Isometric Strength Database for Muscle Maximal Voluntary Endurance Field Tests: Normative Data.

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Abstract

Background:

Different field tests are used to evaluate muscular capacity, in particular maximal voluntary endurance. However, although there are some normative values for a few muscle endurance tests, these do not consider the mass, size or age of individuals, which are well-known factors that influence muscle performance.

Hypothesis/Purpose:

The purpose of this study was to investigate the test-retest reliability of 8 field tests and establish muscle endurance norms, in an healthy population, based on their anthropometric characteristics which could permit to evaluate at best the entire muscle function in a quick manner.

Design:

Case series.

Methods:

This study was conducted in two phases. The first phase was to check the reproducibility inter- and intra-assessor for 8 isometric muscle fields tests on twenty volunteered subjects age of 40.9 ± 11.6 years old. The second part was to establish muscle maximal voluntary endurance norms according of these tests on a total of 400 healthy participants segmented by age (50 males and females by age bracket: 20-29; 30-39; 40-49; 50-59 years old, for a total of 200 males and 200 females).

Results:

The intra and inter-assessor reproducibility tests was very high for all muscle measurements (the ICC varied between 0.915 and 0.996). Good sensitivity is observed for all isometric tests highlights with simple linear regression test demonstrating a significant impact for the variable age for all tests ($p<0.001$). Each muscle belt presents same ratio regardless of the age and gender group. The simultaneous multiple regression analyses highlight that the anthropometric characteristics of subjects influence significantly the performance of isometric tests.

Conclusion:

This study has permitted to established prediction equations in an healthy population according to their anthropometric characteristics as well as agonist/antagonist ratios for eight muscle isometric field tests after to be demonstrated an excellent reproducibility of all tests.

1 Introduction

Despite the amount of research devoted to the prevention and treatment of low back pain, the incidence among the world population is increasing [1]. The chronicity of low back pain induces multiple consequences, such as pain, functional disabilities, degradation of the quality of life and rupture with the professional world [2]. Thus, the multifactorial aspect of this pathology, because of its impacts on physical and psychosocial capacities, makes care complicated. That is why it is necessary to carry out assessments in order to individualize the care [3]. As Demoulin et al. [4] explained, these assessments must consider pain intensity together with its functional implications.

The evaluation of muscular function, in terms of both strength and endurance, contributes to the functional diagnosis of the patient [5]. Indeed, Mayer et al. [6] explain that chronic low back pain patients are physically deconditioned, which is characterized by muscle atrophy, decreased cardiovascular endurance, neuromotor inhibition and a decreased functional load-bearing capacity. In addition, it would appear that atrophy of the postural muscles should be even faster than the locomotor muscles [7], thereby providing a decrease of postural muscle performance and mainly of the spine extensors [8]. This finding translates to a flexor/extensor ratio of the muscles of the trunk greater than 1 [9]. In the same way, Dufour et al.3 report that low back pain patients could have a 40% reduced strength of the lumbar muscles when the abdominal muscles do not exceed 10%. Finally, Duvallet and Poiraudeau [10] show that not only do the muscles of the trunk perform poorly but locomotor muscles are also implicated. These authors have demonstrated a reduction in the strength and fatigue resistance of the quadriceps, and this is more pronounced for the hamstring muscles.

Different field tests are used to evaluate muscular capacity, in particular maximal voluntary endurance. However, although there are some normative values for a few muscle endurance tests, these do not consider the mass, size or age of individuals, which are well-known factors that influence muscle performance [11]. In addition, the postural position of some field tests often induces discomfort and pain, leading to an underestimation of muscle capacity because patients with low back pain can stop the test more prematurely. As a result, these tests can frequently underestimate (because of pain, for example) or overestimate (because of the different anthropometric values among subjects) muscle performance. So, it is important to modify the postural positions of patients during field tests in order to limit the pain and to consider the anthropometric data of each subject while respecting the validity of the tests. Finally, the evaluation encountered in the literature of the maximal voluntary muscular endurance measured using isometric contractions is generally limited to three muscle groups: quadriceps, abdominals and lumbar muscles [4]. Therefore, this assessment provides a somewhat limited overview that does not permit muscle imbalances to be highlighted.

Thus, the objectives of this study were: 1) to validate maximal voluntary muscle endurance through fields tests with adaptatively postural positions if necessary; 2) to establish muscular endurance norms in a healthy population based on its anthropometric characteristics, which could allow, at best, the evaluation of the entire muscular function in a quick and cheap form. These norms could enable identification of the degree of muscular deconditioning and its alteration following a period of rehabilitation in specific diseases like low back pain.

2 Materials And Methods

2.1 Study design

This study was conducted in two phases. The first phase was to check the inter- and intra-assessor reproducibility for isometric muscular field tests, and the second part was to establish muscle maximal voluntary endurance norms according to these tests. The isometric tests allow assessment of trunk flexor muscles, trunk extensor muscles, oblique muscles, quadriceps muscles, hamstring muscles, back muscles and chest muscles [Figure 1].

To be included in the study, the selection criteria for the two phases were: no history of chronic or acute disease; a score < 9 on the Baecke questionnaire, which does not correspond to a sporting way of life [12]; no psychiatric or psychological disorders; no contraindication for exercise.

Before being included in the study, the design, rules and protocol were explained to each subject. Then each subject signed a written consent form. The study protocol was approved by the Ethics Committee under N° 2019-380-S77.

2.2 Part 1: Reproducibility of muscle maximal voluntary endurance field tests

The aim of this first part of the study was to examine intra- and inter-assessor reproducibility in a test-retest during isometric field tests in order to assess the maximal voluntary endurance of the quadriceps, hamstring, abdominal, trunk extensor, right and left oblique, and back and chest muscles [Figure 1].

2.2.1 Subjects

Twenty subjects (9 males, 11 females), with a mean age of 40.9 ± 11.6 years (mean ± SD), were included (Table 1). Subjects completed the Baecke questionnaire12 to determine their physical activity level and were asked about any history of medical conditions in order to verify the entry/exclusion criteria.

2.2.2 Protocol

Two assessors, A and B, each performed two evaluation sessions (A1 and A2 for assessor A and B1 and B2 for assessor B). Prior to data collection, the assessors practised using the test protocols to ensure that standardized procedures were employed.

Each evaluation session lasted for two weeks with a break of at least 24 hours between each one. This 24-hour interval was chosen in order to avoid the impact of fatigue resulting from two sessions being too close together. Only the data of the last three evaluation sessions (A2, B1 and B2) were analysed, with the first session (A1) serving as a familiarization and therefore the results of this session were not considered in the analysis of the data.

No attempt was made to standardize the order in which, or the time of day when, the evaluations were completed. Measurements from the two assessors were recorded on separate data collection forms to ensure that they were blinded to each other's results and their own previous results. Both assessors carried out two assessment sessions for each subject and applied each field test in random order. The randomization was performed with the R software by assigning a number to each test. During the assessment, the antagonist muscle was tested after the agonist muscle. Prior to the assessment of each test, the assessors explained and demonstrated the test procedure to the subject.

Each assessment session started with 10 minutes of cardiorespiratory warm-up on a cycloergometer at 65% of the target heart rate as determined by the Karvonen formula [13], and subjects benefited from at least 5 minutes rest between each test.

2.2.3 Guidelines for postures during the tests

For this study, the objective was to reduce pain generate by the discomfort of the position tests during the evaluation. To do this, the postural position of some tests was modified [Figure 1]. These modifications and all instructions for all tests, including pretest cueing, starting position, subject instructions and termination criteria, are presented in the appendix. Next, there followed a brief presentation of the used tests with their alterations or not: 1) Trunk flexor muscles were evaluated with the test of Ito et al. [14]. Some modifications were carried out, included the position of the legs and the termination criteria. 2) Trunk extension was evaluated by the test of Ito et al. [14] without modification. 3) Right and left oblique muscles were evaluated by a modification of the positions in McGill et al. [15] tests. The modification was the position of the legs. 4) The isometric test of quadriceps by the original Killy test described by Bernard et al. [16] was used. 5) For the hamstring muscles test, a derivative of the bridge exercise to the neutral spine alignment position described by Youdas et al. [17] was used. These modifications included, the pelvis position and the feet position. 6) The back muscles test was an adaptation of the behind-the-neck lat pull-down described by Sperandei et al. [18]. This test required the same movement as the behind-the-neck lat pull-down but the subject is sitting on the floor, with their back, shoulders, elbows, hands and head against the wall. In addition, this test was carried out without equipment and in an isometric way. 7) For the chest muscles test, a derivative of the push-up on the knees exercise described by Vossen et al. [19] was used. In our study, this test was performed in an isometric way, so the termination criteria were not the same.

Participants were individually instructed and supervised by experienced therapists specifically trained in the testing methodology. In each of these tests, the body mass represented the load.

2.3 Part 2: Creation of muscle norms

2.3.1 Subjects

400 healthy participants segmented by age (50 males and females by age bracket: 20–29 years old, 30–39 years old, 40–49 years old and 50–59 years old, for a total of 200 males and 200 females) were

included. The female group was aged 39.7 ± 11.5 years and the male group was aged 39.4 ± 11.4 years [Table 1].

2.3.2 Protocol

Prior to isometrics testing, participants performed 10 minutes of warm-up including all articulations of the body. After that, all subjects performed the eight maximal voluntary muscle endurance tests. Each test was carried out once per session. Tests were conducted in random order with at least 5 minutes rest between two tests. As for the first part, randomization was performed using the R software by assigning a number to each test. The antagonist muscles were systematically tested after the agonist muscles.

Prior to the performance of each test, the assessor explained and demonstrated the test to subjects using standardized instructions. For this part, the same researcher conducted all the tests.

2.3.3 Instructions for end of tests parts 1 and 2

For all endurance tests, in both parts 1 and 2, subjects were encouraged to hold the test position until fatigue, and were given feedback if they deviated from the position. Tests were terminated when the subject could not maintain the position or if there were any obvious signs of fatigue (not maintaining the position in spite of verbal feedback, for example) or a significant emergence of pain or other symptoms. The maximum holding time was recorded in seconds using a stopwatch. The stopwatch was triggered when the subject was in the right position.

2.4 Data analysis

2.4.1 Intra- and inter-assessor reproducibility

Intra- and inter-assessor reproducibility was estimated using intraclass correlation coefficients (ICCs). The intra-assessor reproducibility was quantified by calculating the ICC between the measurement conducted by the same assessor "B1" and "B2". The inter-assessor reproducibility was measured by calculating the ICC between the measurement of assessor A ("A2") and assessor B ("B1" and "B2"). For each ICC, error range and repeatability were calculated with standard error of the measurement (SEM), 95% confidence intervals (CIs) and 95% limits of agreement (LOAs). The standard error of the measurement (SEM) was calculated according to the formula $SEM = SD \sqrt{(1-ICC)}$ [20], to provide an estimate of the precision of measurement, expressed in the units of the measure. The SEM was divided by the mean of the two measurements and multiplied by 100 to give a percentage value (SEM%) [21]. A percentage of 95% of LOA demonstrates the range of measurement error within the sample [22].

The interpretation of the ICCs was obtained according to the study of Shrout [23]: reproducibility was considered strong if the ICC was between 1 and 0.81, moderate between 0.80 and 0.61, fair between 0.60 and 0.41, low between 0.40 and 0.11 and non-reproducible if less than 0.10. The presence of heteroscedasticity was tested using the Pearson correlation test. The performances in all isometric tests for each session of evaluation were expressed as mean ± standard deviation (mean ± SD). Statistical analysis was performed using SPSS version 1.0.0-2483 software.

2.4.2 Muscle norms

The sensitivity for all isometric tests was evaluated using a simple linear regression test to determine the influence of age on performance. The gender influence was evaluated by one-way ANOVA. To establish the norms for the eight muscle field tests, multiple regression analyses were conducted to determine the influence of the anthropometric data (age, mass and body size) on the performance of isometric tests. All values were expressed as mean ± standard deviation (mean ± SD). For the gender parameter, data normality was tested using the Shapiro-Wilk test. The significance level was set at the 0.05 level. The statistical analyses were performed using R software version 3.5.0.

3 Results

Anthropometric characteristics of all subjects included in this study and the overall means of the last three assessments “A2”, “B1” and “B2” for all the isometric tests are presented in Table 1.

3.1 Part 1: Reproducibility of muscle endurance tests

Table 2.a presents the results of the intra-assessor (“B1” and “B2”) reproducibility tests for all muscle measurements. The ICC values of the muscle endurance measurements vary between 0.946 and 0.989, thereby indicating excellent reliability. The bias values range from − 3.9 to 1.0, staying close to zero and indicating a slight systematic improvement between measurements.

Tables 2.b and 2.c present the results of the inter-assessor (between assessments of “B1” and “A2” and between assessments of “B2” and “A2”) reproducibility tests for all muscle measurements. The ICC values indicate excellent inter-assessor reproducibility with measurements varying between 0.915 and 0.996 for the measures of “B1” and “A2” assessments and between 0.955 and 0.996 for the measures of “B2” and “A2” assessments. For inter-assessor comparison, the bias values are negative (ranging from − 5.6 to -0.8 for the measurement between “B1” and “A2” and from − 4.9 to -0.6 for the measurement between “B2” and “A2”), indicating a slight systematic improvement between measurements.

With regard to absolute reliability, the values of SEM% prove a good reliability of the accuracy and precision of the measured values. Indeed, the SEM values of intra- or inter-assessor measurements are less than 10% of the average measured value, so the measurement errors are small, and therefore the measurement is reliable [24]. The Pearson’s correlation coefficient of the absolute differences between test sessions B1 and B2, A2 and B1, A2 and B2 and the mean of the three test sessions is above 0.85 ($r > 0.85$ and $p > 0.001$) for all instances. So, no presence of heteroscedasticity is observed.

3.2 Part 2: Muscle norms

Good sensitivity is observed for all isometric tests as highlighted by a simple linear regression test, demonstrating a significant impact of the variable age for all tests ($p < 0.001$). Regardless of age and genre, the agonist/antagonist ratios do not present some variation. Indeed, the muscles ratios varied form

0.70 ± 0.19 to 0.70 ± 0.46 for the abdominal/lumbar muscles; 1.00 ± 0.17 to 1.00 ± 0.35 for the oblique muscles; from 0.36 ± 0.13 to 0.36 ± 0.26 for the back/chest muscles; from 0.37 ± 0.12 to 0.37 ± 0.18 for the quadriceps/hamstring muscles.

The simultaneous multiple regression analyses highlight that in addition to age, the mass and size of subjects influence performance significantly in isometric tests [Tables 3 and 4]. On the other hand, gender does not influence performance [Table 1]. Prediction equations to estimate performance according to anthropometric criteria can be seen in Tables 3 and 4.

4 Discussion

The main purpose of this study was to validate equations of predictions in a healthy population according to their anthropometric data for eight muscle isometric endurance field tests. The main interest of the creation of these normative data is, in future clinical trials, to evaluate at best people with low back pain, for example, and to propose individual care based on these evaluations during rehabilitation. But to validate these equations, it was necessary to ensure the reproducibility of the muscle endurance tests because original positions from a few tests were altered. Indeed, some positions induce pain or premature fatigue in patients with low back pain, thereby inducing a false evaluation. Our results demonstrated an excellent test-retest reproducibility with ICCs between 0.915 and 0.996 for all tests.

In view of the excellent reproducibility of each test, we have attempted to elaborate normative data for each test according to the anthropometric data of each subject. Our results demonstrated that age, height and mass, but not gender, influence the performance. In view of the literature, this matter has already been widely discussed in recent years but with varied results [25, 26, 27, 28]. The study of McIntosh et al. [27], with a distribution close to our population, showed a similar finding to our study concerning the influence of age but not gender on the performance in five isometric field tests. In contrast, Strand et al. [28] showed a statistical difference between men and women with a test duration 49% higher in men than in women. Before muscle evaluations, all subjects [28] described their habitual physical practice, with 1% of participants declaring that they never practised physical activity, 13% rarely, 26% once or twice a week, 41% three to five times a week and 19% more than five times a week. But the authors did not specify the sex distribution of the population practising a physical activity. Moreover, the authors did not consider the level of physical activity in determining their groups. Indeed, in their study, the authors separated their population into four groups according to their sex and their athletic status: male non-varsity athletes (n = 134), female non-varsity athletes (n = 227), male varsity athletes (n = 59) and female varsity athletes (n = 50). The 109 varsity athletes were all members of the National Collegiate Athletic Association (NCAA). Nevertheless, Strand et al. [28] highlighted that plank test hold time was significantly higher in subjects who practised physical activity at least three times a week. But it is impossible to determine whether the results found were due to a gender or a training effect. And so, the usual level of physical activity according to gender and age is an essential factor to interpret the results of the measurement, as is done in our study.

In our study, we identified the agonist/antagonist ratios for different muscle belts because of their utility before the beginning of the training programme proposed during rehabilitation in low back pain, for example. Indeed, the evidence of a muscle imbalance will direct the clinical decisions regarding the construction of the physical training programme. Imbalance commonly refers to a modification of the strength balance between agonist and antagonist muscles that could accompany a proven pathology, articular conflict or functional impairment. Although no prospective study has been conducted to determine what proportion of a muscle imbalance can cause an injury in an athlete, these ratios are also used in injury prevention in sport because for many authors they constitute an element of functional specificity of joints [29]. However, the primary means to determine the ratios between agonist and antagonist muscles is the use of isokinetic dynamometers, which are very expensive and associated with difficult manipulation. So, the evaluation of postural ratios is most often done through field tests. But there are no known norm ratios in field tests, which are often limited to situating the subject by age [25] or gender [28], thereby limiting the interpretation of results. That is why the prediction equations defined in our study allow the subject to be situated according to their anthropometric criteria, i.e. gender, age, mass and size, while also identifying agonist/antagonist muscle imbalances, which will allow the individualization of rehabilitation programmes.

Limitations of this study

The isometric assessments are associated with a number of disadvantages, such as the impossibility of appreciating the work developed due to the lack of movement during the exercise, a punctual and restrictive definition of the relationship between the muscle tension and length, and technical difficulties in simultaneously evaluating agonist and antagonist muscle groups [30]. But isometric assessment is a reliable method when the standardization of measure is respected [27]; it’s a method that does not require expensive material and a specific room for the evaluation as with isokinetic dynamometers.

The evaluation of muscle endurance in humans often depends on motivation. Moreau et al. [31] explained that psychological issues in regard to motivation and fatigue would be better studied before the measurement of muscle function itself. Indeed, if the subject does not cooperate by giving maximum effort to the point of fatigue, the endurance time can be compromised by a premature termination due to a mental factor but not because of a physical limitation [31]. In our study, the subjects were voluntary participants who were fully informed about the nature of the tests. So, we can conclude from that, that the motivation was equal for all subjects and thus this did not negatively influence their performance.

Lastly, our study was carried out in a French population; thus, as explained by Hogrel et al. [32], our results could present a few variations depending on the races involved (Africa, Asia), because of morphologic, anatomic and cultural differences.

5 Conclusion

Our study has permitted the establishment of prediction equations in a healthy population according to its anthropometric characteristics, namely age, mass, body size and gender, as well as muscle endurance according to agonist/antagonist ratios for eight muscle isometric field tests, with excellent reproducibility being demonstrated for all tests. There are multiple interests related to these prediction equations: identifying muscle imbalances, identifying muscle weakness, individualizing training programmes during rehabilitation with a focus on deficit muscle groups, and following the evolution of patients’ muscle function.

6 Declarations

Ethics approval and consent to participate

Before being included in the study, the design, rules and protocol were explained to each subject. Then each subject signed a written consent form. The study protocol was approved by the Ethics Committee under N° 2019-380-S77.

Consent for publication

“Not applicable”

Availability of data and material

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

“The authors declare that they have no competing interests”

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Authors' contributions

FJ and CF wrote the first draft of the manuscript, CT contributed to revisions of the manuscript. A.LS, BM and FB supervised the study and contributed to data acquisition, procedural protocols. All authors contributed to the study design, procedural protocols, and the drafting of this paper. All authors read and approved the final manuscript.

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7 References

1. Hoy D, Brooks P, Blyth F, Buchbinder R. The epidemiology of low back pain. Best Pract Res Clin Rheumatol, 2010; 24: 769-81.
2. Koes B, Van Tulder M, Thomas S. Diagnosis and treatment of low back pain. *BMJ*, 2006; 332: 1430-34.
3. Dufour X, Barette G, Ghossoub P, Trontte G. Rehabilitation of low back pain according to etiology. *Kinesither Sci*, 2010; 513: 25-34.
4. Demoulin C, Fauconnier C, Vanderthommen M, Henrotin Y. Recommendations for a basic functional assessment of low back pain.*Rev Med Liège*,2005; 60: 661-8.
5. Bruyneel AV, Deat P, Boussion L. Évaluation de la reproductibilité du test de force isométrique sur balance et par dynamomètre à pression pour les muscles extenseurs de genou. *KinesitherRev*, 2012; 12: 33-40, 2012.
6. Mayer T, Smith S, Keeley J, Mooney V. Quantification of lumbar function: Part 2: Sagittal plane trunk strength in chronic low back pain patients. *Spine*, 1985; 10: 765-72.
7. St. Pierre D, Gardiner P. The effect of immobilization and exercise on muscle function: a review. *Physiother Can*, 1987; 39: 24-36.
8. Poiraudeau S, Duvallet A, Dos Santos B, Revel M. Evaluation of a functional restoration program for severely handicapped chronic low back pain patients: a 1-year follow-up study. *Ann Readapt Med Phys*, 1999; 42: 33-41.
9. Yahia A, et al. A study of isokinetic trunk and knee muscle strength in patients with chronic sciatica. *Ann Readapt Med Phys*, 2010; 53: 239-49.
10. Duvallet A, Poiraudeau S. Évaluation de la condition physique chez le patient lombalgique chronique. Lombalgie et évaluation. *Paris: Masson*, 2000; 3: 44-53.
11. Maso F, Robert A. Anthropometric evolution of the elite of the French rugby players. *Sci Sports*, 1999; 14: 301-304.
12. Bigard A, Duforez F, Portero P, Guezennec C. Assessment of physical activity by questionnaire: validity of the Baecke questionnaire.*Sci Sports*, 1992;7: 215-21.
13. Karvonen M, Kentala E, Mustala O. The effects of training heart rate: a longitudinal study. *Ann Med Exp Biol Fenn*, 1957; 35: 307-15.
14. Ito T, et al. Lumbar trunk muscle endurance training: An inexpensive alternative to a machine for evaluation. *Arch Phys Med Rehabil*, 1996; 77: 75–9.
15. McGill S, Childs A, Liebenson C. Endurance times for low back stabilization exercises: clinical targets for testing and training from a normal database. *Arch Phys Med Rehabil*, 1999; 80: 941-44.
16. Bernard J, et al. Muscle assessment in healthy teenagers comparison with teenagers with low back pain. *Ann Readapt Med Phys*, 2008; 51: 274-83.

17. Youdas J, et al. Magnitudes of muscle activation of spine stabilizers, gluteals, and hamstrings during supine bridge to neutral position. *Physiother Theory Pract*, 2015; 31: 418-27.
18. Sperandei S, Barros M, Silveira-Junior P, Oliviera C. Electromyographic analysis of three different types of lat Pull-Down. *J Strength Cond Res*, 2009; 23: 2033-38.
19. Vossen J, Kramer J, Burke D, Vossen D. Comparison of dynamic push-up training and plyometric push-up training on upper-body power and strength. *J Strength Cond Res*, 2000; 14: 248-53.
20. Weir J. Quantifying test-retest reliability using the intra class correlation coefficient and the SEM. *J Strength Cond Res*. 2005; 19: 307-10.
21. Svensson E, Waling K, Hager-Ross C. Grip strength in children: Test-retest reliability using Grippit. *Acta Paediatr*. 2008; 97:1226-31.
22. Bland J, Altman D. Statistical methods for assessing agreement between two method of clinical measurement. *Lancet*. 1986; 1: 307-10.
23. Shrout P. Measurement reliability and agreement in psychiatry. *Stat Methods Med Res.* 1998; 7: 301-17.
24. Liaw L, et al. The relative and absolute reliability of two balance performance measures in chronic stroke patients. *Disabil Rehabil*, 2008; 30: 656-61.
25. Claxton M, McIntosh G. Sidebridge muscle endurance testing: Normative data for adults. *Ortho Division Rev*, 2009; 35-9.
26. Evans K, Refshauge K, Adams R. Trunk muscle endurance tests: Reliability, and gender differences in athletes. *J Sci Med Sport*, 2007; 10: 447-55.
27. McIntosh G, Wilson L, Affleck M, Hall H. Trunk and lower extremity muscle endurance: Normative data for adults. *J Rehabil Outcomes Meas*, 1998; 2: 20-39.
28. Strand S, Hjelm J, Shoepe T, Fajardo M. Norms for an isometric endurance test. *J Hum Kinet*, 2014; 40: 93-102.
29. Olivier N, Daussin F. Isokinetic torque imbalances of shoulder of the French women’s national water polo team. *Sci Sports*, 2019; 34: 82-7.
30. Croisier J, Crielaard J. assessment of muscle performance: A critical analysis. *Ann Readaptation Med Phys*, 1999; 42: 311-22.
31. Moreau X, Green B, Johnson C, Moreau S. Isometric back extension endurance tests: A review of the literature. *J Manipulative Physiol Ther*, 2001; 24: 110-22.
32. Hogrel JY, et al. Development of a French isometric strength normative database for adults using quantitative muscle testing. *Arch Phys Med Rehabil*, 2007; 88: 1289-97.

Appendix

1 General instructions

Pretest cueing for: 1) trunk flexor muscles test; 2) oblique muscles test; 3) quadriceps muscles test; 4) hamstring muscles test; 5) back muscles test:

- To ensure the subject is able to cue the transversus abdominus (T-A), instruct them to pull their "navel to spine".
- Monitor to ensure the subject is able to properly cue T-A.

Subject instruction for all tests:

- One practice trial allowed to ensure the subject is able to assume position only (i.e. not held).
- Subject need breathe normally (do not block breathing).
- Subject keeps the position as long as possible.

Note: *The aim of these assessments was to determine prediction equations for each test. Therefore, we have not determined a maximum holding time for these tests, so the subjects had to maintain the position as long as possible.*

2 Appendix 1: Instructions for trunk flexor muscles test

Starting Position

- Lying on back, the soles of feet on the ground with knees bent 90°.
- Feet and legs are joined.
- The low back is in contact with the ground.
- Hands are placed on the thighs.

Subject Instructions

- Beforehand, perform a pelvis retroversion by pushing the low back against the ground. Instruct subject to cue T-A by drawing navel to spine.
- In this position, touches the knees while take off the shoulder blades and winding the back.
- During the test, keep the low back in contact with the ground and the pelvis in retroversion.

Termination Criteria

- Subject terminates the test
- Subject no longer maintains the pelvis retroversion.
- Subject's shoulder blades go down to the ground.
- Subject's hands are not placed on their knees.
- Subject unable to properly cue T-A.

3 Appendix 2: Instructions for trunk extensor muscles test

Starting Position

- Lying on belly, arms along the body, a small pillow placed under the lower abdomen to decrease the lumbar lordosis.
- Tiptoes and knees in contact with the ground.

Subject Instructions

- In this position, get the chest off the ground and keep the chin on the chest, looking towards the ground.
- Maintain maximum flexion of the spine, with pelvic stabilization through gluteal muscle contraction.
- During the test, feet and knees should remain in contact with the ground.

Termination Criteria

- Subject terminates the test.
- Feet or knees leave the ground.
- The subject’s chest touches the ground.
- The subject’s head rises and the chin is detached from the chest.

4 Appendix 3: Instructions for oblique muscles test

Starting Position

- Lying on side with legs extended, top foot placed over lower foot on the mat for support.
- Torso supported off the mat by the arm with elbow placed directly below shoulder.
- Once in this position, bend the knee from the leg to the ground backwards while maintaining alignment of both thighs.

Subject Instructions

- Instruct patient to cue T-A by drawing navel to spine.
- Instruct the subject to lift hips off the mat to maintain a straight line over their body length so they are supporting themself on one elbow and their feet only.
- To help protect the shoulder girdle it will be necessary to instruct the subject to draw their shoulder toward their ipsilateral hip.
- Uninvolved arm is placed by side.
- Repeat on the other side.

Termination Criteria

- Subject terminates the test.

- Subject’s hips return to the ground.
- Subject unable to assume position in practice trial.
- Subject unable to properly cue T-A.

5 Appendix 4: Instructions for quadriceps muscles test

Starting Position

- Stand comfortably with feet shoulder width apart and about 2 feet from the wall, with back against a smooth vertical wall.
- Perform a pelvis retroversion by pushing the low back against the wall. Instruct subject to cue T-A by drawing navel to spine.

Subject Instructions

- Slowly slide the back down the wall to assume a position with both knees and hips at a 90° angle.
- Move the feet a distance from the wall if required.
- The feet are flat on the ground, the back needs to be kept against the wall with a pelvis retroversion, and the knees and hips are at right angles.
- The knees should be directly above ankles (rather than over toes) and the thighs parallel to the ground.

Termination Criteria

- Subject terminates the test.
- Modification of knee and hip angles.
- The thighs are no longer parallel to the ground.
- Subject no longer maintains the pelvis retroversion.
- Subject unable to assume position in practice trial.
- Subject unable to properly cue T-A.

6 Appendix 5: Instructions for hamstring muscles test

Starting Position

- Lying on back, feet on the ground with both knees bent at a 90° angle.
- Place feet in heel support.
- The feet and legs are glued together.
- Perform a pelvis retroversion by pushing the low back against the ground, then place a piece of paper between knees. Instruct subject to cue T-A by drawing navel to spine.

Subject Instructions

- In this position, press the heels into the ground to curl the pelvis and lift the buttocks of the ground.
- The buttocks are lifted a few inches.
- During this test, keep legs glued together and low back on the ground with a pelvis retroversion.

Termination Criteria

- Subject terminates the test.
- The buttocks are returned to the ground.
- The piece of paper falls, meaning that the legs have separated.
- The low back leaves the ground.
- Subject unable to assume position in practice trial.
- Subject unable to properly cue T-A.

7 Appendix 6: Instructions for back muscles test

Starting Position

- Sitting on the ground, the back and head leaning against a wall, the buttocks are spaced. from the wall by a distance of an open hand.
- Bend both knees at a 90° angle and perform a pelvis retroversion.
- Make a double chin by holding the head against the wall while self-stretching.
- Place the arms against the wall and line them up shoulder-high.
- Elbows and fingers against the wall with elbows bent at a 90° angle.

Subject Instructions

- Keeping fingers and elbows against the wall, slide elbows down to obtain an angle of about 45° between arms and the trunk.
- Keep elbows keep at a 90° angle.
- Keep a pelvis retroversion.

Termination Criteria

- Subject terminates the test.
- Take fingers, elbows or head off the wall.
- Subject no longer maintains the pelvis retroversion.
- Subject unable to assume position in practice trial.
- Subject unable to properly cue T-A.

8 Appendix 7: Instructions for back muscles test

Starting Position

- On all fours, place the hands on the ground so as to be more spread than the width of the shoulders.
- Arms are stretched.
- Knees and feet are glued and in contact with the ground.
- Keep the chin on the chest, looking towards the ground.

Subject Instructions

- In this position, move the chest forward and bend the arms to bring the chest to the ground between both hands.
- Lower until elbows are aligned with shoulders with elbows bent at 90° angle.
- During the test, keep the chin on the chest, looking towards the ground.

Termination Criteria

- Subject terminates the test.
- Subject lifts their head.
- Elbows are no longer aligned with shoulders.

Tables

Table 1:
Characteristics of the study population

	Test reproducibility	Muscle norms participants		
	participants	Males	Females	*p Value*
	(*n=20*)	(*n=200*)	(*n=200*)	
	Mean ± SD	Mean ± SD	Mean ± SD	
Age (years)	40.9 ± 11.6	39.4 ± 11.4	39.7 ± 11.5	NS
Mass (kg)	79.9 ± 16.8	82.9 ± 13.7	66.3 ± 14.6	***
Height (cm)	172.6 ± 7.9	178.0 ± 7.5	165.8 ± 5.9	***
BMI (Kg/m^2)	26.7 ± 4.3	26.2 ± 4.3	24.1 ± 5.0	NS
Baecke score (a.u)	7.1 ± 1.1	7.9 ± 2.1	7.5 ± 1.8	NS
Abdominal muscles endurance (s)	147.3 ± 77.8	121.7 ± 47.9	120.0 ± 67.8	NS
Back extensor muscles endurance (s)	210 ± 76.8	181.0 ± 66.8	183.2 ± 92.8	NS
Right oblique muscles endurance (s)	80.5 ± 35,7	76.9 ± 34.7	76.7 ± 35.2	NS
Left oblique muscles endurance (s)	81.9 ± 30.3	77.7 ± 33.1	77.4 ± 32.8	NS
Quadriceps muscles endurance (s)	75.3 ± 28.4	81.7 ± 29.8	76.8 ± 32.4	NS
Hamstrings muscles endurance (s)	243.2 ± 110.3	240.2 ± 76.5	224.2 ± 90.2	NS
Back muscles endurance (s)	185.7 ± 77.4	183.7 ± 58.8	186.3 ± 79.8	NS
Chest muscles endurance (s)	76.3 ± 25.5	64.3 ± 19.4	63.7 ± 28.8	NS

*SD: Standard Deviation; kg: kilograms; cm: centimeters; BMI: Body Mass Index; a.u: arbitrary units; s: seconds; NS: non-significant; *** p<0.001; The mean and standard deviation of all endurance muscles tests for test reproducibility correspond to overall mean of the last three assessments "A2", "B1" and "B2". A2: second assessment of assessor A; B1 first assessment of assessor B; B2: second assessment of assessor B*

Table 2.a:

Intra-assessor intraclass correlation coefficients

Muscle isometric tests	B1 (sec.) *Mean ± SD*	B2 (sec.) *Mean ± SD*	Bias (sec.) *Mean ± SD*	ICC [95% CI]	95% LOA (sec.) Lower	Upper	SEM (sec.)	SEM (%)
Abdominal muscles endurance	145.2 ± 79.3	146.0 ± 79.1	-0.8 ± 20.1	0.984 [0.961 – 0.994]	-40.15	38.65	2,54	1,75
Back extensor muscles endurance	207.4 ± 81.9	210.9 ± 71.9	-3,5 ± 26.9	0.970 [0.924 – 0.988]	-56.27	49.27	4,66	2.23
Right oblique muscles endurance	77.5 ± 36.0	81.4 ± 36.4	-3,9 ± 14.7	0.956 [0.891 – 0.983]	-32.71	24.91	3.08	3.88
Left oblique muscles endurance	79.2 ± 32.5	82.8 ± 30.6	-3,6 ± 12.9	0.955 [0.889 – 0.982]	-28.85	21.65	2.73	3.37
Quadriceps muscles endurance	74.1 ± 27.8	74.5 ± 31.2	-0.4 ± 11.9	0.959 [0.897 – 0.984]	-23.84	22.94	2.42	3.25
Hamstrings muscles endurance	241.8 ± 114.3	242.2 ± 112.6	-0.5 ± 24.3	0.989 [0.972 – 0.996]	-48.11	47.21	2.55	1.05
Back muscles endurance	185.8 ± 80.6	184.8 ± 75.5	1.0 ± 19.0	0.986 [0.964 – 0.994]	-36.18	38.18	2.24	1.21
Chest muscles endurance	74.2 ± 26.2	77.1 ± 27.6	-2.9 ± 12.1	0.946 [0.866 – 0.978]	-26.69	20.89	2.82	3.73

ICC: intraclass correlation coefficients; CI: confidence intervals; SEM: standard error of measurement; LOA: limits of agreement; sec: seconds; %: percentage; SD: standard deviation; B1: first assessment of assessor B; B2: second assessment of assessor B

Table 2.b:
Inter-assessor intraclass correlation coefficients between assessments “B1” and “A1”

Muscle isometric tests	B1 (sec.) *Mean ± SD*	A1 (sec.) *Mean ± SD*	Bias (sec.) *Mean ± SD*	ICC [95% CI]	95% LOA (sec.) Lower	Upper	SEM (sec.)	SEM (%)
Abdominal muscles endurance	145.2 ± 79.3	150.8 ± 78.9	-5.6 ± 10.2	0.995 [0.983 – 0.998]	-25.66	14.46	0.72	0.50
Back extensor muscles endurance	207.4 ± 81.9	211.8 ± 80.2	-4,5 ± 13.0	0.993 [0.982 – 0.997]	-30.01	21.11	1.09	0.52
Right oblique muscles endurance	77.5 ± 36.0	82.6 ± 36.6	-5,1 ± 9.1	0.980 [0.937 – 0.993]	-22.80	12.70	1.28	1.61
Left oblique muscles endurance	79.2 ± 32.5	83.6 ± 29.2	-4.4 ± 10.1	0.969 [0.916 – 0.988]	-24.29	15.49	1.79	2.21
Quadriceps muscles endurance	74.1 ± 27.8	77.3 ± 27.3	-3.2 ± 9.7	0.966 [0.914 – 0.987]	-22.27	15.87	1.79	2.42
Hamstrings muscles endurance	241.8 ± 114.3	245.6 ± 109.7	-3.9 ± 14.5	0.996 [0.989 – 0.998]	-32.21	24.51	0.91	0.38
Back muscles endurance	185.8 ± 80.6	186.6 ± 80.1	-0.8 ± 15.7	0.991 [0.977 – 0.996]	-31.51	29.91	1.49	0.80
Chest muscles endurance	74.2 ± 26.2	77.7 ± 23.7	-3.5 ± 13.9	0.915 [0.788 – 0.966]	-30.81	23.81	4.06	5.37

ICC: intraclass correlation coefficients; CI: confidence intervals; SEM: standard error of measurement; LOA: limits of agreement; sec: seconds; %: percentage; SD: standard deviation; B1: first assessment of assessor B; A2: second assessment of assessor A

Table 2.c:
Inter-assessor intraclass correlation coefficients between assessments “B2” and “A1”

Muscle isometric tests	B2 (sec.) *Mean ± SD*	A2 (sec.) *Mean ± SD*	Bias (sec.) *Mean ± SD*	ICC [95% CI]	95% LOA (sec.)		SEM (sec.)	SEM (%)
					Lower	Upper		
Abdominal muscles endurance	146.0 ± 79.1	150.8 ± 78.9	-4.9 ± 13.8	0.992 [0.979 – 0.997]	-31.93	22.23	1.24	0.85
Back extensor muscles endurance	210.9 ± 71.9	211.8 ± 80.2	-1.0 ± 20.2	0.983 [0.957 – 0.993]	-40.58	38.68	2.64	1.26
Right oblique muscles endurance	81.4 ± 36.4	82.6 ± 36.6	-1.2 ± 11.7	0.975 [0.936 – 0.990]	-24.08	21.78	1.85	2.33
Left oblique muscles endurance	82.8 ± 30.6	83.6 ± 29.2	-0.8 ± 12.7	0.955 [0.886 – 0.982]	-25.71	24.11	2.70	3.33
Quadriceps muscles endurance	74.5 ± 31.2	77.3 ± 27.3	-2.8 ± 11.9	0.957 [0.893 – 0.983]	-26.06	20.56	2.47	3.32
Hamstrings muscles endurance	242.2 ± 112.6	245.6 ± 109.7	-3.4 ± 13.6	0.996 [0.991 – 0.998]	-30.00	23.20	0.86	0.35
Back muscles endurance	184.8 ± 75.5	186.6 ± 80.1	-1.8 ± 14.6	0.991 [0.978 – 0.997]	-30.47	26.87	1.39	0.75
Chest muscles endurance	77.1 ± 27.6	77.7 ± 23.7	-0.6 ± 10.8	0.956 [0.889 – 0.983]	-21.69	20.49	2.26	3.00

ICC: intraclass correlation coefficients; CI: confidence intervals; SEM: standard error of measurement; LOA: limits of agreement; sec: seconds; %: percentage; SD: standard deviation; B2: second assessment of assessor B; A2: second assessment of assessor A

Table 3: Males performance prediction equations for all isometric tests

	performance prediction equations		*p Value*		
			Age (years)	**Weight (kg)**	**Size (cm)**
Abdominal muscles	-10.92 - (1.18 x age) - (0.87 x weight) + (1.41 x size)		***	***	**
Back extensor muscles	112.42 - (1.89 x age) - (1.10 x weight) + (1.32 x size)		***	**	*
Right oblique muscles	17.44 - (1.13 x age) - (0.78 x weight) + (0.94 x size)		***	***	**
Left oblique muscles	35.49 - (1.11 x age) - (0.87 x weight) + (0.89 x size)		***	***	**
Quadriceps muscles	-9.59 - (0.60 x age) - (0.49 x weight) + (0.87 x size)		***	**	**
Hamstrings muscles	35.17 - (1.66 x age) - (1.33 x weight) + (2.14 x size)		***	***	**
Back muscles	125.19 - (1.94 x age) - (0.84 x weight) + (1.15 x size)		***	**	*
Chest muscles	38.76 - (0.64 x age) - (0.41 x weight) + (0.48 x size)		***	***	**
*Kg: kilograms; cm: centimeter; * p<0.05; ** p<0.01; *** p<0.001*					

Table 4: Females performance prediction equations for all isometric tests

	performance prediction equations		*p Value*		
			Age (years)	**Weight (kg)**	**Size (cm)**
Abdominal muscles	-355.82 - (0.96 x age) - (1.69 x weight) + (3.78 x size)		*	***	***
Back extensor muscles	-683.83 - (1.30 x age) - (2.20 x weight) + (6.42 x size)		*	***	***
Right oblique muscles	- 40.55 - (1.09 x age) - (0.92 x weight) + (1.34 x size)		***	***	***
Left oblique muscles	- 29.35 - (1.06 x age) - (0.88 x weight) + (1.25 x size)		***	***	***
Quadriceps muscles	- 257.23 - (1.74 x age) - (1.47 x weight) + (3.68 x size)		***	***	***
Hamstrings muscles	- 57.63 - (0.64 x age) - (0.45 x weight) + (1.06 x size)		***	**	**
Back muscles	- 81.78 - (0.56 x age) - (0.74 x weight) + (1.39 x size)		**	***	***
Chest muscles	- 282.91 - (1.92 x age) - (1.88 x weight) + (4.27 x size)		***	***	***
*Kg: kilograms; cm: centimeter; * p<0.05; ** p<0.01; *** p<0.001*					

Figures

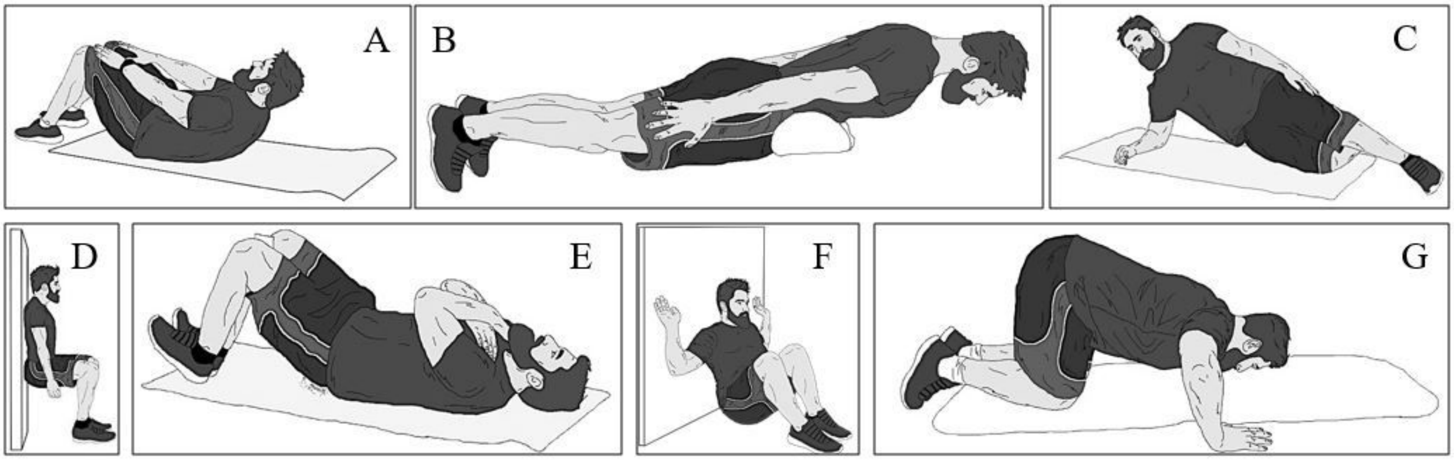

Figure 1

Figures illustrating the measurement muscle isometric endurance. Legend: (A) Trunk flexors, (B) Trunk extensors, (C) Oblique muscles, (D) Quadriceps muscles, (E) Hamstring muscles, (F) Back muscles, and (G) Chest muscles