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Original article

Validity and reliability of three methods of stiffness assessment

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Abstract

Background: Stiffness is commonly assessed in relation to injury and athletic performance. The purpose of this research was to compare the validity and reliability of 3 *in vivo* methods of stiffness assessment using 1 cohort of participants.
Methods: To determine inter-day reliability, 15 female netballers were assessed for stiffness twice within 1 week using unilateral hopping (vertical stiffness), free oscillations of the calf, and myometry of various muscles of the triceps surae. To establish convergent construct validity, stiffness was compared to static and dynamic strength measurements.
Results: Test–retest stiffness results revealed that vertical stiffness produced moderate to high reliability results and myometry presented moderate to very high reliability. In contrast, the free oscillation technique displayed low to moderate reliability. Vertical stiffness demonstrated a significant correlation with rate of force development during a squat jump, whilst myometer stiffness measurements from 3 sites in the lower limb revealed significant correlations with isometric rate of force development. Further, significant negative correlations were evident between the eccentric utilisation ratio and various myometer stiffness results. No relationships were established between the free oscillation technique and any of the performance measurements.
Conclusion: These results suggest that vertical stiffness and myometry are valid and reliable methods for assessing stiffness.

Keywords: Calf stiffness; Free oscillation technique; Myometry; Myoton-Pro; Vertical hop test; Vertical stiffness

1. Introduction

In a mechanical context, stiffness refers to a body resisting an applied change in length.[1,2] Butler and colleagues[3] explain that the concept of stiffness involves deformable bodies that store and return elastic energy. Relatively high stiffness in humans has previously been related to increased risk of repetitive stress injuries as well as soft-tissue injuries such as hamstring strains.[4–6] Further, stiffness has been related to performance of stretch–shorten cycle activities.[7–10] Since athletes strive to remain injury free and to perform optimally, stiffness is an important screening marker for physiotherapists, coaches, strength and conditioning trainers, and other practitioners. As detailed by Hooke's Law, the force required to deform the body is equal to the spring constant multiplied by the distance of deformation.[3] The spring constant relates to the innate stiffness of the body; thus, to calculate stiffness, the required force and the distance of deformation are measured. Many techniques have been successfully implemented to distinguish between relatively stiff or relatively compliant participants. These include ultrasonography,[11] the quick-release technique,[12,13] the vertical hop test,[1] myometry,[14] and the free oscillation technique.[15] The current study will focus on the latter 3, as they are relatively simple to administer, and allow for relatively large cohorts to be tested within restricted time frames. Situations such as these are particularly relevant when testing professional athletes or conducting large-scale field studies.

The vertical hop test was initially outlined by McMahon and Cheng[1] and typically involves unilateral hopping on a force platform. Excellent levels of reliability have been reported[16] and the test is logistically simple to administer requiring the measurement of only 2 mechanical parameters: ground reaction force (GRF) and centre of mass displacement (ΔCOM).[17] Although relatively simple to administer, the nature of the calculation makes many assumptions. Firstly, it assumes that vertical stiffness (K_{vert}) remains constant during hopping. However, it has been reported that K_{vert} increases inversely with ground contact time,[18] and linearly with hopping height.[19,20] Thus, inherent differences in hopping techniques between individuals

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may affect the reliability and validity of this measurement of stiffness.

A further assumption of the vertical hop test is that the human leg works as a single linear spring, and that all components of the leg equally contribute to K_{vert}. However, ankle joint stiffness was reported as the primary modulator of K_{vert} during hopping.[20] Whilst this method involves some assumptions, it is a global, inclusive, and functional measurement of lower-body stiffness.

The free oscillation technique assesses the stiffness of a limb segment based on the assumption that human muscles behave like a damped spring system.[15] This assumption suggests that if any perturbation is applied whilst under load, the system will oscillate at a damped natural frequency due to the nature of the muscle and tendon structures.[21] In a damped spring system, when a perturbation is applied, the damping coefficient causes the subsequent oscillations to subside over time. The free oscillation technique for stiffness assessment has been widely used in previous studies[15,22–24] and has generally been proven to be valid and reliable.[24] Whilst the validity and reliability of these methods have been proven to be strong, accessibility issues may arise due to the limited mobility of the assessment apparatus. Further, procedures often require the assessment of a maximum voluntary contraction prior to stiffness assessment, which requires a greater length of time per testing session.

A further method of stiffness measurement is through the use of a myometer, an electronic device that is capable of recording multiple characteristics related to muscular tone such as tension, elasticity, and stiffness.[14] Muscle stiffness calculation by myometry involves a small perturbation from the device applied to the skin covering the muscle. An accelerometer then measures the deformation characteristics of the muscle and calculates stiffness using the damped natural oscillations exhibited by the recoil characteristics of the muscle.[14,25] Commonly reported myometer models include the Myoton-2, Myoton-3, and more recently, the Myoton-Pro.

The Myoton-2 reportedly has a high level of inter-observer repeatability[14] and inter-day reliability.[25] The sensitivity of the device[25] and its ease of use[14] have been commended; however, its weakness was that it was solely suitable for surface musculature.[14] The Myoton-3 reportedly displays excellent absolute inter-day reliability[26] and significant correlations when evaluating concurrent and predictive validity.[27] Zinder and Padua[28] also reported good reliability and construct validity, noting an advantage of the device was its ability to measure isolated muscles. The Myoton-Pro has shown very high to excellent within-day reliability, and good to high between-day reliability.[29] However, to the best of the authors' knowledge, there are no previous reports of the validity of this device.

It is important to establish the reliability and validity of data collection techniques to ensure any subsequent results are true and consistent. Whilst there have been separate reports of validity and reliability for each individual technique, no previous literature has compared the 3 techniques using the same cohort of participants.[24,25] Further, no previous study has evaluated the validity and reliability of the Myoton-Pro device. Thus, the aim of the current study was firstly to determine the convergent construct validity when compared to performance variables and the inter-day reliability of a new device to measure stiffness (Myoton-Pro), and secondly to compare the inter-day reliability and convergent construct validity of the vertical hop test, myometry, and the free oscillation technique. Knowledge of validity and reliability can assist with sample size calculations, as well as contribute to study design and development of appropriate methodology for future studies.

2. Materials and methods

2.1. Participants

Fifteen females who competed at various levels of competitive netball in the 2012 season, including New South Wales State League and club A-grade, volunteered to participate in this study. Participants were excluded from the study if they had sustained an injury within 3 months of testing, or fell outside the age range of 18–35 years. The study was approved by the Human Research Ethics Committee of the University of Technology, Sydney, and a written informed consent was obtained from each participant.

2.2. Procedures

The participants were assessed for stiffness twice within 1 week. To avoid any possible effects of fatigue, testing was conducted at least 48 h after competition, and sessions were at least 24 h apart. In order to maintain consistency of measurements, stiffness was assessed using 3 methods in the same order (myometry, followed by the free oscillation technique, and followed by the vertical hop test) and at the same time of day on each occasion. The participants were instructed not to deviate from their regular training patterns. In addition, the participants completed various performance tests following stiffness assessment during the first session only, to determine the convergent construct validity of the stiffness assessment methods. Prior to the commencement of Session 1, the participants were weighed on digital scales (Tanita, Sydney, Australia) and body mass was recorded to the nearest 0.1 kg. A 5 min warm-up on a stationary bike was then conducted with a required power output of 100 W.

2.2.1. Static strength measurements

The maximum isometric force (MIF) and rate of force development (RFD) during a unilateral isometric calf raise was measured with participants positioned in a seated calf raise machine with a mechanical winch attached (Fig. 1A). Hip, knee, and ankle joints were aligned at 90°, with the winch adjusted to fix this position during contraction. The participants were instructed to produce maximal force against the knee pad as fast as possible, holding for 3 s. The force data were collected via the load cell (Chase Engineering, Perth, Australia) at a rate of 1000 Hz. MIF was calculated as the peak of the force curve, whilst isometric RFD (RFD_{iso}) was determined as the peak value of the derivative of the force curve using a 5 ms interval.[9] Two trials were completed on each leg, and the greatest MIF value for each limb was used to determine subsequent loads for stiffness assessment.