J. Physiol. (1947) 106, 186–193 612.744.211

THE EFFECT OF SEAT POSITION ON THE EFFICIENCY OF BICYCLE PEDALLING

By P. HUGH-JONES

From the M.R.C. Physiology Laboratory, G.W., A.F.V.S., Lulworth

(*Received* 24 *September* 1946)

Different aspects of cycling illustrate well the various physiological factors that determine the efficiency of utilization of muscle force after this has once been developed by the muscles. For example, the effects of different rates of pedalling have been considered by Benedict & Cathcart (1913), by Hansen (1927), who also considered the effects of different pedal loads, and, more recently, by Garry & Wishart (1931) who demonstrated the existence of a most efficient pedalling speed of 52 r.p.m.

The experiments to be described were undertaken to determine the effect of different seat positions; seat position determines the leg-joint angles which finally control the thrust available from the force produced by the muscles.

The increase in force exertable with knee-joint extension explains the well-known cycling requirement of adjusting the saddle to allow full leg-extension. The findings described in a previous paper (Hugh-Jones, 1947) showed that especially large pushes could be exerted on a foot-pedal by using the leg as a mechanical toggle between a pedal and the back-rest of a carefully adjusted seat. It was, therefore, thought possible that efficiency of cycling might be greater than that obtainable when using a correctly adjusted saddle in the normal cycling position, if the operator used a seat with a back-rest placed in a position both further back and lower than the normal saddle, so allowing full toggle-action with the legs.

The work was started in relation to stationary bicycle pedalling as a means of utilizing human muscular power.

APPARATUS AND METHOD

The standard type of bicycle ergometer, with a 70 lb. fly-wheel, was used. The load on the brake-band was measured, to within 1 %, by taking the difference reading between the two balances; particular care was taken to avoid error from stiction in the system that carried the cords from the brake-band to the balances: only two pulleys, of 5 in. diameter, were included in this system and these were mounted on ball-races lubricated with upper-cylinder lubricant.

A frame was arranged to permit a seat, cut away like a saddle but carrying an adjustable back-rest, to be rigidly fixed in any desired position on the arc of a circle with centre at the pedal axle; the radius of the arc was determined by the effective leg-length of individual subjects.

The Douglas-Haldane method was employed to estimate energy expenditure. The Haldane apparatus was checked before samples were analysed on any day. The readings from this procedure gave a mean O_2 percentage for atmospheric air of $20{\cdot}92 \pm 0{\cdot}003$ (S.E. of mean of 85 observations recorded on different days).

The gas samples for analysis were collected from the Douglas bags into Brodie sampling bottles and analysed in duplicate; the data obtained from the two analyses showed good agreement and their mean value is used in the calculations which follow.

Two males, aged 28 years, of weights 168 and 149 lb., and of heights of 71 and 68 in. respectively, acted as subjects.

Experiments were always started at the same time in the mornings. At every load in 'step-up' experiments (see later), and for each cycling position in the other experiments, the subject pedalled, in time with a metronome, at 52 r.p.m. with the mouthpiece for breathing in position but with the two-way tap open to the atmosphere, for exactly 5 min. This time was chosen as a result of preliminary experiments to determine the minimum time necessary to ensure that a 'steady-state' had been reached. Expired air was then collected over a sampling period, lasting about 2 min., the two-way tap being turned on and off at the end of an inspiration concurrently with a stop-watch which recorded the exact time of sampling. Inspiratory alveolar-air samples were taken, when required, by means of a modified Haldane sampling apparatus (Peters & Van Slyke, 1932) as soon as the collection of expired air was finished.

The cycling was done without holding the handle-bars and without 'ankling' with the pedals, since the advantage gained by such procedures would be both variable and indeterminable.

The experiments lasted over six months. After the first month, which was occupied with the preliminary experiments, further training effects were not noted in the subjects who were in fair training before the start of the experiments. In the main series, the order of experiments was randomized in relation to load and seat position and it is hoped that this minimized any effects of training and day-to-day variation that may have occurred in a subject.

RESULTS

The oxygen requirement is a measure of the energy needed to perform a given amount of mechanical work provided the work can be performed in a 'steady-state' (Hill, Long & Lupton, 1924); this measure was considered to be the best means of comparing the different seat positions by finding for each the effort required to perform a constant amount of mechanical work.

As the preliminary experiments had shown that the differences in oxygen requirement were likely to be small, it seemed important that the constant amount of external work for each subject should be as large as possible and yet be performable in a steady state, that is, the work level should not exceed the 'crest-load'. Moreover, the results for each subject would be better related if the cycling positions were compared at a comparable load for each individual, and for this purpose also, a load just below his crest-load is suitable. The crest-load, therefore, first had to be found.

Determination of the 'crest-load'. Briggs (1920), who introduced the term 'crest-load' as the highest load which could be maintained in a steady state, originally used the load at which a fall in the proportion of carbon dioxide in the expired air occurred; Hill & Lupton (1923) and, later, Bock, Vancaulaert,

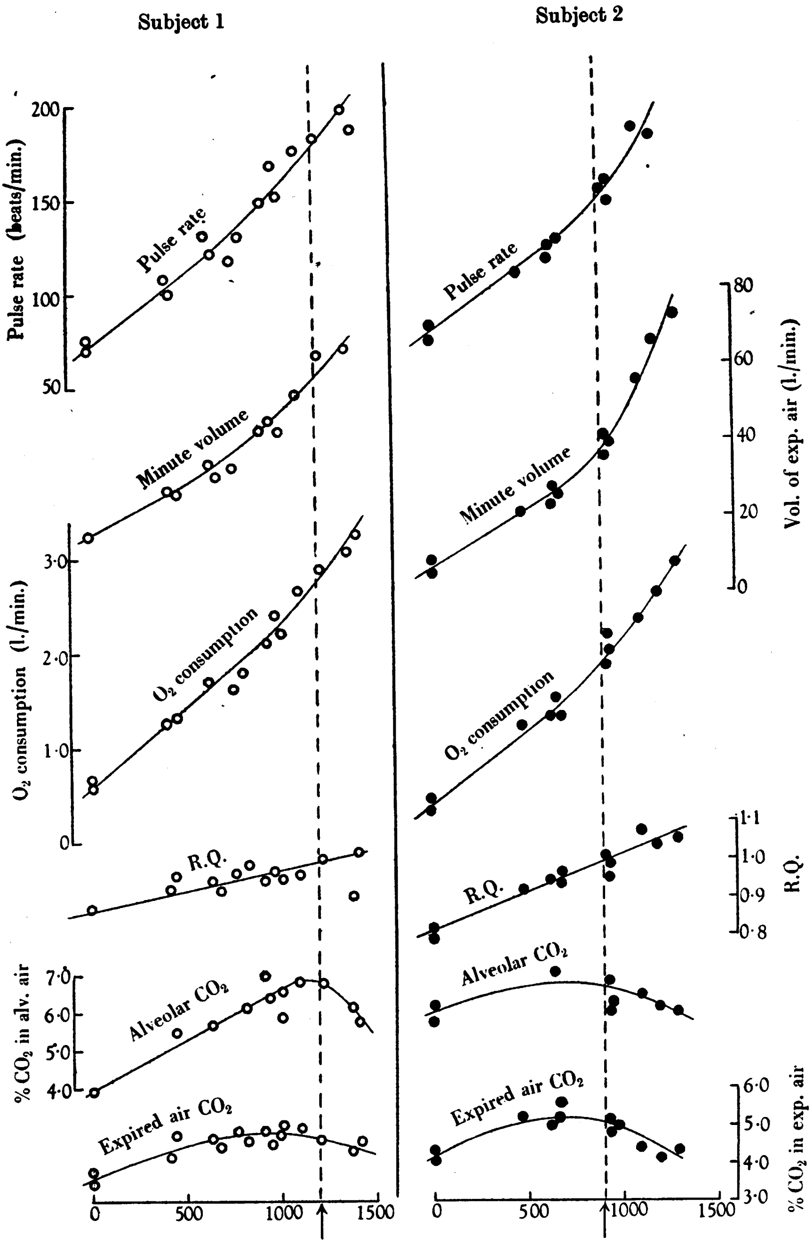

Fig. 1. 'Step-up' experiments to determine the approximate 'crest-load' of the two subjects The approximate 'crest-load' indicated by the arrow is determined from the response of the different physiological functions (ordinates) to increasing mechanical work (abscissae).

Dill, Folling & Hurxthal (1928) showed that the R.Q. passed unity at this load; Schneider (1931) used the load at which heart rate and oxygen consumption failed to show a continued linear increase and at which total ventilation increased excessively. In the present work as many criteria as possible were used, according to the 'step-up' method of experimentation described by Taylor (1941).

The results for cycling with the saddle in the normal position are shown in Fig. 1.

The points on the graphs represent results from five experiments performed on different days. It will be seen that, from the different criteria mentioned (the R.Q. exceeding unity; the minute-volume of air and the oxygen consumption ceasing to increase linearly with load; and the percentage of CO_2 in alveolar air reaching a maximum), the crest-load of subject 1 was approximately 1200 kg.-m./min. while that of subject 2 was only 900 kg.-m./min. approximately.

It is interesting to note that in these two subjects, the rate of increase in oxygen consumption for increasing work is augmented above the crest-load and not diminished as occurred in some of Schneider's subjects. Moreover, the peak of CO_2 in the expired air occurred before the crest-load as judged on the other criteria. This finding does not agree with the results of Briggs but confirms those of Schneider. The results support Taylor's conclusions that these different functions behave in a variable fashion after the limit of work that can be performed in a steady state is reached.

Comparison of the different seat positions. The seat with a back-rest was used. The latter, a small padded rectangular plate of about 6 × 4 in., was adjusted with its centre 6 in. above the seat so that the pelvis was directly supported. The position of the seat on different parts of the arc about the pedal axle was measured by the angle formed between the perpendicular and the line joining the base of the seat-back to the pedal axle. On this basis, the normal cycling saddle makes an angle of 26°.

The load on the ergometer was kept constant, as far as possible, so as to adjust output of each subject to approximately 100 kg.-m./min. below his crest-load. Actually, owing to small changes in brake-band friction, the load varied by just under 2 %; that is, it was always within 1110 ± 20 and 805 ± 15 kg.-m./min., respectively, for the two subjects.

The results are shown graphically in Fig. 2. Here the ordinates represent the mean amount of oxygen consumed for the constant amount of external work. This is given as the former divided by the latter (converted to Calories for convenience) in order to correct for the small day-to-day variation in work, discussed above; this correction is justified as it is small and the relation between the two variables is known to be linear below the crest-load. The abscissae represent the seven seat positions used, given in degrees of rotation about the pedal axle as mentioned above. The limits shown for the mean oxygen consumption represent ± twice the standard error. This is calculated from the number of readings given below each point; these readings were obtained on different days.

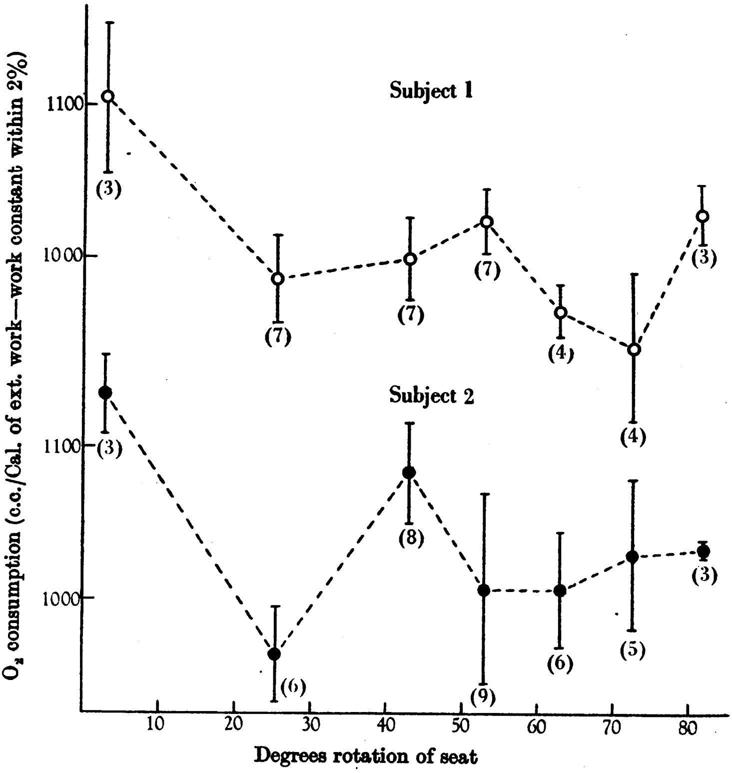

Fig. 2. Oxygen used (ordinates) for performing a constant amount of work with the seat in different positions on the arc about the pedal axle (abscissae). Circles: subject 1; Dots: subject 2.

It will be seen that, for both subjects, the amount of oxygen consumed falls significantly from the 3° position to a minimum at 26° which is the normal cycling position. It tends to rise again as the seat is moved further back, to fall again to another minimum somewhere about 63° (±10°), and finally to rise as the seat, in the 82° position, approaches the horizontal through the pedal axle. These results indicate that two positions only are profitable for cycling; one is the normal saddle position, the other, needs a seat with back-rest, and occurs at about 63° (±10°). It is interesting to note that the latter corresponds with the position adopted in the French 'Velocar' racing bicycle. Between the two positions there appeared no significant difference, so a further series of experiments was made with these two optimum positions only.

Comparison of the two 'optimum' seat positions found. The normal cycling position was compared with the 63° seat position, with the back-rest for the latter at 6 and 11 in. above seat level. 'Step-up' experiments were used involving three different loads, one of which was above the crest-load of the subject. By this means, again by measuring oxygen consumption, it was hoped to detect any difference between the positions. If such a difference existed it would, from the previous results, be very small, but this method might allow two criteria of difference: possibly different loads for the crest-load, and, more likely, divergence of the straight lines joining the points for oxygen consumption at different loads up to the crest-load.

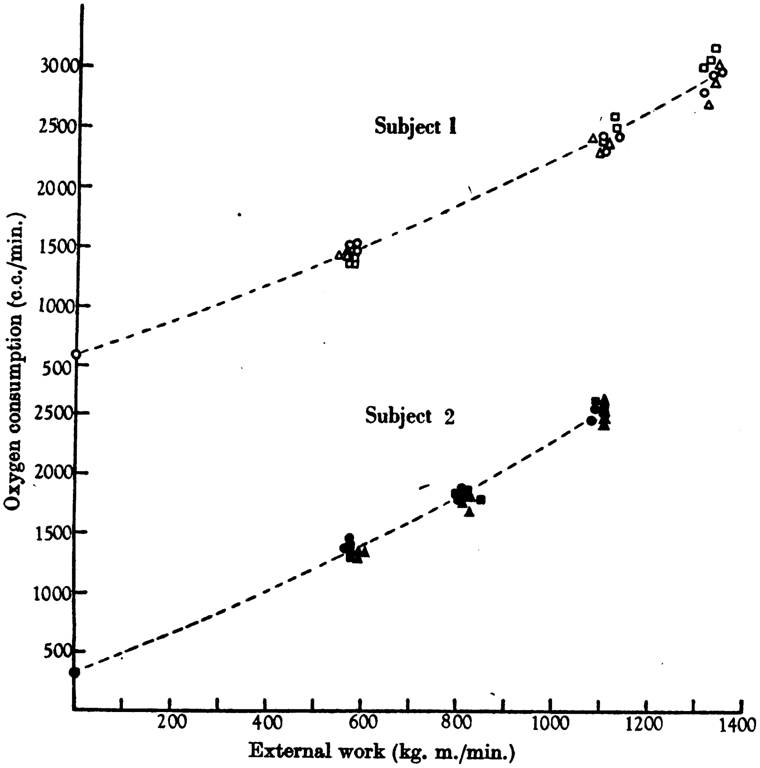

Fig. 3. Comparison of the two 'optimum' cycling positions found in terms of the oxygen consumed (ordinates) at different levels of external mechanical work (abscissae). (Circles = normal cycling position; triangles and squares = alternative position with low and high back-rest, respectively. Open symbols, subject 1; black symbols, subject 2.)

The results are shown graphically in Fig. 3. (The 'no-load' O_2 consumption was not redetermined. The value indicated for it in Fig. 3 is that found in the previous 'step-up' experiments described above.)

From Fig. 3 it will be appreciated that the results might seem to indicate a very slight advantage of the 63° position with a low back-rest over the normal cycling position, but the differences are not statistically significant. It can only be concluded that, with the methods used and number of results obtained, no advantage could be detected in energy cost for 'back-rest cycling' over the more usual position, though it appears to be a practicable alternative to the latter.

DISCUSSION

It seems that the results shown in Fig. 2 may be explained by the operation of two effects: the first is gravitational and helps most when the legs of the operator are vertically above the pedals; the second is mechanical toggle-action between the seat back-rest and pedals and this helps most (as discussed in the previous paper, Hugh-Jones, 1947) when the pedals are on the same horizontal level as the seat. Thus, in Fig. 3, the forward 3° position is less advantageous than the normal cycling position because the cyclist's weight cannot be fully exerted on the pedals which consequently feel subjectively 'too far under the seat'; behind the normal cycling position 'static effort' (Bedford, Vernon & Warner, 1933), from upholding the legs, progressively decreases efficiency as the seat is moved backwards round the arc about the pedals. At the same time, after about the 53° position, the back-rest, of which no use can be made before, increasingly exerts its beneficial influence. It outweighs the adverse effect from static effort at about the 63° position, but then ceases to do so as the seat further approaches the horizontal passing through the pedal axle, because its effect appears to increase less rapidly than that of static effort.

From the aspect of the practical application of the above results two points are interesting: first, in the evolution of the modern bicycle, as given by Sharp (1896), the seat position accepted to-day has been adopted after trial of positions both just in front of, and just behind it; secondly, in view of the difficulty in detecting any significant difference between the usual position and the low back-rest position, the 'Velocar', which employed approximately this second alternative position with a back-rest, gained the kilometre (flying start) and the 50 kilometre (standing start) 'records libres' in recent world cycling records (Union Cycliste Internationale, 1939). The conventional machines, however, gained records for all intermediate distances. Of course, these records were not necessarily achieved by competitiors of the same physiological capacity.

It must be emphasized that the results given here were obtained in an attempt to find, physiologically, the optimum method of employing human muscular effort for conversion to other forms of energy. For this purpose, where stationary cycling has to be considered, the position at about 63° with back-rest has many advantages, though it is doubtful whether these hold for a moving machine where the conventional design is mechanically much simpler.

SUMMARY

1. Results are given which show the effect on the efficiency of bicycle pedalling when the bicycle seat, with an added back-rest, is moved into different positions round the arc of a circle whose centre is the pedal axle.

2. It is found that there are two alternative optimum positions: one, the normal position adopted for the saddle in modern bicycles for which a line joining the rear of the seat to the pedal axle makes an angle of about 26° to the vertical; the other, with a back-rest supporting the pelvis, for which the angle quoted is approximately 63° (±10°). No significant difference between the efficiency of pedalling in these two positions was detected.

3. 'Step-up' experiments on two subjects are given, showing the resulting effects on various physiological functions as the work-loads were increased till the subject was exhausted. They are related to similar previous work.

I am indebted to the Medical Research Council for permission to publish these results and to Prof. I. de Burgh Daly and Dr E. E. Pochin for help and advice. The editor of *Cycling* kindly provided information on cycling records and on the French 'Velocar'.

REFERENCES

Bedford, T., Vernon, H. M. & Warner, C. G. (1933). *J. Hyg., Camb.*, **33**, 118.

Benedict, F. G. & Cathcart, E. P. (1913). *Publ. Carneg. Instn*, No. 187.

Bock, A. V., Vancaulaert, C., Dill, D. B., Folling, A. & Hurxthal, L. M. (1928). *J. Physiol.* **66**, 162.

Briggs, H. (1920). *J. Physiol.* **54**, 292.

Garry, R. C. & Wishart, G. M. (1931). *J. Physiol.* **72**, 425.

Hansen, E. (1927). *Skand. Arch. Physiol.* **51**, 1.

Hill, A. V., Long, C. N. H. & Lupton, H. (1924). *Proc. Roy. Soc.* B, **97**, 155.

Hill, A. V. & Lupton, H. (1923). *Quart. J. Med.* **16**, 135.

Hugh-Jones, P. (1947). *J. Physiol.* **105**, 332.

Peters, J. P. & Van Slyke, D. D. (1932). *Quantitative Clinical Chemistry*, **2**, 164. London: Baillière, Tindall and Cox.

Schneider, E. C. (1931). *Physiology of Muscular Activity*, 2nd ed. p. 68. Philadelphia and London: W. B. Saunders.

Sharp, A. (1896). *Bicycles and Tricycles*, p. 148. London: Longmans, Green.

Taylor, C. (1941). *Amer. J. Physiol.* **135**, 27.

Union Cycliste Internationale (1939). *Records du Monde*. Paris: U.C.I., Boulevard Poissonnière.