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Quadriceps function assessment using an incremental test and magnetic neurostimulation: A reliability study

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ABSTRACT

We investigated the reliability of a test assessing quadriceps strength, endurance and fatigability in a single session. We used femoral nerve magnetic stimulation (FMNS) to distinguish central and peripheral factors of neuromuscular fatigue. We used a progressive incremental loading with multiple assessments to limit the influence of subject's cooperation and motivation.

Twenty healthy subjects (10 men and 10 women) performed the test on two different days. Maximal voluntary strength and evoked quadriceps responses via FMNS were measured before, after each set of 10 submaximal isometric contractions (5-s on/5-s off; starting at 10% of maximal voluntary strength with 10% increments), immediately and 30 min after task failure.

The test induced progressive peripheral (41 ± 13% reduction in single twitch at task failure) and central fatigue (3 ± 7% reduction in voluntary activation at task failure). Good inter-day reliability was found for the total number of submaximal contractions achieved (i.e. endurance index: ICC = 0.83), for reductions in maximal voluntary strength (ICC > 0.81) and evoked muscular responses (i.e. fatigue index: ICC > 0.85). Significant sex-differences were also detected.

This test shows good reliability for strength, endurance and fatigability assessments. Further studies should be conducted to evaluate its feasibility and reliability in patients.

1. Introduction

Neuromuscular function (NMF) can be divided into three main components, i.e. strength, endurance and fatigability. The NMF of locomotor muscles has been extensively studied in the fields of exercise and clinical physiology. Impairment of locomotor muscles function has been identified as a relevant contributing factor of exercise intolerance and disability in various pathologic conditions, such as neuromuscular diseases (Wiles and Karni, 1983; Colombo et al., 2000; Rozman et al., 2001; Grabljevec et al., 2005), chronic obstructive pulmonary disease (COPD) (Saey et al., 2003), and chronic heart failure (Opasich et al., 1999). Quadriceps weakness has been correlated with mortality in COPD (Swallow et al., 2007) and chronic heart failure (Hulsmann et al., 2004) patients. NMF impairment is also critical in the elderly population regarding the occurrence of falls (Moreland et al., 2004) and mortality (Newman et al., 2006).

Strength, endurance and fatigability can be impacted to a different degree depending on the pathology. For instance, COPD patients exhibit larger locomotor muscle endurance impairment than strength impairment (Van't Hul et al., 2004; Saey and Troosters, 2008). In coronary artery disease, endurance can be reduced despite preserved strength (Gayda et al., 2005). Also, strength and endurance may not change in a similar way during the natural history of the disease as well as following therapeutic interventions (Serres et al., 1998). Exercise therapy (Orngreen et al., 2005; van der Kooi et al., 2005) and other emerging therapies seem to present a wide potential to improve NMF. Therefore, there is a need for both diagnosis and follow-up purposes to develop reliable NMF assessment tools providing a comprehensive evaluation of strength, endurance and fatigue (Saey and Troosters, 2008).

Validated procedures to measure volitional quadriceps strength with normative values are well documented (Horemans et al., 2004; Hogrel et al., 2007; Seymour et al., 2010). NMF embraces peripheral and central contribution (Gandevia, 2001) that cannot be explored by the traditional measurement of maximal voluntary

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strength. Artificially-evoked muscular responses via femoral nerve electrical (Prasartwuth et al., 2005; Millet et al., 2011) or more recently, magnetic (Polkey et al., 1996; O'Brien et al., 2008) stimulation have been used as a tool to assess non-volitional peripheral strength and the degree of muscle activation. Similarly, neuromuscular fatigue (i.e. exercise-induced reduction in voluntary strength (Bigland-Ritchie et al., 1978)) involves peripheral (i.e. exercise-induced reduction in muscle contractility) and central mechanisms (i.e. exercise-induced reduction in muscle activation during voluntary contractions caused by a decreased in motoneurons output at the spinal or/and supraspinal level (Gandevia, 2001)) that can be explored with artificial stimulation. Femoral nerve magnetic stimulation (FNMS) has been shown to be better tolerated than traditional electrical neurostimulation (Han et al., 2006; Szecsi et al., 2010) and to provide comparable results (Verges et al., 2009).

Muscle endurance is commonly assessed by the ability to maintain or to repeat a submaximal contraction based on a fraction of the maximal voluntary strength. However, there is no standardized method and various protocols involving different contraction patterns such as isometric or dynamic contractions on isokinetic or custom chairs, sustained or intermittent submaximal contractions (e.g. Serres et al., 1998; Couillard et al., 2003; Koechlin et al., 2004) have been used. The subjects' motivation and their capacity to withstand pain is a key factor in these 'task failure' designs (Enoka and Stuart, 1992). This can, at least partly, explain why patients exhibit a wider variability in endurance time than healthy subjects. For instance, Gruet et al. (2010) found that cystic fibrosis patients had a between-day variability in quadriceps endurance more than twice greater than healthy subjects, even when well encouraged. Typically, muscle fatigue is characterized from pre- to post-maximal exercise measurements only, so that fatigue kinetic is not reported and the amount of fatigue is dependent on the cooperation of the patient to reach maximal achievement. An alternative could be an incremental exercise protocol starting at a low fraction of maximal isometric strength with repetitive NMF assessment to describe fatigue kinetic. Such a test would be more progressive than constant-load protocols usually performed at 50–70% of maximal voluntary strength and achievable by patients, even in advanced stage of disease. Another critical advantage of such a design is to limit motivation and pain confounding factors because it allows comparing a fatigue level after a standardized amount of muscular work rather than a final maximal performance as the only reference.

Hence, we propose a quadriceps intermittent fatigue test (QIF test) aiming to (i) measure strength, endurance and fatigability in a single session, (ii) distinguish peripheral and central fatigue factors using FMNS, and (iii) bypass the influence of psychological/motivational confounding factors on fatigability assessment. The aim of the present study was to evaluate the feasibility and the reproducibility of the QIF test as well as its ability to detect inter-individual differences such as sex differences.

2. Methods

2.1. Subjects

Twenty healthy subjects (10 males and 10 females) volunteered to participate in this study. Their main characteristics are presented in Table 1. The study was conducted according to the Declaration of Helsinki and after approval from the local Committee on Human Research (*Comité de protection des personnes Sud-EST V*). Written informed consent was obtained from all subjects. Subjects had never been exposed to exercise testing, NMF measurement and nerve stimulation procedures.

Table 1
Subjects characteristics and performance during the maximal incremental cycling test.

	Female	Male
Subjects characteristics		
Age (y)	27 ± 10	23 ± 3
Height (cm)	168 ± 8	176 ± 6
Weight (kg)	60 ± 7	71 ± 9
BMI (kg m^{-2})	21.4 ± 1.8	22.7 ± 2.8
Body fat (%)	25 ± 5	13 ± 3
Maximal incremental cycling test		
Maximum work load (W)	179 ± 33	263 ± 42
VO_2 max (mLO_2 min^{-1} kg^{-1})	33.3 ± 6.7	46.8 ± 6.4
VO_2 max (% of predicted)	96 ± 12	101 ± 13
Maximal blood lactate concentration (mmol L^{-1})	9.5 ± 3.3	11.5 ± 4.5

Values are means ± SD. BMI, body mass index; VO_2 max, maximal oxygen uptake.

2.2. Protocol

Subjects performed three exercise test sessions. During a preliminary visit, subjects had clinical examination, anthropometric measurements and performed a maximal incremental exercise test on a cycle ergometer. During the next two sessions, subjects performed a quadriceps intermittent fatigue test (QIF1 and QIF2). Delay between consecutive QIF test sessions was 9 days on average (range: 5–19 days).

2.3. Anthropometric measurements

Body fat percentage was assessed by skinfold technique as described by Durnin and Womersley (1974).

2.4. Maximal cycling test

Subjects performed a standard maximal incremental exercise test (60–80 W initial power and 15 W min^{-1} increment until subject exhaustion) on a computer-controlled electrically-braked cycle ergometer (Ergometrics 800, Ergoline, Bitz, Germany) with expired gas analysis and 12-lead electrocardiogram for the determination of maximal aerobic workload, maximal oxygen uptake and maximal heart rate (Medisoft, Dinant, Belgium). A fingertip blood sample was obtained 3 min after exhaustion and was analyzed for lactate concentration (NOVA +, Nova Biomedical Corporation, Waltham MA, USA).

2.5. Quadriceps intermittent fatigue test (QIF test)

2.5.1. Experimental setup

An overview of the experimental setup is shown in Fig. 1. All measurements were conducted on the right lower limb under isometric conditions. Subject lay supine on a customized quadriceps chair. The knee was flexed at 90° and the hip angle was 130° for proper access to the femoral triangle during FNMS. Voluntary strength and evoked responses to FNMS were measured with an inextensible ankle strap connected to a strain gauge (SBB 200 kg Tempo Technologies, Taipei, Taiwan). Compensatory movement of the upper body was limited by two belts across thorax and abdomen. Subjects were asked to keep their hands on their abdomen. Visual feedback of the force produced and the target force level (see below) was provided to the subjects.

2.5.2. Femoral nerve magnetic stimulation (FNMS)

FNMS was performed with a 45-mm figure-of-eight coil powered by two linked Magstim 200 stimulators (peak magnetic field 2.5 T, stimulation duration 0.1 ms; Magstim, Whitland, United Kingdom). The linking circuitry (Bistim Module, Magstim) was