muscular spasm. Mental condition at the end of the hypoxia: A, insensitive to pin-prick. B, could not be roused. C, could just be roused, amnesia. D, could just be roused, no amnesia.

DISCUSSION

The behaviour of the forearm blood flow in hypoxic coma differs somewhat from that found in lesser degrees of hypoxia. Abramson *et al.* (1941) found a 30% increase in forearm blood flow in subjects who breathed 10% oxygen.

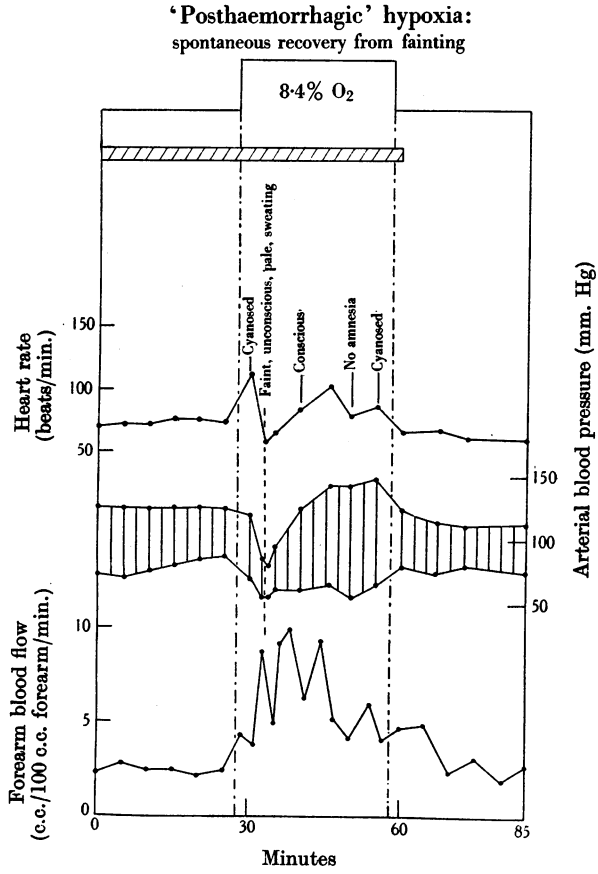

Fig. 5. Typical symptoms and typical changes in heart rate, in arterial blood pressure and in forearm blood flow. Shaded rectangle: pneumatic thigh cuffs inflated.

McMichael & Snyder (1943) found variable changes ranging from −45 to +77% in subjects in a low-pressure chamber at 16,000–18,000 ft. In our own experiments there was not much change in the forearm blood flow in some comatose subjects, in others there was hyperaemia, sometimes very marked; forearm blood flow increased on the average from 3·8 to 11·1 c.c.

The whereabouts of the hyperaemia in the forearms of the comatose subjects was not investigated. In the experiment in which the hyperaemia was most noticeable there was little doubt that it was in the muscle as there were

frequent coarse muscular twitches and muscular activity causes a marked increase in forearm blood flow. As involuntary muscular movements preceded coma in every experiment, it is possible that they caused the hyperaemia seen in most experiments. If the increase in the forearm blood flow, averaging 5·3 c.c./100 c.c. forearm/min., was in the muscle, and if a similar increase took place throughout the skeletal musculature, cardiac output would be increased by approximately 2·5 l./min. (for the basis of this estimate see Barcroft, Bonnar, Edholm & Effron, 1943). Possibly the increase in cardiac output found by Grollman (1930) and others in hypoxia may be mainly due to vasodilatation in the skeletal muscles.

As haemorrhage itself may excite fainting it is not surprising that the incidence of fainting due to hypoxia was increased in the subjects who had previously had a 'simulated haemorrhage'. The need for oxygen at comparatively low altitudes is suggested for wounded men who have lost much blood.

Ershler *et al.* (1942) found a rise in the pressure in the antecubital vein during fainting. They took this to be a sign of right ventricular failure. It seems, however, more likely that it is due to muscle vasodilatation and to increased forearm blood flow. The right auricular pressure is very little changed in fainting (Barcroft *et al.* 1944; Warren, Brannon, Stead & Merrill, 1945).

The view that hypoxic fainting was a heart failure was also held by Whitney (1918) who found that it was preceded by a large increase in the area of cardiac dullness to percussion. So far, X-ray pictures, made just before fainting, have shown no sign of enlargement of the heart (Keys *et al.* 1942). The remarkable recoveries from faints which took place in very adverse circumstances in the experiments described above do not suggest that there is heart failure during fainting.

SUMMARY

1. 7–8% oxygen was administered to thirteen normal subjects till three fainted and ten became comatose.

2. Heart rate, arterial blood pressure and forearm blood flow were determined.

3. *Fainters:* (*a*) During the faint there was pallor, sweating, bradycardia, acute drop in arterial blood pressure, marked increase in forearm blood flow and often loss of consciousness. (*b*) The following average values were obtained: heart rate, 62; arterial blood pressure 95/60 mm. Hg; forearm blood flow 13 c.c./100 c.c. forearm/min. (*c*) The finding of increased forearm flow in hypoxic as well as in posthaemorrhagic fainting indicates that active vasodilatation in skeletal muscle is a constant manifestation of the vaso-vagal syndrome.

4. *Non-fainters:* (*a*) During coma there was cyanosis, tachycardia, and usually rise in arterial blood pressure and increase in forearm blood flow. (*b*) The following average figures were obtained: heart rate, 120; arterial blood

pressure, 155/70 mm. Hg; forearm blood flow 11 c.c./100 c.c. forearm/min. (*c*) Possibly the increase in forearm blood flow and in cardiac output is caused, to some extent, by increase in the blood flow through the skeletal muscles.

5. Recovery from fainting occurred in six subjects while 8% oxygen was being administered and while about 1·5 l. of blood was kept dammed back in the legs. Recovery under such conditions does not support the view that fainting is a form of heart failure.

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