Scand J Rehab Med 2: 149–153, 1970

BACK MUSCLE STRENGTH AND BODY WEIGHT AS LIMITING FACTORS FOR WORK IN THE STANDING SLIGHTLY-STOOPED POSITION

K. Jørgensen

From the Danish National Association for Infantile Paralysis, Copenhagen, Denmark

ABSTRACT. A formula for the prediction of necessary strength of back muscles for work in a standing slightly-stooped position has been developed from the tension -time curve of Rohmert (6) and calculations of the location of the center of gravity of various body segments. In order to maintain the stooped position, it was found that the maximum isometric strength of the back muscles (IS), measured at shoulder height, should exceed 93% of the body weight (w). This predictive relation was tested on 65 rehabilitees engaged in work in a standing, stooped position. In the subjects both IS in a backward pull at the level of the shoulder line and the body weight were measured. The reported pain and/or fatigue during the work was also recorded. The results did not satisfy the relation IS > 0.93 w: 78% of the persons with IS less than 0.93 w could maintain work in a standing, stooped posture without pain and/or fatigue in the back. To elucidate the discrepancy between the predictive formula and the experimental findings the tension-time curve for the back muscles was investigated in 10 highly motivated young students. It was found that even subjects with the lowest endurance time could maintain a 20% load "indefinitely" (Rohmert (6) found 15%). The consequence of those findings was that the predictive formula was changed to IS > 2/3 w. That means that to maintain a stooped position during a work day, the maximum isometric strength of the back muscles must exceed 2/3 of the body weight. Rehabilitees with an IS larger than 2/3 w hardly ever showed pain and/or fatigue during a day's work. Of those with IS < 2/3 w, a large percentage (about 45%) did so.

In most industrialized countries back muscle insufficiency is a very common handicap. Approximately 30% of all physically handicapped in Denmark complain of back-insufficiency (1). In the work assessment department of this institute we find nearly the same percentage of insufficient backs among the patients referred to us from the rehabilitation offices. In spite of the industrial development, many jobs will continue to be carried out in the standing position. It is well known that the back muscles are very important as antigravitational muscles. These muscles show activity especially if the standing work is performed in a stooped position. It must be assumed that a certain strength in the back muscles is necessary to avoid pain and feeling of fatigue in the standing, stooped position. The minimum strength necessary for the back muscles must among other things depend on the weight of the trunk.

The purposes of the present investigation were to develop a simple predictive expression for adequate back strength, if a standing and stooped work position must be endured during a whole workday and, further, to test the validity of such an expression on a group of clients in our work assessment department.

From the theoretical point of view, one would assume that the minimum strength in the back muscles required to endure a standing work position without fatigue would vary with the body weight. The man shown in Fig. 1 is standing in a forward-stooped (20°) position with the arms hanging free. His proportions are in agreement with the average values published by Dempster (4). The range of Dempster's values on 8 male cadavers is given after the means. This means that the collective weight of the head, neck, and trunk is 56.5% (52.1%–61.1%), and the weight of the arms 9.7% (8.6%–11.0%) of the total body weight. The center of gravity of these segments is calculated to be located in the median plane about 2.6 cm in front of a line, l, connecting the midpoints of the ilio-sacral joint and the shoulderline and situated at about 60% of l from the ilio-sacral joint. The gravitational pull on the head, trunk, and arms (P) is the body weight (w) multiplied by $(56.5+9.7)/100$. In other words P

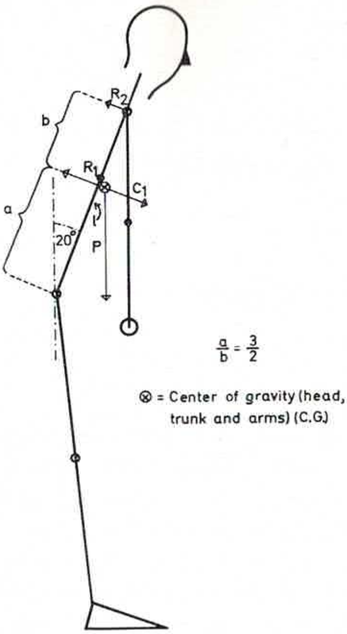

Fig. 1. Schematic drawing of forces acting on a man in a standing slightly-stooped position. *l*, line connecting ilio-sacral joint and shoulder line; *P*, pull of gravity: C_1, *P*'s composant at right angle to *l*; R_1 the resultant of the back muscle force counteracting C_1; R_2, R_1 transferred to shoulderline level.

$= w \times 0.66$. The force *P* can be resolved in 2 components, C_1 at a right angle to *l*, and C_2 (not drawn in the fig.) in parallel to *l*. For a 20° inclination of the trunk in respect to the vertical, C_1 is $P \times \sin 20° = w \times 0.66 \times \sin 20°$. C_1 will tend to bend the back but is counter-balanced by R_1, the resultant of the back muscle forces at this level.

With the resultant force of the back muscles at the level of the shoulder line (i. e. at the level where the maximum isometric pull of the back muscles is measured in the test procedure) equal to R_2 and the fulcrum located at the ilio-sacral joint, we then find:

$R_2 \times 100 = R_1 \times 60$; $R_2 = w \times 0.66 \times \sin 20° \times 0.6$; and $R_2 = w \times 0.13$. The pull of the back muscles, measured at shoulder level, should accordingly be 13% of the body weight in order to counterbalance the pull of gravity in this position.

Rohmert (6) reported that a static muscle contraction producing less than 15% of the maximum isometric strength of the muscle could be maintained "indefinitely". If this statement were correct, R_2 must not exceed 15% of the maximum isometric strength of the back muscles (*IS*), that is $R_2 = y \times 0.13 < IS \times 15/100$ and, therefore, $IS > w \times 0.93$. In other words, in order to maintain the stooped position like that in Fig. 1, the isometric strength of the back muscles, measured at shoulder height, should exceed 93% of the body weight.

In order to test this predictive relation, a group of clients in the work assessment department was investigated.

METHOD

The subjects investigated ($n = 65$, average age 29.1 years) were rehabilitees who had been tested in a standing slightly-stooped work position in the workshop of the institute (e. g. wood-work, lathe-work etc.) within the previous 2 years (1966–1968). Only one of the rehabilitees was a female, the reason for this probably being that female labour in industry rarely is performed in a standing position. According to the diagnoses, back pains could be expected in approximately 33% of the subjects. To avoid bias, neither the patients nor the staff were informed of the project. All the rehabilitees were observed frequently during the work day and in daily reports from the staff an account was given of the patients' troubles together with other important observations.

The administration of a number of physiological tests is part of the work assessment. Among these, the maximum isometric muscle strength of the back muscles is measured. The maximum isometric back muscle strength is measured with the subject in the standing position and the pelvis fixated against a plate. A strap around the shoulders is connected to a strain gauge dynamometer. The maximum backward pull of the trunk is then registered on a recording potentiometer (2, 3).

RESULTS AND DISCUSSION

Corresponding values of body weight and maximum isometric back muscle strength have been plotted against one another in Fig. 2. Data from persons complaining of back pain and/or fatigue during the work day have been marked with a cross. It appears that subjects with strong back muscles hardly ever have complaints and/or feel fatigue. Subjects complaining of back problems are mainly found among those with a much reduced strength in the back. A total of 36 subjects had more than 50 kp strength in the back. Only one of the persons in this group (mb. Scheuermann) had back pains. On the other hand 41% of the 29 subjects with less than 50 kp back

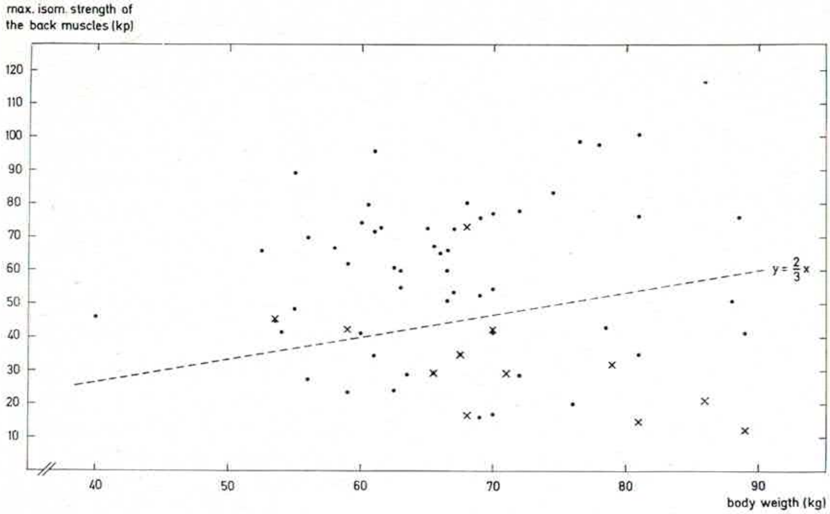

Fig. 2. Max. isometric strength of the back muscles (kp) vs. body weight (kg). The crosses indicate subjects with pain and/or fatigue in the back following work in the standing, stooped position.

strength complained of pain and/or fatigue during the work day.

According to the diagnoses, 23 of the subjects had one or more diseases of the back (e. g. spondylosis dorsalis, deg. disci i. v. lumbalis, kyphosis Scheuermann, kyphoscoliosis dorso-lumbalis m. gr.). It was further found that approximately 50% of these real back cases could mobilize more than 50 kp in the back muscles. These results might indicate that a good muscle strength in the back can prevent pain and fatigue during standing work, even in persons with verified back disease.

The demand, that *IS* must surpass 0.93 *w* is, however, not verified by the experimental findings in Fig. 2: It was found that 78% of the subjects with back muscle strength less than $w \times 0.93$ showed no fatigue or pain during work in a standing slightly-stooped position. The reason for this could be that the endurance time for static work of the back muscles actually is longer than found by Rohmert (6). In experiments on the elbow flexors, Molbech & Johansen (5) found that the endurance time for a certain relative load was longer than that given by Rohmert (6). From a teleological point of view one might expect that the antigravitational muscles (e. g. the back muscles) have a relatively long endurance time for a given relative load, and that more than 15% of the maximum isometric strength can be maintained "indefinitely". The position of the tension-time curve was consequently re-investigated with special reference to back muscles in a group of young normal subjects.

Tension-time curve of the back muscles

A total of 80 isometric endurance time experiments was performed on the back muscles in 10

Table I. *Parameters of 10 normal subjects. Col. 7 is the mean, max. isometric strength of the back muscles in per cent of normal standards (Asmussen & Heebøll-Nielsen (3))*

Subject (1)	Sex (2)	Age (years) (3)	Height (cm) (4)	n (5)	Average max. isometric strength ± 1 S.D. (kp) (6)	(6) in % of normal standard (7)
I. N	♂	38.2	192.0	10	72.5±9.2	66.8
K. J.	♂	31.9	176.0	10	75.8±8.5	84.0
J. M.	♂	31.7	169.5	4	73.5±8.0	87.6
N. W.	♂	23.9	174.0	6	97.5±7.1	114.9
F. R.	♂	25.3	178.5	4	98.5±4.4	108.1
E. P.	♀	46.5	168.5	8	50.5±3.1	86.1
B. D.	♀	30.5	169.5	7	39.1±2.5	63.0
C. S.	♀	22.5	156.5	7	50.9±1.5	98.3
L. S.	♀	23.6	165.0	4	70.8±2.9	122.8
A. K.	♀	26.4	169.0	4	63.5±2.7	103.5

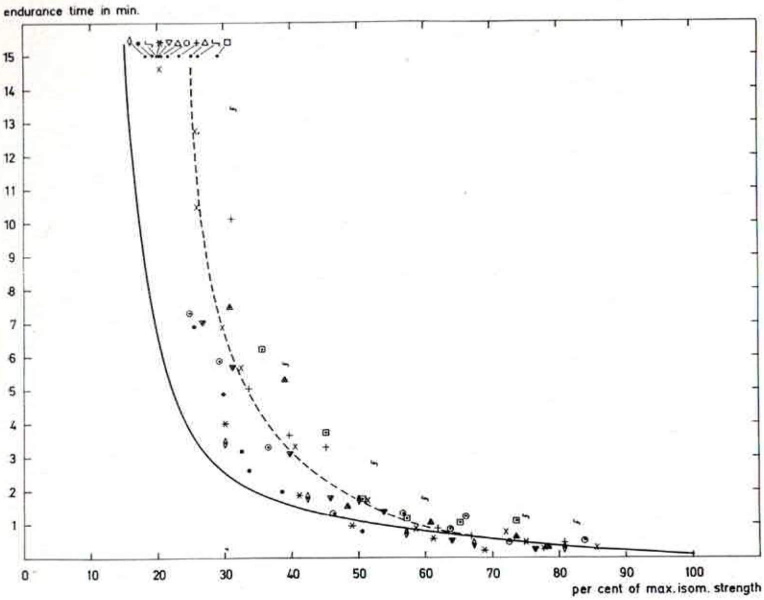

Fig. 3. Dashed line: tension-time curve drawn by eye for the back muscles in 10 normal subjects. Solid line: tension-time curve as given by Rohmert (1960). Plots at 15 min indicate "indefinite" endurance time.

highly motivated young subjects. The data of the subjects appear in Table I.

The body position as well as the dynamometer and registering device have been described above. Endurance time was defined as the maximum time a given static load could be maintained. If endurance time exceeded 15 min, it was considered indefinite. At the beginning of each test the maximum isometric strength of the back muscles was measured. Three measurements were made during each test and the best of the three was used as the maximum isometric strength for that test day. Normally only two endurance time experiments with different loads were performed per day with at least a 20 min interval to avoid the effect of fatigue.

A given relative load was calculated from the maximum isometric strength and marked on the registering paper of the potentiometer writer. Then the dynamometer was engaged by the subject up to the given load in a backward directed pull. During the experiments the subject could observe the potentiometer writer and was requested to control that the pull was constant until complete exhaustion of the back muscles. If the subject performed visible trick movements, the results of the experiment were discarded.

The results of the endurance time experiments are shown in Fig. 3. The dashed line, drawn by eye, is the tension-time curve best fitting the points of the experiments. It can be seen that even the subjects with the lowest endurance time can maintain a 20% load "indefinitely".

It should consequently be possible to perform work in the standing slightly-stooped position without fatique to the back muscles if the following relation is fulfilled:

$IS \times 20/100 = w \times 0.13$ and, therefore, $IS > 2/3\ w$.

The line representing $IS = 2/3\ w$ has been drawn in Fig. 2 as $y = 2/3\ x$.

This prediction is valid only for a body angle of 20° with the unloaded arms hanging vertically down. If the arms are loaded (e. g. by tools) and are working in a more or less outstretched position, the maximum isometric back muscle strength must be larger than $2/3 \times w$. If, on the other hand, the stooping angle is less than 20°, the maximum isometric strength required could be less than $2/3 \times w$. In Fig. 2 the line $y = 2/3\ x$ divides the 65 subjects in two groups. There are 42 subjects over the line, 3 of which had complained of pain and/or fatigue in the back during standing. Below the line are 23 subjects, of which 10 (44%) suffered pain and/or fatigue in the back. It seems that a fairly good agreement between the experimental findings and the prediction is present. In people with a normal relationship between the body segments, both as regards linear dimensions and weight, $IS > 2/3\ w$, therefore, seems to be a useful indicator for their ability to endure continuous work in a standing slightly-stooped position.

From standard height/weight curves and standard values of maximum isometric strength of the back muscles (3) it appears that the maximum isometric strength in 25-year-old normal men is about twice as big as $2/3 \times w$. Further, the calculation of $2/3 \times w$ gives lower values than normal *IS* minus 3 S.D.

In 25-year-old normal women, $2/3\ w$ is equal to about 70 % of standard *IS* and lies in the interval between *IS* minus 1 S.D. and *IS* minus 2 S.D. This means that practically all normal men and about 85–90 % of all normal women have sufficient back muscle strength to endure work in a standing slightly-stooped position.

ACKNOWLEDGEMENT

The author is indebted to Svend Fraugde, civil engineer, head of the workshop, for supplying reports on complaints of the rehabilitees during their stay in the workshop.

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Address for reprints:

Kurt Jørgensen, Scient. Ass.
The Danish National Association for Infantile Paralysis
Tuborgvej 5
DK – 2900 *Hellerup,* Denmark

Key Words: Muscle strength, endurance time, standing position, low back syndrome