THE EFFECT OF STATIC EFFORT ON BLOOD DISTRIBUTION IN A HEALTHY HUMAN SUBJECT

R. A. Shabunin

From the Department of Normal Physiology (Head — Professor N. K. Vereshchagin) Sverdlovsk Medical Institute

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A great many reports have been made of plethysmographic determinations of blood distribution during muscular work.

Weber [7, 8] has proposed that the functional condition of the cardiovascular system can be determined by making plethysmographic measurements on the limbs when performing measured amounts of muscular work by flexing and extending the foot. He reports that in a healthy subject there is a rise in the curve ("positive" plethysmogram) during such work on account of a dilatation of the vessels. When fatigue sets in, the vascular reaction changes, so that the vessels now contract ("negative" plethysmogram). According to him, a change in this curve following a work period of 10-15 seconds indicates a defect in the cardiovascular system.

However, this method has not been brought into general use, because the "negative" has been found to occur sometimes during work by healthy subjects not leading to fatigue [6, 9]. Even Weber himself has shown that in very nervous subjects, a negative plethysmogram may occur during muscular work. All the same, most investigators consider that dynamic work leads to dilatation of the blood vessels [1, 2, 4, 7, 8].

Comparatively little attention has been paid to the distribution of the blood during static effort.. Recordings of the tension developed by clenching the first with maximum force for 3 minutes [5] showed three kinds of curves: of these, 93 plethysmograms (82%) belonged to the first type. After the tension had developed, there was a constriction of the blood vessels lasting for 30-60 seconds, and subsequently the curve rose, showing the vessels had dilated.

A. G. Zima [3] showed that when the rubber bulb of a manometer was compressed by hand, at the beginning of the static effort there was a contraction of the vessels of the opposite forearm. As fatigue developed, and long before the end of the effort, the curve gradually rose, in some cases returning to its initial level. It must be noted that the rise in the curve, corresponding to a dilatation of the vessels, begins essentially after the end of the static work. When a dumbbell was held in one hand, and static work was carried out by the opposite leg bent at the knee joint; even at the onset of the work, a considerable dilatation of the vessels was observed. Unfortunately, Zima gave no value for the static effort or for the number of experiments carried out.

In static work by the muscles of the forearm, the dilatation of the vessels of the opposite arm does not occur during the working period, but after it. However, after many repetitions, the onset of the dilatation shifts until it occurs at the onset of the work, just as in dynamic work [1].

We have studied alterations of the plethysmogram occurring during different degrees of static effort involving both small and large groups of skeletal muscles.

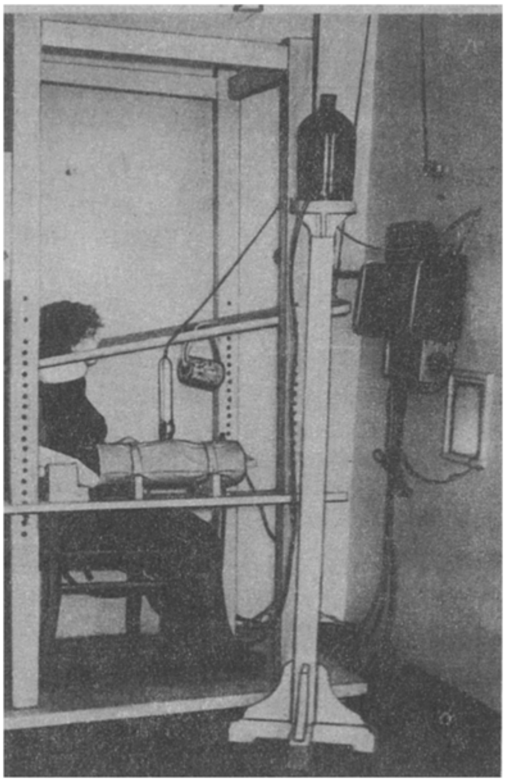

Fig. 1. General view of the stand for studying the vascular reaction during static effort.

METHOD

The investigations were carried out using a Mosso-Novitskii plethysmograph applied to the arm. The plethysmogram of the right arm was recorded to show the response to static effort of different groups of muscles. In some experiments, the pneumogram was recorded simultaneously. The subjects were placed in either the sitting or the standing position, and carried a load equal to one third, one half, or the whole of the body weight; with their left hand they compressed the rubber bulb of a mercury manometer with a force equal to 1/6, 1/4, 1/3, or 1/2 of the maximal effort and maintained the pressure until their strength gave out. Also, another set of observations was made in which a maximum effort was made with the flexors of the foot.

In order to record the plethysmogram with the subject in different positions, and for the experimenter to be able to increase or decrease the load from his own separate room, the subject was placed in a specially constructed stand (Fig. 1). This arrangement enabled external stimuli to be eliminated.

In the first tests, the subjects learned to maintain a fixed body position, and recordings were made of the so-called "zero" plethysmogram, which served as base line.

The verbal announcement by the experimenter that the work was to begin was by itself sufficient to cause a reaction in which the blood vessels contracted. To eliminate this verbal stimulus, the subject pressed the rubber bulb of the mercury manometer without any signal being given 2-3 minutes after the onset of recording the plethysmogram, and raised the mercury column to the required height. When this was done, the electrical circuit was closed, thereby recording the onset of the static work. As soon as the subject ended the work, and the mercury column fell, the contact broke and the end of the working period was recorded.

In the first observations with a load, it was found that the actual procedure of placing the weight on the shoulders was itself a powerful stimulus. Many of the subjects became agitated at this moment. We therefore caused an extinction of this vascular reaction to placing a load on the shoulders.

Twenty-five medical students aged 19-20 years were used as subjects, and 205 plethysmograms showing the response to static effort were made.

RESULTS

Static contraction of a large group of muscles (carrying various load on the shoulders) causes a dilatation of the arm vessels.

With a moderate load, in which the subjects held a load equal to half the body weight on the shoulders, out of 59 subjects, in 53 a dilatation of the vessels occurred at the onset of the effort, and was maintained during the whole of the muscular contraction period. Usually, the greatest dilatation was observed in the first 3-4 minutes after the load had been applied. When the static effort ceased, the vessels gradually returned to their normal size (Fig. 2). In 5 subjects, there was no vascular reaction to the load, and in 1, there was a biphasic plethysmogram in which at the onset of the effort the vessels contracted and then later dilated.

When repeated tests were made with the load, in some subjects, merely being placed in the special stand caused approximately the same reaction as did carrying the load. The dilatation of the vessels before the static

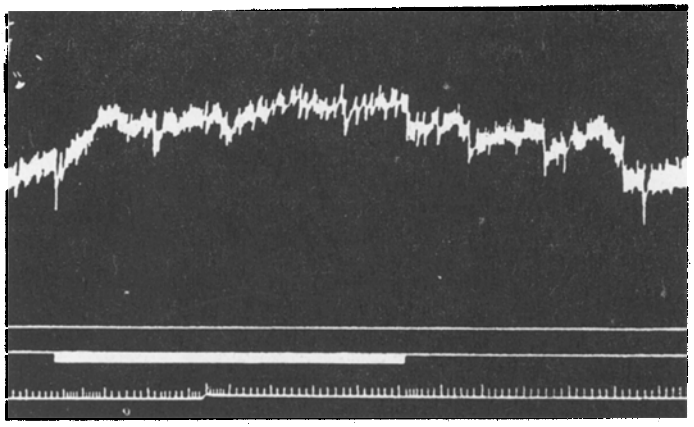

Fig. 2. Changes in the plethysmogram during the carrying of a load equal to half the body weight on the shoulders. Curves, from above downwards: plethysmogram ; base line; application of static load; time marker (10 seconds).

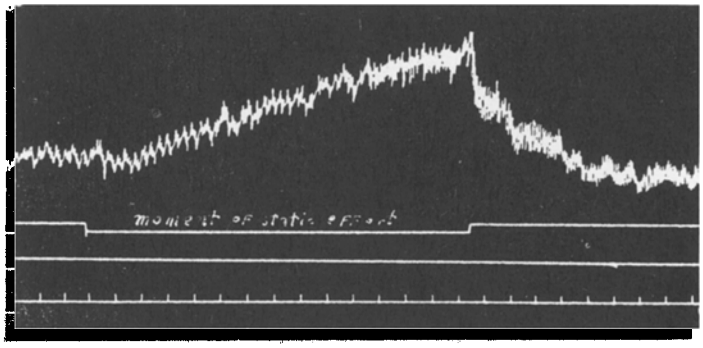

Fig. 3. Changes in the plethysmogram following a squeezing movement with the hand recorded by a mercury dynamometer; $\frac{1}{3}$ maximal effort. Curves as in Fig. 2.

effort was considerable, and after the application of the load, the additional dilatation was not great. We are inclined to interpret this reaction as a conditioned reflex developed by association with the experimental setup. This view is confirmed by the fact that besides this reaction which occurred before the work began, there was also an increase in the heart rate of 6-12 beats per minute. This phenomenon is clearly similar to that found in athletes before the beginning of an event.

With large loads up to two thirds of the body weight, the change in the size of the vessels is the same as for a medium load, i.e., the vessels dilate, but the change is more marked.

When the bulb is squeezed with one third of the maximal effort, in 22 out of the 30 trials, there was a dilatation of the vessels of the arm. The reaction occurred either immediately after the static effort, or 15-40 seconds afterwards (Fig. 3). The greatest vascular dilatation occurred during the second half of the muscular effort, and the plethysmogram reached its peak before the end of the work. Releasing the muscular tension caused a marked drop in the curve, and within the first minute it returned to the base line. In 8 tests there was either a constriction of the blood vessels or else a biphasic plethysmogram trace was obtained.

When half the maximal effort was applied to the dynamometer, in 33 out of 41 cases, the typical vascular dilatation was observed. When the reaction did not occur immediately, the delay was less than in cases when one third of the maximun effort was exerted, the time interval being usually 5-25 seconds. The extent of the dilatation was greater and developed more rapidly. Only 2 cases of vascular constriction occurring were observed. Six biphasic curves were obtained in which the line first fell, and then rose.

When one quarter of the maximum force was exerted, at first there was no reaction of the vessels, and then a gradual dilatation occurred. With a still smaller static effort of one sixth of the maximal value, change in the blood volume of the hand was negligible, though even here there was some slight dilatation.

Just as when a load was carried on the shoulders, when muscular tension was developed by a small group of muscles, in this case the flexors of the hand, using one third or one-half the maximal tension, in some cases a conditioned reflex dilatation occurred before the effort was made.

When maximal compression of the bulb was maintained by the foot for 3-5 minutes, usually a biphasic curve was obtained in which there was first a constriction and then a dilatation of the blood vessels.

Thus, the results of these observations show that different static efforts by both large and small muscle groups usually lead to a dilatation of the arm vessels. This dilatation begins either immediately or shortly after the effort is started. When the flexors of the foot exert their maximal effort, the vascular reaction is biphasic. Such a response is evidently associated with the fact that when making a maximum effort, there is a marked excitation of the sympathetic system. With smaller static efforts, this sympathetic effect does not usually occur.

Evidently, such factors as the condition of the subject and the excitability of his cardiovascular system, as well as the conditions under which the test is carried out, have an influence on the result. Thus, for instance, we found that if the task was carried out while the subject was in an excited condition, either before or after an examination, either there was no vascular reaction, or else the vessels contracted.

The atypical vascular reaction to static effort, which may take the form simply of a contraction or else of a contraction followed by a dilatation, is found chiefly in excitable subjects. Tests have shown that in these subjects there was a preponderance of excitatory over inhibitory processes. Usually, the atypical reaction appeared only during the first few performances with a static load, and later the usual dilatation reaction developed. It must be pointed out that in excitable subjects the vascular constriction occurred not only when working with static loads, but also during work involving muscular movements, such as rhythmically squeezing the dynamometer.

When using the plethysmograph, it is important to realize that every new stimulus induces the usual vascular constriction which is a component of the orienting reaction. Therefore, before studying the plethysmographic changes due to muscular work, prelimiray experiments must be made in order to extinguish any effect which may result from the experimental setup on the vessels and to establish the base line for the plethysmogram.

It might be thought that the actual work itself could constitute a new stimulus, and might induce a vascular reaction as a component of the orienting response. Therefore, before the main observations are made, the subject must become familiar with the kind of effort which he will have to carry out. Some such experience of the work to be done is absolutely necessary. This view is borne out by some observations we made on 9 subjects who had never worked with a plethysmograph before, and had never used a dynamometer statically. It was typical, that in 5 of these inexperienced persons, when exerting one-half the maximal effort, an atypical reaction was obtained in which either there was a vascular constriction or a biphasic response. During this reaction, in two cases a change in the breathing rate during the exertion of the effort evidently influenced the result. A record of the pneumogram from the upper region of the abdomen showed that in these experiments there was a disturbance of the respiratory movements and that a considerable tension was developed.

The variation in the results obtained by different workers on the effects of a static effort, may be, to a large extent, due to different methods of investigation.

Atypical vascular reactions must not be interpreted as indicating any abnormality of the vasomotor center, since they are evidently associated in healthy subjects with individual characteristics of the nervous system.

In static work, we never found there was a change from a positive to a negative plethysmogram. On the contrary, when the effort ended, when fatigue was at its maximum, there was a maximum increase in blood volume. The response of the vessels to a steadily maintained tension of the muscles depends primarily upon reflex effects; the conditioned reflex dilatation which occurs before work is commenced serves as an example of how the human organism prepares itself for muscular work which is about to be undertaken. It must, however, be realized that humoral factors are also concerned in these vascular changes. In certain cases we found that at the start of the work, there was no reaction, and the change in the blood vessels occurred only after the muscular tension had been maintained for 10-40 seconds.

Our investigations have shown that changes in the blood volume of a limb whose muscles are maintaining a steady tension are in the same direction as those which occur when changes in muscle length occur and external work is done.

SUMMARY

Static efforts of various strength, developed by small and large groups of skeletal muscles, provoke vascular dilatation in the hand; it starts directly or some time after the commencement of the effort. With the maximal static effort the vascular reaction was found to be biphasic: the vessels being first constricted and then dilated. Atypical reactions of the vessels in static efforts are revealed mainly in the excitable subjects during the first observation. The reaction of the vessels in static efforts depends mainly on the reflex influences. In a number of cases conditioned reflex dilatation of the vessels was observed. Humoral factors apparently are also involved in the vascular reaction.

LITERATURE CITED

[1] D. A. Il'inskii, Theses and Reports at the Plenary Session of the Section for Studying Problems of Pavlovian Physiology as Applied to Physical Training.* (Leningrad, 1952).

[2] L. A. Isaakyan, Byull. éksptl. biol. i med. 4(10), 6-10 (1953).

[3] A. G. Zima, Transactions of the Department of Physiology of the Kazakh Institute of Physical Culture,* Alma-Ata. 138-140 (1955).

[4] B. A. Kogan and I. N. Rogovskii, Vrach. delo. 24, 1988-1994 (1926).

[5] M. A. Men'shchikova, Fiziol. zhurn. SSSR. 24, 5, 896-900 (1938).

[6] B. P. Titov and A. A. Levin, Mediko-biol. zhurn. 6, 38-49 (1927).

[7] E. Weber, Arch. Physiol. 290-304 (Leipzig, 1914).

[8] E. Weber, Ztschr. exper. Path. u. Therap. Bd. 18, S. 325 (1916).

[9] G. Grill, Scandinav. arch. physiol. Bd. 67, S. 1-35 (1934).

* In Russian.