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## Auteurs

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## **A submaximal test to assess back muscle capacity: Evaluation of construct validity**

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(1) back muscles, (2) strength, (3) relative endurance, (4) rehabilitation, (5) absolute endurance

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**CONFLICT OF INTEREST STATEMENT**

We state that no financial and personal relationships with other people or organizations inappropriately influenced (biased) our work.

## ABSTRACT

A *functional endurance test* more specific to common occupational tasks is proposed for assessing back muscle capacity. The test involves static intermittent contractions (8-s work-rest cycles) using a predefined absolute load (90 Nm) across subjects. Since the test involved an absolute endurance task, it was hypothesized that performance would be influenced by both the strength and relative endurance of the subjects, thus demonstrating the construct validity of this new test. Fifteen males and 17 females were assessed on three different days to allow familiarization and to measure their *Strength* as well as their absolute and relative endurance. Absolute and relative endurance were defined as the time to reach exhaustion ( $Tend_{abs}$  and  $Tend_{rel}$ , respectively) during a fatigue protocol including both an absolute (90 Nm) and a relative (40% of individual strength) load (extension moment at the L5/S1 joint). *Strength* and  $Tend_{rel}$  each explained an almost equivalent portion of  $Tend_{abs}$  (total variance explained: 61.5%), thus confirming the construct validity of the *functional endurance test*. This new test should better identify the back muscle impairments (weakness, fatigability) often observed in chronic low-back-pain patients.

## INTRODUCTION

Back pain is one of the most prevalent conditions in developed countries. The decrease in back muscle performance (strength and endurance) following a first episode of LBP, the so-called “deconditioning syndrome,” is proposed as a potential cause of recurring LBP (Mannion, 1999). An increase in back muscle strength has represented one of the main goals of rehabilitation programs in recent decades. However, only back muscle endurance (not strength) is a predictor of first-time occurrence of low-back pain (Biering-Sorensen, 1984) and is of value in predicting long-term back-related disability (Enthoven et al., 2003). It appears that strength influences back injury propensity only when it is expressed relative to task demands (relative strength) (Dempsey et al., 1997). Consequently, successful monitoring of back muscle endurance during rehabilitation might help clinicians to identify highly fatigable back muscles. It can also help to validate rehabilitation modalities programmed to reverse this lumbar impairment.

Endurance performance can be defined either by mechanical or electromyographical (EMG) criteria. In submaximal testing, one of the mechanical indices refers to the holding time of a prescribed force level, which requires a maximal effort to reach complete exhaustion. If the force is the same for all subjects, the task measures **absolute endurance**. When the force used in the test is a percentage of the maximal voluntary contraction (MVC) of a given subject (ex: 50% of MVC), **relative endurance** is measured. EMG, on the other hand, has the main advantage of containing information related to the presence of muscle fatigue even during limited-duration submaximal contractions. Thus, the use of submaximal exertion may make EMG clinically more acceptable, especially when applied to chronic LBP subjects. However, most EMG-based back muscle fatigue assessments have used a relative endurance protocol involving a sustained static effort at a high force level (Mannion et al., 1997a; Roy et al., 1997). Although this allows the phenomenon of muscle fatigue to be quickly revealed through processed EMG, it is clear that muscle endurance is evaluated under conditions that do not correspond to tasks actually performed in the workplace. These tasks usually involve intermittent contractions at a low to moderate force level. Testing the endurance of muscle fibers recruited at high force levels (60-80% of the MVC) implies near or complete occlusion of intramuscular blood flow. Conversely, testing the endurance of muscle fibers recruited at low to moderate force levels (25-60% of the MVC) causes partial and intermittent occlusion of blood flow. These task parameters involve completely different fatigue mechanisms. In fact, the physiological mechanisms implicated are very different because the energy pathways are not involved in the same proportions and the metabolic byproducts are not generated and eliminated at the same rate. There is a growing interest in applying EMG measurements to the quantification of muscle fatigue during more complex tasks performed intermittently at low to moderate intensity in order to better mimic occupational tasks (Nussbaum, 2001). Such assessment protocols would help in making inferences about muscle endurance in work situations.

In the present paper, a new *functional endurance test* (FET) is proposed. Briefly, this test involves repeated (cyclic) intermittent back extension efforts at a predefined absolute force level (absolute endurance protocol) that is applicable to all individuals (males and females, weak and strong subjects, back pain and healthy subjects). The main drawback of

such an absolute endurance measurement is its partial dependency on the MVC level (Caldwell, 1961): strong subjects maintain an absolute force level longer than weak subjects, at least when moderate to high relative force levels are involved (Start and Graham, 1964; Zatsiorsky, 1995). At first glance, this measurement approach may appear inappropriate for endurance evaluation. However, practically, it is very important to test this functional form of endurance because the same external forces and torques must be generated on the environment (tools, production devices, materials to be handled) for all individuals in many working tasks. This explains why the FET is considered “functional.” This bypasses the main limitation of relative endurance testing that requires estimating the MVC level because the measurement of MVC is flawed with patients suffering from back pain.

Previous work (Caldwell, 1961) suggests that an individual’s strength entirely determines his absolute endurance. However, it appears that more than an individual’s strength is involved. The relationship between absolute endurance and strength mainly depends on whether the circulatory occlusion threshold is exceeded or not during muscle contraction. This strength-endurance relationship is moderate to high ( $r^2$  between 0.45 and 0.77) when the complete occlusion threshold is exceeded (Caldwell, 1961; McGlynn and Murphy, 1971; Start and Graham, 1964; Tuttle et al., 1950). However, the relationship is much weaker, and even nonexistent, when this critical occlusion threshold is not reached (Start and Graham, 1964; Zatsiorsky, 1995). When a muscle contraction is above the occlusion threshold, muscle endurance depends mainly on local energy stores. In this case, endurance is inversely related to the level of contraction, and consequently, subjects using a higher proportion of their maximal strength (weaker subjects) will have less endurance than subjects using a lower proportion (stronger subjects). This explains the high relationship between absolute endurance with strength. However, with a contraction below the occlusion threshold, the efficiency of the local circulation as well as the quantity of oxidative enzymes then become determinant in generating sources of energy via aerobic energy pathways (Start and Graham, 1964). It is clear that these physiological determinants are more closely tied to relative endurance than to strength.

Considering the low to moderate relative intensity of the contraction (which depends on the subject’s strength) and the intermittent nature of the task involved in the FET, both strength and relative endurance should have an impact on performance, depending on the subjects’ muscle properties (strength, capillarity, oxidative enzymes, etc.). In other words, the FET would be expected to measure both strength and relative endurance. So far, the criterion validity, between-day reliability and construct validity (men vs women) of the corresponding EMG fatigue indices have been established (Lariviere et al., 2006; Lariviere et al., 2008a; Lariviere et al., 2008b; Lariviere et al., 2009), so no EMG results will be reported here. The purpose of the present study was to further substantiate the construct validity of the FET by verifying the relative weight of strength and relative endurance in explaining the absolute endurance of the back muscles. In other words, if the FET really measures the concept of absolute endurance, strength and relative endurance would significantly explain a complementary proportion of its variance. Consequently, it was hypothesized that the absolute endurance of back muscles is determined by both maximal strength and relative endurance.



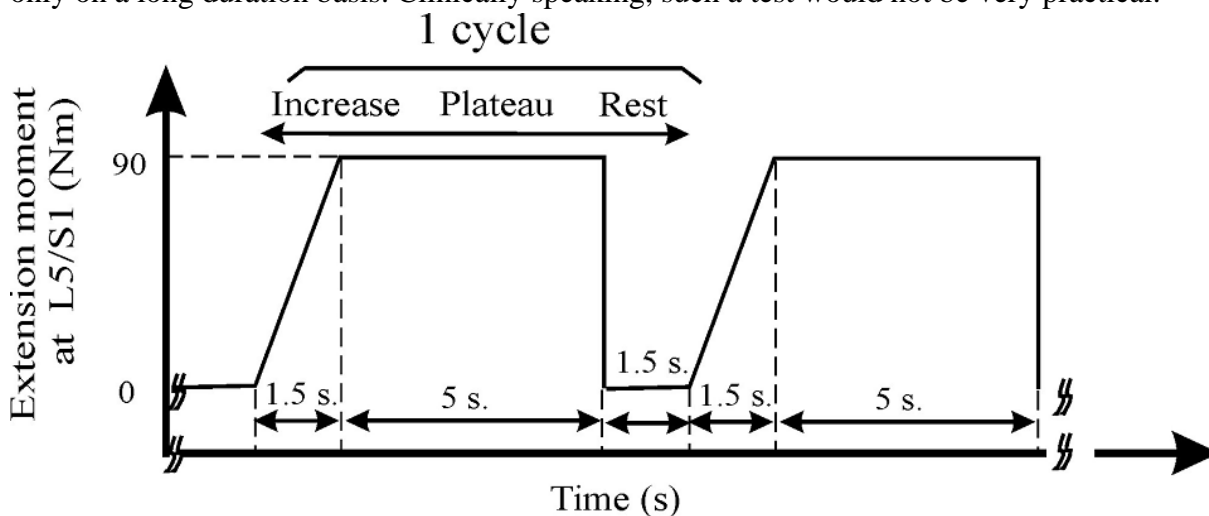
## MATERIALS AND METHODS

### *Description of the FET*

This new FET was designed to bridge the gap between the practical issues of measurement (clinical and EMG issues), the physiological phenomenon involved, and the external validity of the task performed. In this test, repeated lifting was simulated by intermittent static trunk extension efforts (Figure 1). The test consists of repeated 8-s cycles subdivided into 1.5 s of progressive rise to reach a 90-Nm absolute L5/S1 extension moment target, 5 s to sustain this force level (plateau), and 1.5 s of rest. The progressive 1.5-s increase should allow the subject to stabilize his force at 90 Nm to facilitate the acquisition of the EMG measurements that were taken during this plateau. The test lasts 5 min (37 cycles) for women and 10 min (75 cycles) for men (Lariviere et al., 2008a, Lariviere et al., 2008b) or, in some exceptional cases, until the subject fails to maintain the force target (90 Nm) for three consecutive cycles (more details below).

The 90-Nm absolute load was determined from our earlier studies (Larivière et al., 2003) to ensure that it was below the strength of the great majority of subjects (males and females, weak and strong subjects, back pain and healthy subjects). This load was comparable to the maximal limit of 80 Nm load suggested earlier (Parnianpour and Shirazi-Adl, 1999) for assessing the trunk functional capacity of LBP patients while minimizing the joint forces in the spine. According to estimations based on previous findings (Lariviere et al., 2003a), the FET would involve an average relative load of 40% MVC in a group where males and females are equal in number.

The choice of a short rest period (1.5 s) was based on various considerations. Firstly, the blood flow takes at least 1 s to allow its beneficial effects (fuelling the muscles via aerobic energy pathways, washing metabolic byproducts) to take place as shown by the increase in endurance time accompanying such intermittent contractions in comparison to sustained contractions (Bjorksten and Jonsson, 1977; Duchateau and Hainaut, 1985). Secondly, too long a rest period would allow too much recovery, especially for the highly capillarized back muscles (Jorgensen et al., 1993), leading to a test where fatigue effects would be measurable only on a long duration basis. Clinically speaking, such a test would not be very practical.



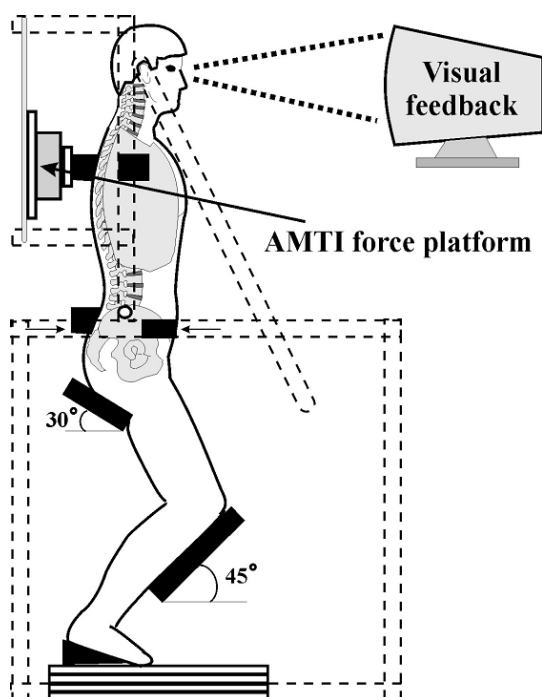
**Figure 1.** Description of one work-rest cycle (8 s) in the functional endurance test.

## *Subjects*

Thirty-two healthy subjects (15 men and 17 women between 20 and 60 years of age) were recruited on a voluntary basis from the general population (details in Table 1). Exclusion criteria were the following: back pain in the previous year or back pain lasting longer than one week in previous years, surgery on the musculoskeletal system of the trunk, known congenital malformation of the spine or scoliosis, leg length discrepancy ( $>1.5$  cm), body mass index  $> 30 \text{ kg/m}^2$  (obesity criterion), systemic - neurological - degenerative disease, history of stroke, pregnancy, one positive response to the Physical Activity Readiness Questionnaire (Thomas et al., 1992), abnormal blood pressure, family history of heart attack, medication for cholesterol or triglyceride control, claustrophobia (lumbar dynamometry assessment, see Figure 2), or involvement in a new training program. The study and consent form were approved by the ethics committee of the “Centre de Recherche Interdisciplinaire en Réadaptation du Montréal métropolitain.” The subjects were informed about the experimental protocol and potential risks and gave written consent prior to their participation.

## *Schedule of assessments and tasks*

Each subject participated in three assessments performed on three different days, approximately at the same time of the day in order to control for the effect of circadian rhythms on muscle strength measures. The first session (session 1) was used to familiarize the subject with maximal voluntary contractions (MVC) and the FET. This familiarization was necessary to control for the confounding learning effect in the generation of an MVC that should be stabilized at the second session (Lariviere et al., 2003b). The second and third sessions were conducted with a minimum of two days between sessions but no more than one week apart so that the initial learning was retained.



**Figure 2.** Back extension triaxial static dynamometer.

In each session, three to five submaximal extension exertions (about 50% of the subject's estimated maximal contraction) were done to warm up and to familiarize the participant with the device and target. This was followed by three MVCs (separated by a minimum of 2 min rest) and by the FET. Back strength (*Strength*) was defined as the peak L5/S1 extension moment among the three MVCs in session 2. To avoid spuriously high transient forces resulting from jerky exertions, the subject was asked to follow the visual feedback (initially established at 300 Nm and subsequently adjusted, but in a conservative manner, to the subject's capacity) to allow a progressive (ramp) increase in the force toward the maximum, lasting between 3 and 5 s depending on the subject's strength. The reliability of this measure (*Strength*) is good in healthy (Intra-class correlation coefficient: 0.73, standard error of measurement: 9%) and CLBP (Intra-class correlation coefficient: 0.85, standard error of measurement: 13%) subjects (Lariviere et al., 2002). The FET was performed (90 Nm for 10 min for males and females) during the familiarization session. However, it was performed until exhaustion during sessions 2 and 3 to measure the mechanical criterion of fatigue (time to exhaustion or  $Tend = 8 \text{ s} \times \text{number of cycles}$ )  $Tend_{abs}$  and  $Tend_{rel}$ .  $Tend_{abs}$  corresponds to the absolute endurance protocol (absolute load = 90 Nm) performed in session 2.  $Tend_{rel}$  corresponds to the relative endurance protocol (relative load = 40% of MVC) performed in session 3, but using the MVC strength values measured in session 2 (justification below). To avoid confusion, we reiterate that the FET is intended to be of short duration (5 and 10 min in women and men, respectively) because EMG is used to estimate back muscle fatigue, which does not necessitate reaching exhaustion. However, to validate the corresponding EMG parameters (previous studies) and to assess its construct validity (present study), the FET had to be performed until exhaustion to obtain a criterion of muscle fatigue ( $Tend_{abs}$  or  $Tend_{rel}$ ). The 40% MVC load was grossly estimated from a database of male and female subjects (see the *Description of the FET* section above) to take a relative load that corresponded (on average across the subjects) to the absolute load used in the FET (90 Nm). Such a priori estimation was necessary because knowing the average relative load (across subjects) corresponding to 90 Nm would have required carrying out the second session on all subjects. Since the sessions had to be performed not too far apart to retain initial learning, this was impossible. Fortunately, this estimation (40% MVC) was almost perfect as calculated a posteriori using the present study results (39% MVC, Table 2). Finally, session's 2 MVC value was selected, instead of session's 3 MVC value, to determine session's 3 relative load (40% MVC) to be able to correlate measures (*Strength*,  $Tend_{abs}$  and  $Tend_{rel}$ ) that correspond as much as possible to measures performed on the same day to minimize the potential effect of learning. The excellent reliability results (Intra-class correlation coefficient: 0.91, standard error of measurement: 9%) corresponding to these MVC measures (sessions 2 and 3), as reported elsewhere (Larivière et al., 2006), support this strategy.

**Table 1.** Demographic, physical characteristics, and back muscle performance (strength and endurance assessments) corresponding to the male and female samples in the study

Variable <sup>*</sup>	Males (n = 15)		Females (n = 17)		<i>P</i>	Statistical
	Mean	(SD)	Mean	(SD)		
Age (yr)	38.7	(10.4)	31.8	(9.4)	0.061	T-test
Mass (kg)	74.2	(10.0)	59.1	(7.4)	< 0.001	Mann-Whitney
Height (m)	1.72	(0.07)	1.62	(0.05)	< 0.001	T-test
% fat	21.6	(4.7)	27.1	(4.5)	0.002	T-test
Phys. activity	7.53	(1.18)	8.78	(1.94)	0.038	T-test
<i>Strength</i> (Nm)	305	(71)	200	(30)	< 0.001	Aspin-Welch
90Nm/Strength	0.31	(0.08)	0.46	(0.07)	< 0.001	T-test
<i>Tend<sub>abs</sub></i> (min)	16.3	(10.8)	11.4	(8.3)	0.093	Mann-Whitney
<i>Tend<sub>rel</sub></i> (min)	7.1	(5.2)	12.6	(6.2)	0.007	Mann-Whitney

\* % fat: percentage of body fat (Durnin and Womersley, 1974); Phys. Activity: physical activity level (Baecke et al., 1982); Strength: peak maximal voluntary contraction (session 2) expressed in Nm (L5/S1 extension moment); 90Nm/Strength: ratio of the absolute load to the strength to know the relative load imposed by the 90-Nm absolute endurance protocol on each subject; *Tend<sub>abs</sub>*: time to exhaustion corresponding to the absolute endurance test (90 Nm); *Tend<sub>rel</sub>*: time to exhaustion corresponding to the relative endurance test (40% MVC); † The statistical test was used in accordance with the normality and the equality of variances of the two samples, as assessed with the modified-Levene test.

The subjects were given strong verbal encouragement during the MVCs as well as during both endurance tests in order to delay exhaustion. During the endurance tests, exhaustion was observed as a reduction in strength performance, which was defined as the inability to generate or maintain the 90-Nm (absolute test) or 40% (relative test) plateau for three consecutive cycles. The force level was considered as inadequately maintained when the load remained below the lower bound of the target (described below) for at least 1 s. This was grossly estimated by the experimenter who reminded the subject to stay in the target for the entire 5-s plateau. In the cases where the force level was only transiently not respected once, the cycle was considered acceptable. Finally, a time limit of 60 minutes was set to stop the fatigue test because the 90-Nm load was relatively small for the stronger subjects, making the test unnecessarily long. The data of these subjects (n = 14 males and 1 female) were not used in the present study. This means that 47 subjects were assessed to obtain the present sample of 32 subjects. To ensure the subjects' safety, heart rate was continuously monitored (Polar

Electro Inc., Port Washington NY 11050, USA) to ensure that the maximal heart rate (220 beats/min minus age in years) was not exceeded.

### *Dynamometry*

A trunk dynamometer consisting of a triaxial force platform (Advanced Mechanical Technology Incorporated, model MC6-6-1000) mounted on a steel frame that allows stabilization of the feet, knees and pelvis was used (Lariviere et al., 2001). The subject was in a semi-seated position to minimize the contribution of the hip extensors and to avoid fatigue in the lower limbs (Figure 2). During each extension effort, the extension moment at L5/S1 was displayed in real time as visual feedback on a monitor positioned in front of the subject. The visual feedback consisted of a vertically moving square target with lower and upper bounds corresponding to a tolerance limit of  $\pm 10\%$  of the prescribed extension moment (absolute endurance test:  $90 \text{ Nm} \pm 9 \text{ Nm}$ ; relative endurance test:  $40 \pm 4\% \text{ MVC}$ ). The lateral bounds of the target corresponded to a tolerance limit of  $4.5 \text{ Nm}$  [corresponding to  $40\% \text{ MVC}$ , (Lariviere et al., 2001)] to control for axial rotation moments. This square target allowed the subject to respect the parameters of the FET without generating asymmetric efforts (sufficiently close to pure sagittal extension efforts). The dynamometer's signals (three forces and three moments measured on the platform and three L5/S1 moment components) were collected at a sampling rate of 128 Hz. EMG signals were also collected concomitantly (Lariviere et al., 2008a; Lariviere et al., 2008b) but were not used in the present study.

**Table 2.** Descriptive strength and endurance statistics

Variable	Mean	SD	Minimum	Maximum
<i>Strength</i> (Nm)	249	75	153	433
<i>Tend<sub>abs</sub></i> (min)	13.68	9.68	2.67	46.80
<i>Tend<sub>rel</sub></i> (min)	9.99	6.27	2.00	24.27
90Nm/ <i>Strength</i> *	0.390	0.105	0.208	0.587

\* 90Nm/*Strength*: ratio of the absolute load to individual strength

### *Data analysis and statistics*

Because the relationship between strength and both endurance measures is generally non-linear (Rohmert, 1960), *Tend<sub>abs</sub>* and *Tend<sub>rel</sub>* were logarithmically transformed (*LogTend<sub>abs</sub>* and *LogTend<sub>rel</sub>*) using the natural logarithm. This also allowed these variables to be normally distributed, as verified with the Wilk-Shapiro test (*Strength* was already normally distributed). Comparisons between males and females (demographic and physical characteristics) were performed with different tests (T-test, Mann-Whitney, Aspin-Welch) to

respect the normality and equality of the variance assumptions. Pearson correlations were calculated among the main variables of the present study (*Strength*, *LogTend<sub>abs</sub>* and *LogTend<sub>rel</sub>*). Stepwise multiple linear regression analyses were carried out with *LogTend<sub>abs</sub>* as the dependent variable and *Strength* and *LogTend<sub>rel</sub>* as the main independent variables. Additional variables (gender, age, height, mass, % fat, physical activity) that had the potential of mediating the association between the independent and the dependent variable were also considered. However, they were considered only one at a time considering our small sample size, in order to follow the “10 subjects per independent variable” rule of thumb commonly used in multiple linear regression analysis. All analyses were done with NCSS statistical software (version 6.0 for Windows), using an alpha of 0.05. for significance testing.

## RESULTS

### *Gender differences and other bivariate analyses*

The physical characteristics of the male and female subjects and their performances in the different back assessments (strength, absolute and relative endurance) are detailed in Table 1. As expected, several characteristics distinguished males from females.

The maximum heart rate reached during the fatigue tests was on average moderate during the 10-min FET at 90 Nm performed in session 1 (Mean:  $124 \pm 22$  beats/min; Min.: 89; Max.: 182). Comparable values were obtained during session 2 (Mean:  $127 \pm 17$  beats/min; Min.: 101; Max.: 164) and session 3 (Mean:  $131 \pm 19$  beats/min; Min.: 90; Max.: 179).

Peak MVCs were not significantly different ( $P = 0.156$ ) between sessions (session 1:  $242 \pm 67$  Nm; session 2:  $249 \pm 75$  Nm; session 3:  $256 \pm 84$  Nm), indicating that motor learning did not influence the subjects' strength.

There was large inter-subject variability (Table 2). Significant correlations were present between *LogTend<sub>abs</sub>* and *Strength* ( $r = 0.61$ ;  $P < 0.001$ ), between *LogTend<sub>rel</sub>* and *Strength* ( $r = -0.60$ ;  $P < 0.001$ ), but not between *LogTend<sub>abs</sub>* and *LogTend<sub>rel</sub>* ( $r = 0.05$ ;  $P = 0.772$ ).

### *Multiple regression analyses*

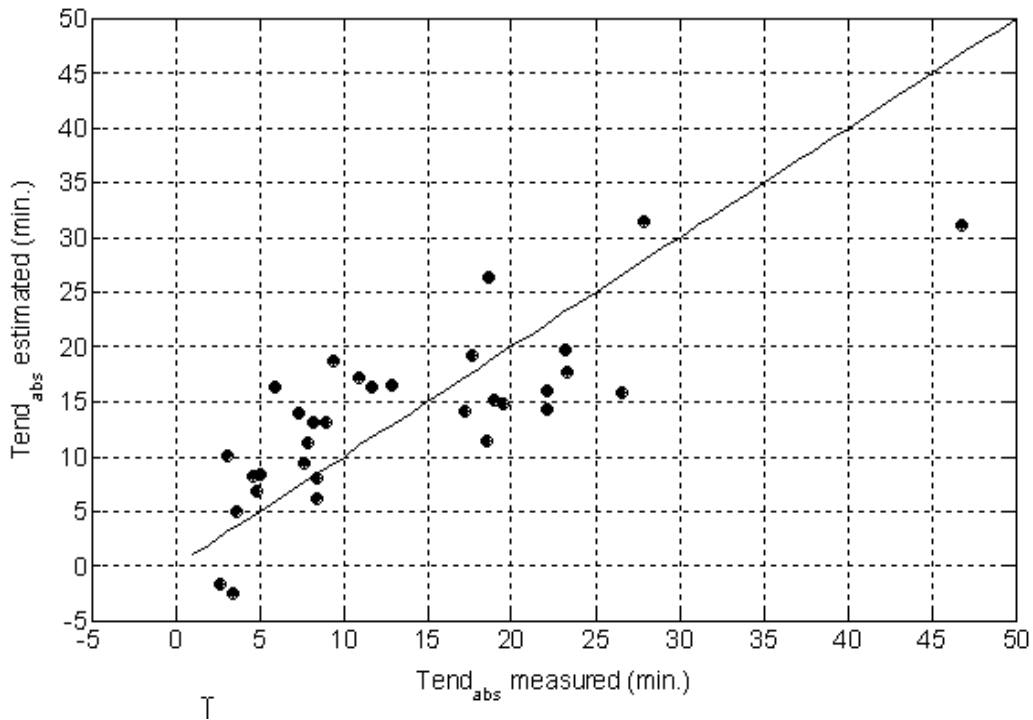
Stepwise regression analysis revealed that the variance of *LogTend<sub>abs</sub>* was explained by *Strength* (first selected variable: 34.7% of the variance) and by *LogTend<sub>rel</sub>* (second selected variable: 26.8% of the variance), totaling 61.5% of the explained variance ( $R^2$  adjusted for the number of variables included in the model = 0.615; Standard error of the estimate = 0.4561 in log(min)). The regression equation was:

$LogTend_{abs} = -1.586 + 0.009781 \times Strength + 0.723 \times LogTend_{rel}$ , which can be expressed as follows to obtain more meaningful units (in min):

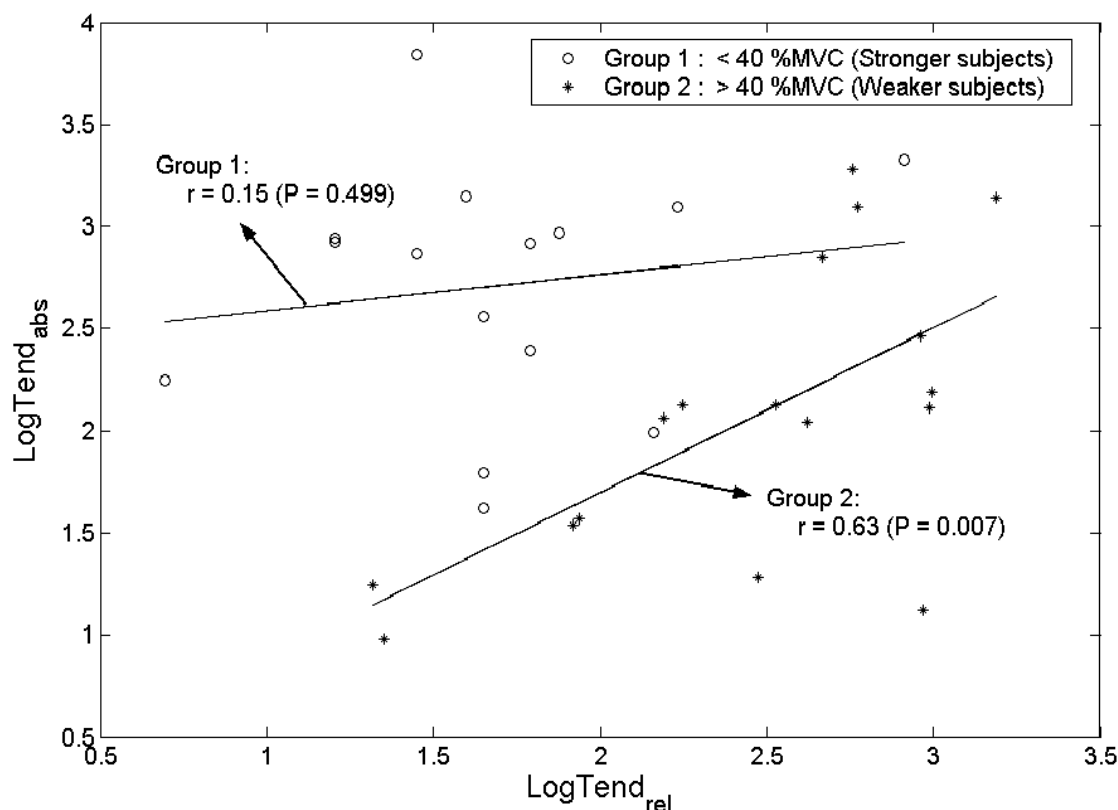
$$Tend_{abs} = e^{-1.586 + 0.009781 \times Strength + 0.723 \times LogTend_{rel}}$$

A low variance inflator factor ( $VIF = 1.559$ ; 10 representing the tolerance limit as a rule of thumb) indicated that no multi-collinearity was present (Kleinbaum et al., 1988). Potential mediating factors (gender, age, height, mass, % fat, level of physical activity) were forced into the model (one at a time) but did not further (significantly) explain  $LogTend_{abs}$  variance and were consequently not retained in the final regression model. Figure 3 shows the relationship between measured and estimated  $Tend_{abs}$  values.

The significant partial correlation ( $r = 0.66$ ;  $P < 0.001$ ) between  $LogTend_{abs}$  and  $LogTend_{rel}$  (controlling for *Strength*) explained why relative endurance ( $LogTend_{rel}$ ), which was not correlated ( $r = 0.05$ ) with absolute endurance ( $LogTend_{abs}$ ), became significantly associated with absolute endurance ( $LogTend_{abs}$ ) once *Strength* was taken into account. To further clarify this situation, a grouping was made according to the relative load sustained by each subject during the absolute endurance test ( $90Nm/Strength$  variable in Tables 1 and 2). It was hypothesized that subjects exerting below the complete blood vessel occlusion threshold for back muscles [40% MVC as estimated in three subjects; (Bonde-Petersen et al., 1975)] would behave differently than subjects exerting above this threshold, even though the use of a presently unknown absolute threshold might better characterize muscle ischemia (Barnes, 1980). The first group was thus composed of 15 subjects ( $90Nm/Strength$  from 21 to 38% MVC), while 17 subjects were classified in the second group ( $90Nm/Strength$  from 41 to 59% MVC). Interestingly, the mean  $90Nm/Strength$  obtained for the entire sample (39.0, SD 10.5% MVC;  $n = 32$ ) was not significantly different from the occlusion threshold of 40% MVC (one-sample t-test:  $P = 0.600$ ). Figure 4 illustrates the relationships between  $LogTend_{rel}$  and  $LogTend_{abs}$ . For the <40%-MVC group (stronger subjects), it was not significant ( $r = 0.15$ ;  $P = 0.499$ ), while for the >40%-MVC group (weaker subjects), it was highly significant ( $r = 0.63$ ;  $P = 0.007$ ).



**Figure 3.** Relationship between measured and estimated  $Tend_{abs}$  values. The straight line represents the line of identity.



**Figure 4.** Illustration of the ability of *Strength* and  $\text{LogTend}_{\text{rel}}$  to estimate  $\text{LogTend}_{\text{abs}}$ . The composition of Groups 1 and 2 was based on the relative load (relative to their strength) sustained by each subject during the absolute endurance test (90Nm). The threshold (40% MVC) separating the two groups corresponds to the complete blood vessel occlusion threshold (40% MVC) for back muscles (Bonde-Petersen et al., 1975) so that stronger and weaker subjects constitute Group 1 ( $< 40\% \text{ MVC}$ ) and 2 ( $> 40\% \text{ MVC}$ ) respectively. Note that the correlation between  $\text{LogTend}_{\text{rel}}$  and  $\text{LogTend}_{\text{abs}}$  is significant in weaker subjects (Group 2) while no correlation was obtained in stronger subjects (Group 1). Also, note that it is possible for some “weak” subjects from Group 2 (4 points encircled in the figure) to have an absolute endurance comparable to the stronger subjects constituting Group 1. These 4 subjects showed some of the highest strength values (207 to 222 Nm) of the “weaker” Group 2 (range: 153 to 222 Nm) but the fact that appreciable absolute endurance values were attainable was also attributable to their good relative endurance.

## DISCUSSION

A new testing protocol, the FET, has been proposed. This test, which assesses back muscle fatigue according to a new paradigm (assessment of absolute rather than relative endurance), could potentially allow the user to make inferences concerning muscle endurance in relation to work. This test is assumed to better reflect fatigue mechanisms corresponding to many occupational tasks than previous tests using sustained high-intensity-level contractions, but this remains to be demonstrated. The results of the present study demonstrated that back muscle strength and relative endurance ( $\text{LogTend}_{\text{rel}}$ ) can, when considered concomitantly,



account for up to 61.5% of the absolute endurance ( $LogTend_{abs}$ ) variance. This agreed with our hypothesis and supported the test's construct validity because allowing intermittent blood flow enhanced the contribution of relative endurance and was theoretically linked to absolute endurance as much as strength. More importantly, the estimation of absolute endurance ( $LogTend_{abs}$ ) using strength and relative endurance ( $LogTend_{rel}$ ) as independent variables was not mediated by any of the possible covariates considered (gender, age, height, mass, % fat, level of physical activity), thus demonstrating the robustness of the regression equation.

These results imply that the FET is likely to be influenced by back muscle strength and relative endurance concomitantly, although these results represent only an associative relationship (not a causal link). The test cannot differentiate these two intrinsic properties of muscles. However, in a return-to-work perspective, this is not important as long as absolute endurance is sufficient to protect the spine from re-injury (Biering-Sorensen, 1984).

### *Study limitations*

The regression analyses were based on a relatively small subject sample, thus preventing the simultaneous consideration of all the independent variables, and consequently the testing for possible significant interactions between variables. The regression model can only be considered as associative, thus preventing cause and effect inferences. Its predictive value would be established only by carrying out a cross-validation study using subjects not used in developing the regression equation. Also, it is very difficult to reach a true maximal contraction due to a lack of central drive (Morton et al., 2005) and consequently, the results may have been adversely affected. However, we believe that this effect should be minimal considering the good reliability of strength measures using this protocol (Lariviere et al., 2002) and that healthy subjects were used. Unfortunately, the reliability of the other measures ( $Tend_{abs}$ ,  $Tend_{rel}$ ), using this particular task, is unknown. The subjects were not specifically trained in fatiguing back muscles to the point of exhaustion and, consequently, this may affect the validity of these measures. However, it is likely that doing so would have decreased the variability in these measures and as a result, would have enhanced the association between the variables.

As reported in the methodology, 15 subjects (14 males and 1 female) were excluded from the analysis because they were able to hold the absolute load longer than the upper limit of 60 minutes. Considering that this group was mainly composed of males ( $n = 14$ ), they were compared (2 sample T-test) to the males retained in the present study. Even though these 14 excluded males were comparable relative to body size (Mass:  $75.9 \pm 7.7$  kg; Height:  $1.76 \pm 0.05$  m), they were significantly younger ( $28.3 \pm 9.8$  yrs;  $P = 0.010$ ) and stronger ( $391 \pm 77$  Nm;  $P = 0.004$ ) than the males in the sample retained for the analysis (see Table 1). The female (Age: 35 yrs) was relatively heavy and tall (Mass: 73 kg; Height: 1.70 m) and showed the highest strength performance (275 Nm) relative to the females retained (Range: 153-257 Nm). We believe that their exclusion probably did not invalidate the main conclusions of the present study because even though they were able to reach the limit, muscle fatigue was probably present in these subjects, and other measures such as EMG indices could be useful for quantifying endurance. In fact, as mentioned in the introduction, it is our intent to develop

an EMG approach so that the FET does not have to be performed to exhaustion. Thus, we believe that fatigue could be estimated even in the strongest subjects using an EMG criterion of fatigue.

### *Relationships between strength and endurance measures*

As expected, a correlation was observed between back *Strength* and *LogTend<sub>abs</sub>* ( $r = 0.61$ ). The relationship between strength and absolute endurance has already been substantiated for the bench press exercise using an absolute endurance protocol, with  $R^2$  values reaching 0.88 (Mayhew et al., 2002). Such striking results are probably attributable to the involvement of well-trained and motivated collegiate athletes, generally accustomed to performing this strength training exercise. The subjects in the present study were much more heterogeneous in age, athletic background and competitive skills, and the task performed was far from customary.

Strong relationships between strength and relative endurance are difficult to establish according to the various results reported in the literature [see (Allman and Rice, 2002) for a review on this topic]. In the present study, the significant negative correlation ( $r = -0.60$ ) indicated that the stronger the subject, the lower his/her relative endurance. This supports the muscle mass and strength hypothesis that stronger subjects occlude their muscle blood flow more than weaker subjects at a given relative load (Barnes, 1980), precipitating muscle fatigue. The relative load of the fatigue test (40% MVC) corresponded to the threshold for complete blood flow occlusion of back muscles [approximately at 40% MVC, (Bonde-Petersen et al., 1975)]. Consequently, it is probable that a proportion of the subjects reached complete occlusion while the others had sufficient blood flow to pursue the fatigue test longer. This particular condition introduced sufficient variability in the results to achieve a significant correlation.

### *Physiological and training issues*

The back muscle absolute endurance (*LogTend<sub>abs</sub>*) corresponding to the FET was well associated with *Strength* and relative endurance (*LogTend<sub>rel</sub>*) when considered concomitantly. The meaning of this regression model has physiological foundations as well as training and ergonomic implications. These issues will be discussed separately.

The physiological explanation of the present results is complex. The relative load involved during the 90-Nm absolute endurance test was obviously easier to sustain by stronger subjects. The size principle would dictate that stronger subjects would satisfy this absolute task using a higher proportion of smaller motor units, which are mostly composed of fatigue-resistant type I fibers. Furthermore, the stronger subjects would benefit from better blood flow circulation in their active muscles because they probably exert below the complete blood vessel occlusion threshold (40% MVC). These two factors could explain why *Strength* was selected first in the regression model. On the other hand, the stronger subjects had lower relative endurance and were unable to further increase their absolute endurance, as illustrated by the absence of a relationship ( $r = 0.15$ ;  $P = 0.499$ ) between relative and absolute endurance

in Group 1 (Figure 4). In fact, as depicted in Figure 4, the higher relative endurance corresponding to weaker subjects was sufficient to increase (if a cause and effect relationship is assumed) their absolute endurance during the absolute endurance test, even if the 90-Nm absolute load represented a higher relative load for them. The intermittent nature of the FET might allow these subjects to capitalize on their capacity to produce ATP via aerobic energy pathways.

There might be some speculative training implications associated to the regression model. Our results suggest that the development of absolute endurance requires training in strength and also training in relative endurance. This agrees with McGill (McGill, 1998) who proposes that back muscle strength training should not be overemphasized at the expense of endurance. Furthermore, according to the proportion of  $LogTend_{abs}$  variance explained by  $Strength$  (34.7%) and  $LogTend_{rel}$  (26.8%), both of these intrinsic muscle properties tended to have approximately the same importance relative to absolute endurance. The appropriate exercise program would require an adequate dosage because it is impossible to achieve maximal gains in strength and relative endurance simultaneously according to the so-called “strength-endurance continuum” (Fleck and Kraemer, 1997). The few studies available on this topic suggest that strength training is not as good as endurance or concurrent (strength-endurance) training for developing absolute endurance (Anderson and Kearney, 1982, Stone and Coulter, 1994). From a practical or clinical standpoint, a concurrent training protocol ( $\approx$  15-20 repetitions/set) might be optimal for chronic LBP patients because it does not require high exertion (strength training) and does not require a long endurance time ( $>30$  repetitions/set).

#### *Relevance of the FET for chronic LBP patient assessment*

It is tempting to extrapolate how this FET would be useful for assessing chronic LBP patients. Besides revealing back muscle weakness, the FET has the potential to highlight another important back muscle impairment (fatigability) characterizing chronic LBP subjects. The use of a fatigue test allowing partial or intermittent blood circulation generally magnifies gender- (Maughan et al., 1986) and age-related (Hunter et al., 1998) differences in muscle endurance. In fact, the differences separating genders or elderly subjects from young subjects are related to the capacity to use aerobic energy pathways. Likewise, given the larger proportion of type II fibers in chronic LBP subjects (Mannion et al., 1997b), we hypothesize that this form of muscle fatigue assessment would be efficient in demonstrating their reduced capacity to use aerobic energy pathways, a capacity that is generally less developed in type II fibers. Furthermore, changes in muscle capillarity generally accompany the oxidative capacity of a muscle (Henriksson, 1992). Consequently, allowing partial blood flow could possibly highlight the impairment in muscle capillarity that would be expected in chronic LBP subjects (more type II fibers = decrease in oxidative capacity = decrease in capillarity) relative to healthy individuals. This should be paralleled by changes in EMG signal content, since the median frequency of its power spectrum is sensitive to the accumulation of metabolic byproducts, a phenomenon that is amplified by muscle ischemia (Merletti et al., 1984) or, in other words, by an impairment in muscle blood flow that would go along with a

low capillarity density. Unfortunately, this latter hypothesis is not supported in the literature because back muscle biopsy studies that contrast healthy and chronic LBP subjects do not include data on capillarity.

## CONCLUSION

A new FET has been proposed for assessing back muscle strength and endurance. The test is similar to common occupational tasks and involves the repetition of isometric intermittent contractions using an absolute load to define the intensity level of contractions. Since the intermittent nature of the task likely allows for adequate muscle blood flow during the test, it was hypothesized that performance on this test, which primarily measures absolute endurance, would be influenced by both the strength and relative endurance of the subjects. This hypothesis was supported by strength and relative endurance ( $LogTend_{rel}$ ), explaining an almost equivalent portion of the absolute endurance variance ( $LogTend_{abs}$ 's total variance explained: 61.5%). These results support the construct validity of the FET and demonstrate that it has the potential of better assessing the strength-endurance capacity of chronic LBP patients relative to conditions more specific to common occupational tasks. Furthermore, given the changes in back muscle composition characterizing chronic LBP subjects, the FET proposed here has the potential of highlighting clinically important back muscle impairments (weakness and fatigability) characterizing this population. Finally, our results also suggest that the development of absolute endurance requires training in strength and relative endurance.

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## REFERENCES

- Allman B L, Rice C L. Neuromuscular fatigue and aging: central and peripheral factors. *Muscle Nerve* 2002; 25: 785-796.
- Anderson T, Kearney J T. Effects of three resistance training programs on muscular strength and absolute and relative endurance. *Research Quarterly for Exercise and Sport* 1982; 53: 1-7.
- Baecke J A H, Burema J, Frijters J E R. A short questionnaire for the measurement of habitual physical activity in epidemiological studies. *The American Journal of Clinical Nutrition* 1982; 36: 936-942.
- Barnes W S. The relationship between maximum isometric strength and intramuscular circulatory occlusion. *Ergonomics* 1980; 23: 351-357.
- Biering-Sorensen F. Physical measurements as risk indicators for low-back trouble over a one-year period. *Spine* 1984; 9: 106-119.
- Bjorksten M, Jonsson B. Endurance limit of force in long-term intermittent static contractions. *Scandinavian Journal of Work Environment and Health* 1977; 3: 23-27.
- Bonde-Petersen F, Mork A L, Nielsen E. Local muscle blood flow and sustained contractions of human arm and back muscles. *European Journal of Applied Physiology* 1975; 34: 43-50.
- Caldwell LS. The relationship between the maximum force exorable by the hand in a horizontal pull and the endurance of a submaximal holding response. 470. 1961. USAMRL, Fort Knox, Ky.
- Dempsey P G, Burdorf A, Webster B S. The influence of personal variables on work-related low-back disorders and implications for future research. *Journal of Occupational and Environmental Medicine* 1997; 39: 748-759.
- Duchateau J, Hainaut K. Electrical and mechanical failures during sustained and intermittent contractions in humans. *Journal of Applied Physiology* 1985; 58: 942-947.
- Durnin J V G A, Womersley J. Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged from 16 to 72 years. *British Journal of Nutrition* 1974; 32: 77-97.
- Enthoven P, Skargren E, Kjellman G, Oberg B. Course of back pain in primary care: a prospective study of physical measures. *Journal of Rehabilitation Medicine* 2003; 35: 168-173.
- Fleck S J, Kraemer W J. Designing resistance training programs. Human Kinetics, Champaign, U.S.A. 1997.
- Henriksson J. Effects of physical training on the metabolism of skeletal muscle. *Diabetes Care* 1992; 15: 1701-1711.

- Hunter S, White M, Thompson M. Techniques to evaluate elderly human muscle function: a physiological basis. *The journals of gerontology. Series A, Biological sciences and medical sciences* 1998; 53: B204-B216.
- Jorgensen K, Nicholaisen T, Kato M. Muscle fiber distribution, capillary density, and enzymatic activities in the lumbar paravertebral muscles of young men. Significance for isometric endurance. *Spine* 1993; 18: 1439-1450.
- Kleinbaum D G, Kupper L L, Muller K E. Applied regression analysis and other multivariable methods. In: Manque titre. Boston: PWS-KENT Publishing Company, 1988; 2e édition.
- Lariviere C, Arsenault A B, Gravel D, Gagnon D, Loisel P. Evaluation of measurement strategies to increase the reliability of EMG indices to assess back muscle fatigue and recovery. *Journal of Electromyography and Kinesiology* 2002; 12: 135-146.
- Lariviere C, Arsenault A B, Gravel D, Gagnon D, Loisel P. Surface electromyography assessment of back muscle intrinsic properties. *Journal of Electromyography and Kinesiology* 2003a; 13: 305-318.
- Lariviere C, Gagnon D, Gravel D, Arsenault A.B. The assessment of back muscle capacity using intermittent static contractions. Part I - validity and reliability of electromyographic indices of fatigue. *Journal of Electromyography and Kinesiology* 2008a, 18: 1006-1019.
- Lariviere C, Gagnon D, Gravel D, Arsenault A.B., Dumas J, Goyette M, Loisel P. A triaxial dynamometer to monitor lateral bending and axial rotation moments during static trunk extension efforts. *Clinical Biomechanics* 2001; 16: 80-83.
- Lariviere C, Gravel D, Gagnon D, Arsenault A.B. The assessment of back muscle capacity using intermittent static contractions. Part II -validity and reliability of biomechanical correlates of muscle fatigue. *Journal of Electromyography and Kinesiology* 2008b, 18: 1020-1031.
- Lariviere C, Gravel D, Gagnon D, Arsenault A.B. Towards the development of predictive equations of back muscle capacity based on frequency- and temporal-domain electromyographic indices computed from intermittent static contractions. *The Spine Journal* 2009, 9 (1), 87-95..
- Lariviere C, Gravel D, Gagnon D, Arsenault A B, Loisel P, Lepage Y. Back strength cannot be predicted accurately from anthropometric measures in subjects with and without chronic low back pain. *Clinical Biomechanics* 2003b; 18: 473-479.
- Lariviere C, Gravel D, Gagnon D, Gardiner P, Bertrand A A, Gaudreault N. Gender influence on fatigability of back muscles during intermittent isometric contractions: A study of neuromuscular activation patterns. *Clinical Biomechanics* 2006; 21: 893-904.
- Mannion A F. Fibre type characteristics and function of the human paraspinal muscles: normal values and changes in association with low back pain. *Journal of Electromyography and Kinesiology* 1999; 9: 363-377.

- Mannion A F, Connolly B, Wood K, Dolan P. The use of surface EMG power spectral analysis in the evaluation of back muscle function. *Journal of Rehabilitation Research and Development* 1997a; 34: 427-439.
- Mannion A F, Weber B R, Dvorak J, Grob D, Muntener M. Fibre type characteristics of the lumbar paraspinal muscles in normal healthy subjects and in patients with low back pain. *Journal of Orthopaedic Research* 1997b; 15: 881-887.
- Maughan R J, Harmon M, Leiper J B, Sale D, Delman A. Endurance capacity of untrained males and females in isometric and dynamic muscular contractions. *European Journal of Applied Physiology and Occupational Physiology* 1986; 55: 395-400.
- Mayhew J L, Ware J S, Cannon K, Corbett S, Chapman P P, Bembien M G, Ward T E, Farris B, Juraszek J, Slovak J P. Validation of the NFL-225 test for predicting 1-RM bench press performance in college football players. *Journal of Sports Medicine and Physical Fitness* 2002; 42: 304-308.
- McGill S M. Low back exercises: evidence for improving exercise regimens. *Physical Therapy* 1998; 78: 754-765.
- McGlynn G H, Murphy L E. The effects of occluded circulation on strength and endurance at different levels of strength. *American Corrective Therapy Journal* 1971; 25: 42-47.
- Merletti R, Sabbahi M A, De Luca C J. Median frequency of the myoelectric signal. Effects of muscle ischemia and cooling. *European Journal of Applied Physiology* 1984; 52: 258-265.
- Morton J P, Atkinson G, Maclaren D P, Cable N T, Gilbert G, Broome C, McArdle A, Drust B. Reliability of maximal muscle force and voluntary activation as markers of exercise-induced muscle damage. *European Journal of Applied Physiology* 2005; 94: 541-548.
- Nussbaum M A. Static and dynamic myoelectric measures of shoulder muscle fatigue during intermittent dynamic exertions of low to moderate intensity. *European Journal of Applied Physiology* 2001; 85: 299-309.
- Parnianpour M, Shirazi-Adl A. Quantitative assessment of trunk performance. In: *The occupational ergonomics handbook*. (Eds. Karwowski W, Marras WS). New York: CRC Press, 1999; 1st: 985-1006.
- Rohmert W. Ermittlung von Erholungspausen für statische Arbeit des Menschen. *Int Z angew Physiol einschl Arbeitsphysiol* 1960; 18: 123-164.
- Roy S H, De Luca C J, Emley M, Oddsson L I E, Buijs R J C, Levins J A, Newcombe D S, Jabre J F. Classification of back muscle impairment based on the surface electromyographic signal. *Journal of Rehabilitation Research and Development* 1997; 34: 405-414.
- Start K B, Graham J S. Relationship between the relative and absolute isometric endurance of an isolated muscle group. *The Research Quarterly* 1964; 35: 193-204.
- Stone W J, Coulter S P. Strength/Endurance effects from three resistance training protocols with women. *Journal of Strength and Conditioning Research* 1994; 8: 231-234.

- Thomas S, Reading J, Shephard R J. Revision of the Physical Activity Readiness Questionnaire (PAR-Q). *Canadian Journal of Sport Science* 1992; 17: 338-345.
- Tuttle W W, Janney C D, Thompson C W. Relation of maximum grip strength to grip strength endurance. *Journal of Applied Physiology* 1950; 2: 663-670.
- Zatsiorsky V M. Science and practice of strength training. Human Kinetics, Champaign, IL 1995.