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Reliability of telemetric electromyography and near-infrared spectroscopy during high-intensity resistance exercise

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ABSTRACT

This study quantified the inter- and intra-test reliability of telemetric surface electromyography (EMG) and near infrared spectroscopy (NIRS) during resistance exercise. Twelve well-trained young men performed high-intensity back squat exercise (12 sets at 70–90% 1-repetition maximum) on two occasions, during which EMG and NIRS continuously monitored muscle activation and oxygenation of the thigh muscles. Intra-test reliability for EMG and NIRS variables was generally higher than inter-test reliability. EMG median frequency variables were generally more reliable than amplitude-based variables. The reliability of EMG measures was not related to the intensity or number of repetitions performed during the set. No notable differences were evident in the reliability of EMG between different agonist muscles. NIRS-derived measures of oxyhaemoglobin, deoxyhaemoglobin and tissue saturation index were generally more reliable during single-repetition sets than multiple-repetition sets at the same intensity. Tissue saturation index was the most reliable NIRS variable. Although the reliability of the EMG and NIRS measures varied across the exercise protocol, the precise causes of this variability are not yet understood. However, it is likely that biological variation during multi-joint isotonic resistance exercise may account for some of the variation in the observed results.

1. Introduction

Surface electromyography (EMG) provides a non-invasive, objective method to measure physiological processes occurring during muscular contraction. The EMG signal is influenced by a number of factors, such as motor unit discharge rates, muscle fibre membrane characteristics, and non-physiological properties including electrode size, shape and placement (Farina et al., 2004). Daily variations in EMG recording may be associated with differences in electrode re-application, including alterations in electrode position and differences in skin preparation. Although EMG has demonstrated moderate to high levels of reliability during quadriceps contractions (Larsson et al., 2003; Mathur et al., 2005), the systems typically used have required wired attachment between electrodes and an EMG amplifier. Such systems are cumbersome when performing complex movements, limiting their application during field-based testing. Furthermore, the risk of leads becoming dislodged from their electrode increases the chance for data loss.

Recent technological advances have resulted in the development of telemetric EMG systems to mitigate these limitations. These systems require only one electrode for targeted muscles, compared to wired systems requiring up to two electrodes per muscle and an additional reference electrode. However, whether this telemetric configuration results in reliable data is not well understood. While one investigation has reported the reliability for telemetric EMG during uphill running activity as 0.98 (presumably correlation coefficient) (Lowery et al., 2014), the methods and analyses employed to assess reliability were not stated.

It must also be acknowledged that research examining the reliability of EMG technologies has not typically used dynamic multi-joint exercises, or assessed whether resistance exercise intensity can affect the reproducibility of EMG variables. As such, the current body of reliability research in this field may be limited in its application to common resistance training methods. For increases in muscular size and strength, resistance training is typically performed using moderate and high loads, and with a set volume (i.e. number of repetitions in a set) that corresponds to the exercise intensity (Bird et al., 2005). However, it is not currently clear

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whether manipulating these training variables affects the reliability of EMG measurements.

Muscle oxygenation status has also been investigated during resistance exercise models to describe the intramuscular metabolic environment (Azuma et al., 2000; Hoffman et al., 2003). During resistance exercise, increases in intramuscular mechanical pressure lead to reduced blood flow (MacDougall et al., 1985), resulting in transient muscle hypoxia (Spiering et al., 2008), which may facilitate increased hypertrophy (Hoffman et al., 2003). Indeed, localized muscular hypoxia induced via blood flow restriction has resulted in enhanced anabolic responses to resistance exercise (Abe et al., 2005; Takarada et al., 2000). While the effects of muscle oxygenation status on resistance training adaptations are not fully understood, the use of near infrared spectroscopy (NIRS) to monitor muscle oxygenation has become popular among exercise scientists (Quaresima et al., 2003). This may be especially important for research investigating resistance training with blood flow restriction or additional systemic hypoxia, which is currently promoted as a beneficial new training stimulus (Scott et al., 2014b). NIRS is non-invasive, and reflects the balance of oxygen delivery to working muscles and oxygen consumption in capillary beds.

NIRS values during isometric erector spinae activity have demonstrated a moderate to strong intraclass correlation coefficient (ICC; 0.69–0.84) (Kell et al., 2004). NIRS data during knee extension exercise has also yielded moderate to strong ICC values during both isokinetic (0.73–0.97) (Pereira et al., 2005) and isotonic (ICC = 0.85 and coefficient of variation [CV] = 0.07%) (Tanimoto and Ishii, 2006) exercise protocols. More recently, significant ICC values (0.39–0.87) have been shown for NIRS measures in the forearm muscles during handgrip exercise at various intensities (Celie et al., 2012). While these studies have reported the reliability of NIRS during single-joint resistance exercise, no data have reported on the reliability of NIRS measures during multi-joint isotonic resistance exercise. Furthermore, these studies reporting on the reliability of NIRS have utilized static or seated exercises, and it remains unknown whether the greater postural control required during dynamic exercises might affect its reliability. It is possible that different contributions from synergistic muscles during dynamic multi-joint exercise may alter the reliability of muscle oxygenation within a single muscle.

It is evident that the reliability of telemetric EMG and NIRS devices during dynamic multi-joint resistance exercise at various intensities is not yet known. Understanding the reliability of these technologies during resistance exercise is important to ensure that any measured differences in muscle activation or oxygenation status are indicative of actual change, rather than error in the measurement itself. In addition, many studies investigating the reliability of EMG and NIRS variables have focused largely on ICC values to test reliability. The ICC is a relative measure of reliability, and is affected by the range of the values being assessed (Atkinson and Nevill, 1998). For a more detailed reliability analysis, further statistics such as typical error (often expressed as a percentage CV) should be included (Atkinson and Nevill, 1998; Hopkins, 2000). Therefore, the purpose of this study was to comprehensively investigate the intra- and inter-test reliability of a telemetric EMG system and NIRS device during moderate- and high-intensity dynamic multi-joint resistance exercise. The research also aimed to determine if the intensity or number of repetitions performed within a set affected reliability.

2. Methods

2.1. Experimental approach to the problem

Subjects visited the laboratory on four occasions, each separated by one week. Sessions one and two involved familiarisation and 1RM testing using a modified harness back squat (HBS) exercise (Fig. 1). Sessions three and four were identical, and involved experimental trials of a high-intensity resistance exercise protocol using the HBS. During experimental trials, muscle activation and oxygenation status were continuously monitored to determine the reliability of telemetric EMG and NIRS technologies.

2.2. Participants

Twelve healthy males (age: 24.8 ± 3.4 yr, height: 178.6 ± 6.0 cm, body mass: 84.8 ± 11.0 kg) volunteered to participate in this study. All participants had at least two years resistance training experience and were free of musculoskeletal disorders. Prior to commencement, participants were informed of the nature of the research, provided informed consent, and were screened for medical contraindications. They were instructed to abstain from alcohol and caffeine for 24 h before each testing session, and to avoid any strenuous physical activity for the duration of the research. Subjects were also instructed to replicate their food and liquid intake for the 24-h period prior to each test. The University of Newcastle Human Ethics Committee approved the study and its methods.

2.3. Familiarisation and 1-repetition maximum testing

To ensure subjects were confident in performing the HBS exercise, which has been described previously (Scott et al., 2014a), they were familiarized with testing procedures and equipment prior to experimental trials. This exercise was chosen as it is a dynamic multi-joint exercise, and has both clinical and athletic applications. Within one week of familiarization, subjects were tested for 1RM of the HBS exercise. For the 1RM test, subjects completed a general warm-up (5 min on a cycle ergometer at a moderate intensity), before performing three specific warm-up sets of the HBS, comprised of 10 repetitions at 50% of predicted 1RM weight (as estimated by the subject), 5 repetitions at 70%, and 1 repetition at 90%. Following the warm-up sets, weight was increased by ~5% and subjects performed a single repetition. This process continued until subjects were unable to successfully perform a lift, with 3 min rest between attempts. Subjects' 1RM was defined as their heaviest completed repetition, and was determined within 3–6 sets.

2.4. Experimental trials

Subjects reported to the laboratory on two further occasions to perform identical resistance exercise trials. Upon arrival, EMG and NIRS devices were affixed before subjects completed a general warm-up, followed by three specific warm-up sets (10 repetitions at 50% of measured 1RM, 5 repetitions at 65%, and 1 repetition at 80%). Following the warm-up, subjects rested for 3 min, before beginning 12 sets of a high-intensity resistance exercise protocol (Table 1), during which muscle activation and oxygenation status were monitored via EMG and NIRS, respectively. Subjects wore the same footwear for each trial.

The exercise protocol was designed to assess muscle function within both single and multiple repetition sets at various high-intensity loads, in order to provide a comprehensive examination of device reliability. Single-repetition sets were included to examine EMG and NIRS reliability during a maximal effort at a given intensity, as subjects were instructed to perform the concentric phase of the lift as quickly as possible. Multiple-repetition sets were included to quantify reliability during sets at various high-intensities when a typical set volume was employed. That is, for individuals completing strength training it is common to perform 3, 6, and 10 repetitions at intensities of 90%, 80% and 70% 1RM, respectively.