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Abstract

The reliability of electromyographic (EMG) data has been examine for isometric and slow dynamic tasks, but little is known about the repeatability of this data for ballistic movements. The purpose of this study was to examine the within-session, trial-to-trial reliability of a variety of quadriceps and hamstrings muscles during isometric and ballistic activities. Data were analayzed by way of intraclass correlation coefficients (ICC), inter-subject coefficients of variation (CV_{inter}), and intra-subject coefficients (CV_{intra}). Twenty-four subjects performed 3 repetitions each of 2 randomly ordered test exercises, including landing from a depth jump (J) and cutting after a 10-m sprint (C). Data were acquired and processed with root mean square EMG for the muscles assessed, and data were analyzed for each exercise using a repeated measures analysis of variance. Results revealed that all ICC values were greater than 0.80, with most values greater than 0.90, CV_{inter} values ranged from 5.4% to 148.7%, and CV_{intra} values ranged from 11.5% to 49.3%. This study indicates that EMG is a reliable method for assessing the reproducibility of both the quadriceps and hamstrings muscle activation during either isometric or ballistic exercises.

Key Words: reproducibility, sport simulated movement, coefficient of variation, intraclass correlation coefficient, interclass correlation coefficient

Introduction

Surface electromyography (EMG) is commonly used to quantify the magnitude and timing of muscle activation during various physical tasks, which has broad application in sport science research. Electromyography has been used to assess muscle activity during isometric, slow dynamic, and ballistic tasks. Muscle activity during ballistic movements, such as explosive hip and knee extension tasks, are of particular interest because these are characteristic of nearly all sport movements.

Although the noninvasive nature of surface EMG makes this technique ideal for clinical use and research, EMG data can be variable, which raises questions about the reliability of this technique. Repeatability of EMG data is established for many isometric exercises (4,11,14,18,20) but less is known about the reliability of this method of analysis during dynamic exercise, particularly ballistic movements. Most research assessing EMG data reliability in dynamic movements has investigated slow, controlled tasks, such as resistance training exercise (3,6,16,18) or gait (2,10,22). Therefore, evaluation of the reliability of EMG during ballistic tasks is essential to determine the viability of this methodology for clinical and research applications.

For EGM research, careful consideration should be given to the statistics used in the assessment of reliability. Statistics used for reliability assessment frequently include the intraclass correlation coefficient (ICC), which is considered to be a direct approximation of reliability. The ICC is often accompanied by other statistics that are also used to define reproducibility, such as coefficients of variation (CV).

Although discussions of reliability in EMG research often include CV, the interclass and intraclass CV (CV_{inter} and CV_{intra} respectively) are not frequently distinguished from each other. The CV_{inter} describes the variability of subjects within the group for 1 data set and can be obtained without repeated tests (12). Because some variability between subjects is needed to demonstrate reproducibility, a high CV_{inter} may be conducive to finding reproducible results with study replication. Conversely, a low CV_{inter} suggests group homogeneity, which may be desirable for comparing similar populations (12). The CV_{intra} is derived from repeated subject measures and estimates the magnitude of pure measurement error (12). A low CV_{intra} value is desirable because it indicates consistency between repeated measures (12). Therefore, both the CV_{inter} and CV_{intra} are valuable statistics in reliability analyses of EMG data.

The reliability assessment of EMG should include multiple statistics, including ICC, CV_{intra}, and CV_{inter}. Reliability of EMG data between testing sessions has typically been assessed for isometric (11,14,16,17,23), slow dynamic (2,19), and infrequently for ballistic movements (8). The reliability of EMG data between testing sessions of isometric exercises has been shown to be highly reliable for quadriceps muscle activation, with a mean ICC of 0.99 and CV_{intra} ranging from 5.30% to 7.2% (14,17) and moderately to high reliable for the hamstrings, with ICC values ranging from 0.69 to 0.77 (11). Similarly, the reliability of MG data between testing sessions of slow dynamic and ballistic movements revealed high reliability for several lower-leg muscles during gait (2,10) and for the quadriceps during vertical jumping, with ICC values of 0.70 to 0.88 (8). On the other hand, reliability of hamstrings muscle EMG data between testing sessions of vertical jumping was poor, which was demonstrated by an ICC of 0.24 for the biceps femoris (8).

Within-session reliability of EMG data of lower-extremity muscles during slow dynamic movements, such as mini-squats, hip abduction exercises, and gait, have produce ICC values ranging from 0.93 to 0.99, CV_{inter} values ranging from 46% to 105.6%, and CV_{intra} values ranging from 11% to 51.5% (3,6,10,12,22). However, the usefulness of this information for understanding EMG reliability during sport movements is limited because of the lack of movement specificity between the slow, controlled motions assessed and the ballistic muscle actions produced in athletics.

Few studies have analyzed EMG data reliability for muscles of the lower body within a testing session, and only 1 previous study compared EMG reliability within a single testing session for both isometric and dynamic exercises (12). Furthermore, only 1 study has assessed EMG repeatability during an athletic movement (8), and no studies have compared within-session reliability of EMG data from a variety of lower-body muscles between isometric and ballistic movements. Historically, EMG data acquired from isometric exercises have yielded more highly reliable results compared with dynamic exercises (11,14). However, the repeatability of EMG data acquired from athletic movements has not been compared with the traditionally better reliability values yielded by isometric muscle actions. Consequently, reliability of EMG data during ballistic movements, such as jump landings and cutting after a sprint, is poorly established. The purpose of this study was to examine the within-session, trial-to-trial reliability of a variety of quadriceps and hamstrings muscles during isometric knee flexion and extension, as well as during jump landings (J) and cutting after a sprint (C), by way of analysis of ICC, CV_{inter} and CV_{intra} values.

Methods

Experimental Approach to the Problem

This study evaluates the reliability of EMG as a tool to assess the activation of various quadriceps and hamstrings muscles during isometric and ballistic movements from trial to trial within a single session. Independent variables include isometric knee flexion and extension exercises, as well as J and C test exercises. Dependent variables include ICC, CV_{intra}, and CV_{inter} values. The researchers hypothesized that the reliability of EMG data would be great for isometric compared with ballistic exercises but that EMG data from both the quadriceps and hamstrings muscles assessed would prove to be reliable during ballistic sport-simulated movements as well.

Subjects

Subjects included 24 university students (12 men and 12 women; mean ± *SD*; age = 21.13 ± 1.6 yr; height = 67.89 ± 4.0; weight = 158.09 ± 26.1). Inclusion criteria consisted of mixed sex subjects who were 18 to 27 years old and were either NCAA Division-I or club sports athletes or recreationally fit. Exclusion criteria included any orthopedic lower-limb pathology that restricted athletic functioning, known cardiovascular pathology, and inability to perform exercises with maximal effort. All subjects provided informed consent before the study, and the university's internal review board approved the study.

Procedures

Subjects attended 2 sessions, including 1 pretest habituation session and 1 testing session. At the beginning of each sessions, subjects participated in a standardized general warm-up and dynamic stretching exercises consisting of approximately 15 seconds for each major muscle group. During the pretest habituation session, subjects' maximum stationary bilateral countermovement jump height was assessed using a Vertec (Sports Imports, Boynton Beach, FL, USA), with the highest of 3 trials recorded as their maximal vertical jump. Subjects were then instructed in and practiced the isometric and dynamic test exercises. Maximum voluntary isometric contractions (MVIC) were performed at 60º of knee flexion for the quadriceps and hamstrings muscles, with the leg extension (Magnum Fitness Systems, South Milwaukee, WI, USA) and seated leg curl (Hammer Strength, Schiller Park, IL, USA) machines, respectively, each loaded with an immovable mass. In addition to the isometric tests, the ballistic simulated sport movements, including the J and C, were performed. The J was performed using a box height equal to each subject's maximum vertical jump height. Subjects initially stood on top of the box, and a switch mat was placed directly below to synchronize EMG activity with the jump landing. Subjects stepped off the box, leading with the right foot, and landed on both feet synchronously. Subjects were instructed on proper mechanics, including landing softly with feet approximately should width apart, maintaining alignment of knees over toes and shoulders over knees, and stabilizing in a partial squat position of a consistent depth from trial to trial. The C was preceded by a 10-m sprint and performed by planting with the right leg and cutting at a 45º angle to the left of the sagittal plane. The angle of the cut was measured with a goniometer and marked by cones to visually guide subjects. Subjects were encouraged to accelerate maximally, plant the right foot on a switch mat, and cut sharply to the left between the cones, without changing the stride pattern before the C, and to maintain their speed for at least 3 strides after the C. Subjects were allowed to practice the J and C until they reported feeling comfortable with the tasks and were able to perform consecutive repetitions with proper technique, as determine by certified supervising personnel. All supervising personnel were either National Strength and Conditioning Association Certified Personal Trainers or Certified Strength and Conditioning Specialists.

Subjects returned for the test session after approximately 48 hours, which included the same general warm-up and dynamic stretching, followed by 3 minutes of rest and then 3 repetitions of

MVICs for both the quadriceps and hamstrings muscles. Isometric knee extension and flexion exercises were alternated, with the first test exercise assigned randomly. Isometric muscle actions were performed for 6 seconds with 1 minute of rest in between each repetition. Equal verbal encouragement was provided for all subjects. After completion of the MVICs, subjects performed a specific warm-up with the J and C. Subjects were allowed to practice the J and C until they were comfortable and the certified supervisor confirmed proper technique. Subjects then rested for 3 minutes and performed 3 consecutive repetitions of the J and C. Subjects rested 1 minute in between each repetition and 3 minutes in between the J and C. The test exercises were assigned randomly to eliminate order effects.

During the testing session, quadriceps and hamstrings muscle activation was evaluated using surface EMG. Data were acquired with an 8 channel, fixed shielded cabled, telemetered EMG system (Myomonitor IV, DelSys, Inc., Boston, MA, USA). Electromyographic data were recorded at sample rate of 1024 Hz using rectangular shaped (19.8 mm wide and 35 mm long) bipolar surface electrodes with 1 x 10 mm 99.9% Ag conductors and an interelectrode distance of 10 mm. Electrodes were placed on the longitudinal axis of the muscles with the rectus femoris (RF) electrode placed halfway between the greater trochanter and medial epicondyle of the femur. The vastus lateralis (VL) electrode was placed one quarter of the distance from the midpoint of the lateral line of the knee joint to the anterior superior iliac spine. The vastus medialis (VM) electrode was located 20% of the distance from the anterior superior iliac spine to the midpoint of the medial joint line. The hamstring belly electrode was located halfway between the gluteal fold and the popliteal fossa. The lateral hamstring electrode was placed halfway between the ischial tuberosity and the insertion site at the fibular head, whereas the medial hamstring electrode was placed hallway between the ischial tuberosity and the medial knee joint space. A common reference electrode was placed on the lateral malleolus. Electrode placement was chose to assess uni-articular and bi-articular knee extensor and flexor muscles, and electrode sites were selected in accordance with previously published placement recommendations (7). Skin preparation included shaving if necessary, as well as abrasion and cleansing with alcohol. Elastic tape was applied to ensure electrode placement and provide strain relief for the electrode cables. Surface electrodes were connected to an amplifier and streamed continuously through analog to digital converter (DelSys Inc. Boston, MA, USA) to an IBM-compatible notebook computer.

All data were filtered with a 10 to 450 Hz band pass filted, saved, and analyzed with the use of software (EMGworks 3.1, DelSys, Inc., Boston, MA, USA). The input impedance was 1015 Ohms, and the common mode rejection ratio was greater than 80 dB. Raw data were acquired and processed using root mean square (RMS) EMG with a moving window of 125 milliseconds and were analyzed for seconds 2 to 3 of the MVICs and for pre- and postfoot contact muscle bursts for the J and C. The timing of foot contact was synchronized with the EMG system using a switch mat (Model CVP 1723, Lafayette Industries, Lafayette, IN, USA). Muscle burst onset and offset were determined as the points at which the raw EMG values exceeded and fell below 150% of raw baseline EMG values, respectively, to the nearest 1/100th of a millisecond. Duration of the burse of onset and offset was determined as length of time between the point of burst onset or offset and the point of foot contact, and these durations were averaged over the 3 trials (Figure 1). The RMS EMG values for the J and C were normalized to the average RMS EMG of the 3 trials of the MVIC.

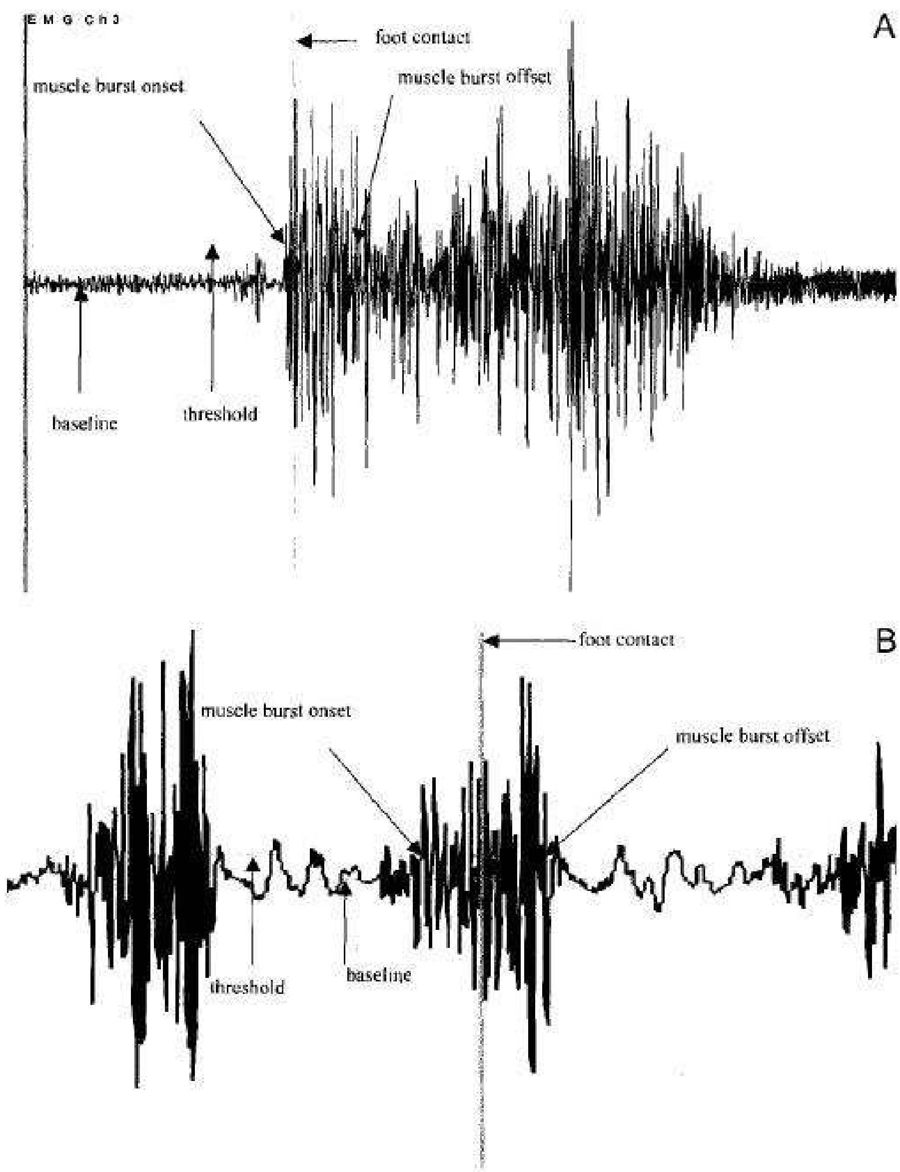

Figure 1. Trace electromyography (EMG) of vastus medialis (VL) for jump landing test (a) and cutting test (B). Determination of prefoot contact onset was accomplished by identifying point at which prefoot contact raw EMG values exceeded 150% of baseline value. Duration of muscle burst was calculated as time elapsed between onset of muscle burst and foot contact. Similar procedures were used for determination of postfoot contact offset and duration of muscle burst, using point after foot contact at which raw EMG values fell below 150% of baseline values.

Statistical Analyses

Data were evaluated with SPSS 16.0 (Chicago, IL, USA). Average intertribal reliability of quadriceps and hamstrings RMS EMG between subjects was assessed using the ICC. The CV_{inter}, defined as the square root of the sample *SD* divided by the mean, assessed variability between subjects for single data sets, independent of repeated measures. Within-subjects, intertribal reliability was valued by the CV_{intra}, which was defined as the square root of the mean squared error across trials divided by the mean of all observations. All normalized values were averaged over the 3 trials.

Table 1. Descriptive statistics, intraclass correlation coefficients (ICC), 95% confidence intervals (CI), interclass coefficient of variation (CV_{inter} and CV_{intra}) for isometric, jump (J), and cut (C) tests (*n* = 24).

	HB	LH	MH	RF	VL	VM
Isometric						
Mean *SD* (mV)	0.16 ± 0.10	0.16 ± 0.18	0.18 ± 0.21	0.16 ± 0.07	0.20 ± 0.010	0.16 ± 0.09
ICC	0.96	0.96	0.94	0.96	0.95	0.97
95% CI	0.91–0.98	0.93–0.98	0.88–0.97	0.92–0.98	0.89–0.98	0.93–0.99
CV_{inter} (%)	63.2	118.3	113.2	44.8	47.2	56.4
CV_{intra} (%)	12.7	21.9	18.3	11.5	12.9	12.3
J (prefoot contact)						
Mean *SD* (% MVIC)	15.44 ± 1.81	21.79 ± 2.66	32.23 ± 3.87	20.53 ± 1.69	28.53 ± 2.04	33.55 ± 2.57
ICC	0.83	0.95	0.96	0.93	0.90	0.90
95% CI	0.66–0.93	0.89–0.97	0.92–0.98	0.86–0.97	0.79–0.95	0.81–0.96
CV_{inter} (%)	11.7	12.2	12.0	34.7	7.15	7.68
CV_{intra} (%)	47.2	42.2	49.3	35.3	39.2	37.1
J (postfoot contact)						
Mean *SD* (% MVIC)	10.40 ± 10.76	29.91 ± 44.48	23.31 ± 27.87	65.02 ± 59.63	82.91± 61.50	82.86 ± 44.70
ICC	0.89	0.90	0.97	0.85	0.92	0.86
95% CI	0.77–0.95	0.80–0.96	0.93–0.98	0.71–0.94	0.84–0.97	0.70–0.94
CV_{inter} (%)	103.4	148.7	120.0	91.7	74.2	53.9
CV_{intra} (%)	36.6	33.2	29.6	24.5	21.2	25.6
C (prefoot contact)						
Mean *SD* (% MVIC)	91.54± 4.98	109.53 ± 73.98	103.52 ± 64.60	44.33± 40.66	96.62 ± 61.81	95.90 ± 40.38
ICC	0.93	0.96	0.95	0.78	0.94	0.88
95% CI	0.85–0.97	0.93–0.98	0.91–0.98	0.55–0.90	0.88–0.97	0.76–0.96
CV_{inter} (%)	5.4	67.5	62.4	91.7	63.9	16.9
CV_{intra} (%)	20.5	20.5	20.3	45.6	24.8	23.8
C (postfoot contact)						
Mean *SD* (% MVIC)	53.39 ± 35.82	122.47 ± 78.3	51.83 ± 45.6	91.14 ± 63.74	109.48 ± 66.3	108.77 ± 49.90
ICC	0.93	0.92	0.84	0.52	0.94	0.90
95% CI	0.86–0.97	0.84–0.96	0.68–0.93	0.27–0.79	0.87–0.97	0.78–0.95
CV_{inter} (%)	67.1	63.4	67.9	69.9	60.6	45.9
CV_{intra} (%)	26.3	32.6	34.3	20.1	23.0	23.8

HB = hamstring belly; LH = lateral hamstring; MH = medial hamstring; RF = rectus femoris; VL = vastus lateralis; VM = vastus medialis; MVIC = maximum voluntary isometric contractions.

Results

Intraclass correlation coefficient analysis revealed that all ICC values were greater than 0.80, with most values greater than 0.90, with the exception of the RF EMG data during the C in both pre- and postfoot contact conditions. Intersubject CVs were calculated to determine between-subjects variability and ranged from 5.4% to 148.7% for all muscles and all test conditions. Intrasubject CVs were calculated to asses within-subjects variability between repeated tests, and values ranged from 11.5% to 49.3% for all muscles and all test conditions. Table 1 demonstrates the means and *SD*s, ICC, 95% confidence intervals, CV_{inter}, and CV_{intra} for each muscle group and test condition assessed.

Discussion

To our knowledge, this is the first study to examine intrasession EMG reliability of the quadriceps and hamstrings muscles for both isometric and ballistic activities. Results from the present study indicate that, for habituated subjects, EMG is reliable for muscles in both the hamstrings and quadriceps groups during isometric and ballistic exercises, such as the J and C, when tested within the same session. Although the repeatability of EMG data from the isometric exercises was predictably greater than that of the athletic movements, both movements yielded similarly reliable data for the most part. With few exceptions, all ICC values for the hamstrings and quadriceps muscles assessed were highly reliable, and ICC, CV_{inter}, and CV_{intra} values were consistent with previous work (3,6,8,12,14,18,20) and standards for reliability measures (13,15). Thus, the EMG of the hamstrings and quadriceps is reliable for ballistic movements, as well.

Electromyographic reliability of the hamstrings muscles during isometric testing was high and yielded ICC values ranging from 0.94 to 0.96, which were comparable with previous report (4,11). Intraclass CVs for the hamstrings muscles EMG during the isometric tests ranged from 12.7% to 21.9% in the present study. These values were slightly higher than the CV_{intra} values found for the quadriceps muscles EMG in the isometric condition (11.5=12.9%). Both the hamstrings and quadriceps EMG data yielded lower CV_{intra} values during the isometric compared with the ballistic tasks, confirming the relatively higher reliability of muscle activation during isometric tasks.

The present study yielded highly reliable ICC values for the hamstrings muscle EMG assessed during the J and C, ranging from

0.83 to 0.97. These results contrasted with previous research reporting ICC of 0.24 for the biceps femoris EMG during a vertical jumping task (8). Previously, poor reliability of the hamstrings muscles EMG assessed during the vertical jump was attributed, in part, to its role as a stabilizer, as opposed to a prime mover, during hip extension (8). However, in the present study, the hamstrings muscles assessed directly contributed to deceleration of extension of the tibia at the knee in the prefoot contact conditions of the J and C and deceleration of flexion of the femur at the hip in the postfoot contact conditions of the J and C, all by way of eccentric muscle action. The role of the hamstrings muscles as a prime mover in the test exercises in the present study may have contributed to the reliability of EMG data from these muscles. These present results suggest that the hamstrings can be reliably assessed using EMG during functional athletic movements.

Intersubject CVs yielded by hamstrings muscles EMG ranged from 5.44% to 148.7% in the present study, indicating a wide range of variability between subjects in the magnitude of EMG amplitude yielded by the hamstrings muscles during the dynamic tasks. Prefoot contact CV_{inter} values for the J and C ranged from 4.44% to 67.5%, whereas postfoot contact CV_{inter} ranged from 5.44% to 148.7%. The trend toward more variable between-subjects hamstrings muscle activation in the postfoot contact condition may be attributed to difference in landing mechanics and varying ability of subjects to attenuate ground reaction forces. Previous research assessing reliability of hamstrings muscle activation during gait within a session revealed CV_{inter} values ranging from 60% to 62% (10), which were lower than the values found in the present study. However, gait is a cyclic activity that is thought to be under the control of central pattern generators located within the spinal cord (10). Conversely, ballistic movements, such as the J and C, are acute, ballistic events that demand higher level motor control and greater variability in recruitment of motor units. These differences in task requirements may explain the higher CV_{inter} values found in this study when compared with gait analysis.

Intrasubject CVs of the hamstrings muscles EMG during the J and C ranged from 20.3% to 49.3% and were comparable with those found for the quadriceps muscles (20.1-45.6%) during the same activities. These values were similar to those yielded by EMG data from a variety of other lower-extremity muscles in previous research of slow dynamic exercises, which ranged from 11.0% to 51.5% (3,12). These results indicate that the reliability of EMG data produced by ballistic hamstrings muscles activation is comparable with data yielded by slow dynamic movements of various muscles of the lower body, which contrasts with previous research that has suggested that EMG data from ballistic hamstrings muscle activation are relatively unreliable (8).

Intraclass correlation coefficients for the quadriceps muscle EMG during isometric muscle actions tested in the present study ranged from 0.95 to 0.97. These values were highly reliable (13) and comparable with those found in other studies assessing static reliability of a variety of muscles in the quadriceps group during the seated leg extension, which ranged from 0.85 to 0.99 (14,18, 20). The present study sought to compare the reliability of EMG data from ballistic and isometric tasks and found that ICC values yielded by the isometric tests were generally similar to, but slightly greater than, those yielded by J and C for all quadriceps muscles assessed. With the exception of the RF in the C test, differences, between static and dynamic ICC values were all equal to or less than 0.11. Isometric CV_{intra} values from the quadriceps ranged from 11.5% to 12.3%, whereas CV_{intra} values during the J and C ranged from 7.51% to 91.7%, which, similar to the ICC values, confirmed the hypothesis that EMG data from isometric activities are more reliable than that of ballistic activities. Ultimately, however, both isometric and ballistic tasks yield reliable EMG data from the quadriceps. Slightly lower EMG reliability during dynamic compared with isometric exercises has been attributed to a variety of factors, including crosstalk from adjacent muscles, varying contributions and inconsistent synchronization of synergist muscles between trials (23), varying degrees of muscle coactivity, difference in joint position and velocity, and greater variability of EMG from bi-articular muscles (8).

The EMG data from the 3 quadriceps muscles assessed in this study were highly reliable for the ballistic tasks. The ICC values ranged from 0.86 to 0.94, with the exception of RF EMG data from the pre- and postfoot contact conditions of the C, in which ICC values were to

0.78 and 0.52, respectively. These values were similar to those reported in an evaluation of reliability of EMG during vertical jumps, in which ICC values for the RF and VM were 0.88 and 0.70, respectively (8). Previously, a mean ICC value of 0.99 was found for EMG data from the VM and VL during mini-squats (6), which exceeded the ICC values for each of the quadriceps muscles during the ballistic tasks assessed in the present study. However, the mini-squat exercise was slower than the J and C tested in the present study. Previous research demonstrated that the rate of change of muscle length and tension affects the magnitude of EMG amplitude (9), and the rapid movements tested in the present study may have predisposed them to varying patterns of motor unit recruitment and greater variability in muscle activation compared with mini-squats. In addition, the study involving the mini-squat exercise excluded the RF from analysis, whereas the present study included this muscle. The bi-articular nature of the RF renders it more susceptible to changes in length compared with muscles that only cross a single joint, and such length changes affect the magnitude of EMG amplitude (9). This may explain the lower reliability of EMG, as assessed by ICC values, yielded by the RF in the present study compared with the VL and VM a previous study assessing mini-squats.

Intrasubject CVs from ballistic quadriceps muscle activation in the present study ranged from 20.1% to 45.6%. The CV_{intra} was consistently equal to or higher for the prefoot contact compared with the postfoot contact conditions of the J and C, which represents higher variability in preactivation of the quadriceps before contact compared with the postfoot contact condition. The CV_{intra} values found in the present study were similar to those reported in other studies that have delineated CV_{inter} and CV_{intra} of lower-etremity muscles in dynamic exercises. For example, reliability analysis of EMG data from the gastrocnemius yielded CV_{intra} values ranging from 27.2% to 51.5% during a cyclic balance board activity (12). An assessment of reproducibility of gluteus maximus muscle activation during hip abduction exercises yielded CV_{intra} values that were 11% to 18%, which was lower than the values found in the present study (3). However, as discussed above, these differences were likely related to the slower, more controlled nature of the hip abduction exercises, compared with the J and C tested in the present study.

Intersubject CVs ranged from 7.1%5 to 91.7% for EMG from the quadriceps muscles during the J and C, with the majority of values ranging from 34.7% to 91.7%. These CV_{inter} values were comparable with those found in other studies assessing EMG data from slow dynamic activities, which ranged from 55% to 91% for a variety of lower-extremity muscles (3,12). These data from previous studies and the present study suggest that CV_{inter} values from quadriceps EMG data are similar for both slow dynamic and ballistic tasks, indicating a similar degree of reliability of quadriceps muscle activation during these 2 types of activities. The combination of high ICC values and relatively low CV_{intra} values demonstrated by a heterogeneous sample during the J and C tested in the present study suggests that the reliability of EMG data from ballistic hamstrings and quadriceps muscle activation are similar to the reliability of slower, controlled dynamic movements (3,6,12).

Practical Applications

Assessment of the reliability of EMG during both isometric and ballistic tasks is essential for validating the clinical and research applications of this important technique. Ballistic muscle activation in this study yielded high ICC values and relatively low CV_{intra} values for both the quadriceps and hamstrings muscles EMG during the J and C. These results refute previous reports that hamstrings muscles EMG data are not reliable during sport-simulated movements (8), and indicate that, for the most part, EMG is a reliable method to assess activation of quadriceps and hamstrings muscles during either isometric, slow dynamic, or ballistic movements, such as the J and C, tested within the same session. Researchers and clinicians who assess muscle activation using EMG during ballistic movements are encouraged to properly prepare skin for electrode placement (e.g., by shaving when necessary, lightly abrading, and cleansing with alcohol), provide strain relief for electrode cables to reduce motion artifact, carefully habituate their subjects to the test exercises by demonstrating and providing ample practice until the technique is mastered, and carefully control the exercise techniques during testing sessions.

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