THE MEASUREMENT OF MUSCULAR STRENGTH

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The purpose of this paper is to describe the measurement of strength and to indicate its possible application to weight training and weight lifting.

The tension developed in the tendon of a muscle is a function of the number of active motor units and their individual capacities to develop tension. Therefore strength is determined by the capacity to recruit into activity the maximal number of motor units of given strengths.

Normally this capacity cannot be determined at the tendon of the muscle and therefore it is measured indirectly by the application of muscular force to an external measuring device. Dynamic application of force is affected by change in length of the muscle, speed of movement, acceleration due to gravity, mass and inertia of moving parts and numerous other factors. Therefore strength is usually measured under static condition (known as isometric strength) although this in turn is affected by three major factors.

First, Clarke (1966), has shown that changes in posture affect the magnitude of external force developed isometrically.

Secondly, Hood & Forward (1965), demonstrated that familiarity of the subject with the testing position produces apparent increases in strength in the absence of a training programme.

Finally, Ikai & Steinhaus (1961), showed that various forms of external motivation can either increase or decrease strength dramatically. However, if these three variables can be controlled, reliable measurements of strength can be made.

From the point of view of weight lifters, strength is measured by the poundages lifted using relatively complicated techniques. Thus measurements of isometric strength may not be readily accepted. A compromise may be reached by measuring strength in terms of weight lifted in isolated positions to assess the capabilities of a particular region of the body. However, static measurement of strength is the least liable to error.

I would suggest that four major reasons for including the measurement of isometric strength in training programmes for weight lifters are as follows.

1. It is often desirable to assess the position of the weakest point in the range of an isolated movement. This position is related to changes in both the mechanical advantage of the joint and the tension which a muscle can exert at different lengths. It is also related to the direction of the resisting force which is almost wholly vertically downwards in weight lifting. The position of the weak point may vary slightly between lifters but recognition of its position will help any one lifter to determine at what point adjustment of associated structures may occur. These adjustments enable the weak point to be passed as quickly as possible. An example of this is during an Olympic Press. When the weak point is reached during elbow extension the shoulders drop slightly to allow the elbow joint to extend past the weak point.
2. It would seem desirable to assess the effect of training upon muscular strength while keeping the effects of skill learning to minimal levels. This assumes that the individual is familiar with the testing position.
3. The testing of strength is, by its nature, a form of training and can therefore provide variety in training. Assuming that isometric strength increases, it is likely that the lifter will be motivated to train knowing that his training is useful.
4. It is possible to assess the relative strengths of different parts of the body which are functionally related in a given movement. Injuries may occur when one region is too weak to sustain stress imposed by the action of other regions. Referring once again to the Olympic Press, when the shoulders drop, their movement must be arrested by the action of Rectus Abdominis. This action throws considerable load upon the muscle and it may result in injury if its strength is insufficient to bear the load.

Of the numerous techniques available for measuring strength, all are designed to minimise the effects of skill, thus resulting in valid and reliable indications of strength. Instruments vary from cable tensiometers, where the tension developed in a cable is displayed on a dial, to strain-gauge dynamometers, where the output of electrical current is changed by applying force, the change being displayed on a suitable recording device.

I feel that I can best illustrate techniques used in the measurement of strength, and the type of information which may be gained by describing an experiment which was performed by Chapman & Troup (1969).

Fig. 1. A lateral view of the subject in the apparatus and in the posture used for training and measuring the strength of the pull.

Thirteen normal healthy male medical students exerted horizontal forces manually on the handles of a dynamometer as shown. The apparatus was adjustable in two dimensions to allow accurate reproduction of posture from day to day. The force applied was displayed on a galvanometer as shown in Fig. 2 and the dynamometer was calibrated in the position shown in Fig. 3. Training and testing occurred in the same posture.

Fig. 2. The arrangement of the galvanometer (centre) and the dynamometer (right).

Fig. 3. The dynamometer in the horizontal position used for calibration with a tray, loaded with weights, suspended from the point of attachment of the handle.

On the first day of testing each subject performed three pulls, the greatest of which was recorded as the individual maximal voluntary contraction (Table 1). They did not attend for a period of two weeks and then underwent submaximal training, designated as Phase I; twice daily for 5 days. They rested for a further period of two days and then underwent maximal training, Phase II, performing three maximal efforts twice daily for a total of nine days.

For the purpose of Phase I submaximal training subjects were divided into two groups (Table 2). Group A, comprising five subjects, performed pulls of 10 second duration at 10%, 20% and 30% of their individual maxima the series being repeated five times per session, two sessions per day. Group B, comprising eight subjects, sustained pulls at 30% of individual maxima for four minutes twice daily.

<u>Table 1</u>	
<u>Training</u>	
<u>Day 1</u>	Record maximal pulling force.
<u>Days 15 - 19</u>	PHASE 1 - Submaximal Training 2 x daily.
<u>Days 22 - 26</u> <u>29 - 32</u>	PHASE 2 - Maximal Training 2 x daily.

<u>Table 2</u>	
<u>Phase 1 - Submaximal Training</u>	
<u>Day 15 - 19</u>	
<u>Group A (5 subjects)</u>	
	10 sec. pulls at 10%, 20% and 30% of maxima repeated 5 x per session, 2 x daily.
<u>Group B (6 subjects)</u>	
	Pull of 30% of maximum sustained for 4 minutes, 2 x daily.

After Phase I submaximal training there was an increase in strength of 7.2% for group A and 7.4% for group B. After Phase II maximal training a further increase in strength of 7% was obtained for combined groups, only one subject showing no increase.

In a study performed under similar conditions by Troup & Chapman (1967), a mean increase in strength of 3.5% was obtained in 24 subjects after an interval of not less than two weeks. Ten of the 24 pulled less strongly on the second occasion and no training programme was given.

This work indicates that an increase in strength of approximately 7.0% obtained in the present study could not have occurred by chance and can probably be attributed to the training programme in Phase I. During training it is likely that subjects learned to recruit into activity more motor units in a maximal contraction due to their familiarity with the testing position. For it is unlikely that training of this intensity could have led to physiological increases in strength of individual muscle fibres of as much as 7.0%

The further increase in strength attributable to Phase II of training may have been the result of a combination of further learning to apply force in the position and a physiological increase in the strength of muscle fibres. This work forms part of a paper by Chapman & Troup (1969) in which the topic is discussed in more detail and further evidence is given to substantiate these conclusions. However, the results do illustrate the need for complete familiarization of the subject with the apparatus whenever strength is tested in order to ensure that some component of skill is not being included.

Information gained from testing lifters either in this posture or modifications of it may be used to advantage in the context of a particular phase of weight lifting. That which I have chosen is the 'clean' which involves pulling a bar vertically from a semi-squatting position as shown in Fig. 4.

Fig. 4. The vertical movement of shoulder and hip joints with respect to time, the point (0, 0) being the first recorded frame after the load left the floor.

Any individual who has experienced a deep knee bend with weights knows that there is a weakest point during extension of the knee. On getting past this point further extension is comparatively easy. When 'cleaning' a bar considerable extension of the knees is required during the pulling phase. Thus it is likely that the knees will extend rapidly in order to pass the weakest point as soon as possible. Fig. 4. shows the vertical movements of shoulders and hips during a clean and it can be seen that as the weight leaves the ground the hips move upwards faster than the shoulders. This manoeuvre is the result of early extension of the knees to increase the force of extension and to enable the bar to pass the knees while maintaining a vertical path. Whatever the most important of these reasons the effect is to increase the angle of the trunk to the vertical.

Great load is put upon the structures of the lower back which produce extension of the spine. Thus there is a possible danger in this movement and it is directly opposed to that which one would prescribe in normal daily lifting situations. An exaggerated form of this technique is shown in Fig. 5 which is a lifting position in which injuries occur frequently.

Fig. 5. A stooping lift.

It is unlikely that the normal cleaning technique will change because, by its use, greater loads can be cleaned than with the safer lift keeping the trunk upright. Furthermore, in my experience strong, accomplished lifters do not appear to suffer low back disorders as a result of this technique. Its dangers apply mainly to novices in two ways. First, if they are taught this method of lifting they may throw considerable load on to the structures of the back which are unused to bearing such loads. This may be magnified in their attempt to increase poundages rapidly. Secondly, if left to their own devices, they are likely to perform the same manoeuvre as it enables the bar to pass the knees more easily. In either case it is the lower back which will suffer.

This problem may be overcome initially either by training legs and back separately or by using dumbbells for heavy lifting training. The latter overcomes the problem of passing the knees with the bar. The problem that remains is when to start the acceptable cleaning techniques as this is what lifters are aiming for. The results of testing the strength of legs and back of experienced lifters would yield a quantitative relationship between their relative strengths. This would obviously vary between lifters, but it would provide guide lines for determining the readiness of a novice to participate in the present cleaning technique. I suggest that measurement of strength should also be included to obtain the additional advantages outlined earlier in this paper.

The cable tensiometer which can be used for testing strength is relatively inexpensive and with modifications I suggest that it would prove to be a valuable addition to a weight lifting gymnasium. With suitable instruments and techniques of measurement information could be gained which is applicable to most weight lifting situations.

Tests could be designed with a little thought and the results obtained would possibly reduce the risk to those youngsters beginning weight lifting.

References

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