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Abstract:

Purpose: The objectives were, i) to determine whether differences exist in relative activation amplitudes for participants with asymptomatic knees and participants with moderate medial compartment knee osteoarthritis during a series of maximal effort contractions and ii) to determine whether maximum activations occurred on similar exercises for both groups.

Scope: Sixty-eight participants with asymptomatic knees and 68 participants with moderate medial compartment knee osteoarthritis completed eight standardized three-second maximal voluntary isometric exercises. Maximal electromyographic amplitudes were identified for a 100 ms window from three quadriceps, two gastrocnemius and two hamstring muscle sites for each exercise. For each exercise, amplitudes were normalized to percent of the absolute maximum activation (%MVIC). Frequency counts for exercises eliciting absolute maximum amplitudes were recorded. Analysis of Variance models determined exercise and group main effects and interactions in relative amplitudes (%MVIC) for each muscle.

Conclusion: The exercises produced similar relative activation amplitudes between groups. The highest relative amplitude occurred for gastrocnemius during standing plantar flexion (86-93%MVIC), for the vasti during knee extension (45^{o}) and (15^{o}) (81-86%MVIC), for rectus femoris during knee extension (15^{o}) (89%MVIC) and for hamstring muscles during knee flexion (15^{o}) and prone knee flexion (55^{o}) (81-94%MVIC). No single exercise elicited absolute maximum activation for every

participant for each muscle, supporting the value of using an exercise series for normalization purposes.

Introduction

Surface electromyography has been employed to investigate neuromuscular function, offering insight on muscle responses during fundamental movements such as gait and how responses are altered with orthopaedic impairments [Hubley-Kozey et al, 2006; Hubley-Kozey et al, 2009; Winter and Yack 1987]. Signals are derived from summing motor action potentials within a volume of muscle tissue located within the surface electrode pickup region [Soderberg and Knutson 2000]. Electrical properties of the electrode-muscle tissue interface are subject specific and may vary based on electrode location [Campanini et al, 2007; Mercer et al, 2006; Rainoldi et al, 2004], electrode or muscle fibre orientation, tissue characteristics [Winter et al, 1994] and skin preparation procedures. To provide data to compare the electromyogram between subjects and muscle sites, amplitude normalization methods have been employed [Knutson et al, 1994].

Amplitude normalization of the electromyogram (EMG) recorded during sub-maximal activity to maximal amplitudes obtained during a maximum voluntary isometric contraction (MVC or MVIC) has been utilized to understand neuromuscular alterations during gait in individuals with knee osteoarthritis (OA) [Hubley-Kozey et al, 2006; Lewek et al, 2004; Ramsey et al, 2007b; Rudolph et al, 2007]. During normalization procedures, individuals are instructed to voluntarily produce a maximal effort during an isometric contraction for a given muscle group [Soderberg and Knutson 2000]. Compared to other normalization techniques, including dynamic peak methods [Kean et al, 2009; Schmitt and Rudolph 2007], MVIC methods provide a physiological reference in which to make comparisons across muscles and subjects [Vera-Garcia et al, 2009].

Knutson et al., [1994] concluded that MVIC normalization should be the standard in both healthy adult and orthopedic populations.

Variation exits in the literature on the specific exercises used for normalization. In knee OA studies, the quadriceps, hamstrings and gastrocnemius normalization exercises largely encompass an open kinetic chain mode [Childs et al, 2004; Hubley-Kozey et al, 2006; Zeni et al, 2009]. Compared to closed kinetic chain exercises, the use of open kinetic chain exercises allow for muscle group specific standardization. Many studies do not report knee joint positions utilized during MVIC procedures [Lewek et al, 2004; Ramsey et al, 2007b; Rudolph et al, 2007] or they employ a single standard exercise for each muscle grouping [Childs et al, 2004; Zeni et al, 2009]. Recently, Vera-Garcia et al. [2009] found that during MVIC procedures for spinal and abdominal muscle activation, a single exercise did not elicit maximum activity supporting the need for a series of exercises rather than relying on one exercise. This approach of utilizing a series of exercises has been employed for the lower limb musculature in the study of knee OA gait [Hubley-Kozey et al, 2006]. Since many primary outcome measures are based on amplitude characteristics of the electromyogram, understanding the effects of different normalization exercise protocols and the potential differences in those with pathology could enhance the development of standard procedures or at minimum raise the awareness of the potential effects that different approaches can have on interpreting and comparing EMG data across studies. As a first step, we sought to determine the influence of exercise positioning on activation levels of specific lower extremity muscles in asymptomatic and patient groups.

The purpose of this investigation was two fold. First, to determine the relative activation amplitudes associated with an exercise series aimed to elicit maximal activation for quadriceps, hamstrings and gastrocnemius muscles, and to determine if there were differences between participants with asymptomatic knees and a clinical population of participants with moderate knee OA. Secondly, to determine whether maximum activations occurred on the same exercise between participants with asymptomatic knees and a clinical population of participants with moderate knee OA.

Methodology

Sixty-eight participants with asymptomatic knees (age=49 years, SD=9.5, body mass=75.5 kg, SD=15.3, height=1.69 m, SD=0.08, and Body Mass Index (BMI)=26.1 kg/m^2, SD=4.3) were recruited from the general community through website and bulletin board advertisements. A standardized telephone questionnaire was used to ensure individuals in this group presented with no lower extremity injuries within six months prior to data collection and no symptoms of lower extremity degenerative joint disease including knee pain, morning stiffness and prior knee surgery or fracture. A clinical population of 68 participants with knee OA (age=56.9 years, SD=8, body mass=92.3 kg, SD=18.3, height=1.74 m, SD=0.09, and BMI=30.53kg/m^2, SD=5.3) were recruited from the caseload of one high volume orthopaedic surgeon (WDS) and were diagnosed based on the American College of Rheumatology Criteria [Altman 1991]. Standard AP radiographs confirmed predominant medial compartment radiographic disease presence (2 cases were confirmed using magnetic resonance imaging). Radiographs were later scored using the Kellgren Lawrence scale [Kellgren and LAWRENCE 1957]. Given the poor association between patient reported function and radiographic OA severity [Barker et al, 2004; Creamer et al, 2000], moderate knee OA was also determined using a functional criterion [Hubley-Kozey et al, 2006]. Patients with moderate knee OA reported that their knee OA would not limit the performance of three functional tasks; i) jog five meters, ii) walk one city block and iii) reciprocally ascend and descend 10 stairs. If these tasks were limited in any capacity or patients were candidates for knee arthroplasty based on symptoms and function, they were excluded. All participants were over 35 years of age and excluded if cardiovascular/respiratory disease or neurological disorders were present that would affect their neuromuscular control (i.e. Stroke, Parkinson's Disease etc.) or their ability to complete the data collection protocol safely (i.e. myocardial infarct, arrhythmias). Written informed consent was provided in accordance with the Research Ethics Board.

Individuals were recruited to the Dynamics of Human Motion Laboratory, Dalhousie University, Halifax, Nova Scotia for muscle strength, gait biomechanics and electromyographic studies. A standard protocol for electrode placement and validation has been described previously [Hubley-Kozey et al, 2006]. Skin preparation (light shave and abrade with 70% alcohol wipes) and placement of circular surface electrodes in a bipolar configuration (Ag/AgCl, 10 mm diameter, 20 mm interelectrode distance) over lateral gastrocnemius (LG), medial gastrocnemius (MG), vastus lateralis (VL), vastus medialis (VM), rectus femoris (RF), biceps femoris (LH) and semitendinosis/membranosis (MH) was performed using standard electrode placements (Table 1). All participants with knee OA reported unilateral symptoms and the affected lower extremity was tested with a randomly assigned limb tested for individuals with asymptomatic knees. Muscle palpation and a series of isometric contractions were used to validate the electrode placement to minimize crosstalk [Winter et al, 1994] and for setting appropriate gain adjustments. At least 20 minutes elapsed before surface electromyographic recordings were made. Electromyographic signals were recorded using an AMT-8 (Bortec, Inc., Calgary, AB, Canada), eight-channel EMG measurement system (Input Impedance: ~10GΩ, CMRR:115dB at 60 Hz, Band-pass (10-1000 Hz))

[Insert Table 1]

Table 1: Guidelines for muscle site, location and orientation utilized for the standardized placement of surface electrodes on the lower extremity.

Muscle Site	Location	Orientation
Lateral Gastrocnemius (LG)	**30% distance from lateral knee joint line to the tubercle of the Calcaneous (Ankle in Neutral Position)**	**Along lead line**
Medial Gastrocnemuis (MG)	**35% distance from medial knee joint line to the tubercle of the Calcaneous (Ankle in Neutral Position)**	**Along lead line**
Vastus Lateralis (VL)	**25% distance from the lateral joint line of the knee to the ASIS**	**45 degrees medial and inferiorly to lead line**
Vastus Medialis (VM)	**20% distance from the medial joint line of the knee to the ASIS**	**45 degrees lateral and inferiorly to lead line**
Rectus Femoris (RF)	**50% distance ASIS to superior border of patella**	**Along lead line**
Bicep Femoris (LH)	**50% distance from the ischial tuberosity to fibular head**	**Along lead line**
Semitendinosus / Semimembranosis (MH)	**50% distance from the ischial tuberosity to the medial joint line of the knee**	**Along lead line**

References: Leveau (1992), Hubley-Kozey and Smits (1998), SENIAM (1999).

A baseline recording was made while participants relaxed in supine lying, then a series of eight standardized exercises were performed (Fig. 1). These exercises were identified from a series of pilot studies to determine exercise positions that elicited maximal activation amplitudes from the seven muscle sites in a small test set. This MVIC exercise series has been previously utilized for EMG normalization purposes [Hubley-Kozey et al, 2006]. For exercise familiarization, a warm-up, specific to the MVIC exercise and at least one practice contraction was completed. When participants reported satisfactory familiarization, two three-second maximal isometric contractions were completed for each exercise. Participants were instructed to provide maximal efforts on each trial. Standardized positions are shown in Figure 1 including i) knee extension at 45^o of knee flexion (KE45) in sitting, ii) knee extension at 15^o of knee flexion (KE15) in supine, iii) knee extension-hip flexion at 45^o of knee flexion and 90^o of hip flexion (KEHF) in sitting, iv) knee flexion at 55^o of knee flexion (KF55) in sitting, v) knee flexion at 15^o of knee flexion (KF15) in supine, vi) knee flexion at 55^o of knee flexion (prone KF55) in prone, vii) sitting plantarflexion with the ankle in neutral and viii) standing unilateral plantar flexion. A Cybex™ dynamometer (Lumex, NY, USA) was employed for exercises i-vii. A minimum 60-second rest period separated each contraction, and standardized verbal encouragement was given [Hubley-Kozey et al, 2006]. Decisions to accept or repeat trials were based on examining the torque and/or EMG signals in real time to determine if a maximal steady state contraction was achieved and to identify artefact. Participants were provided with verbal feedback. If a steady state contraction was not achieved or a difference between trials greater than 10% was noted, the lower exercise trial was repeated. All electromyographic signals were analogue to digital converted at 1000Hz (16bit, +/- 2V) and stored for processing.

[Insert Figure 1]

Data Processing

Electromyographic data were processed through custom MatLab™ Ver 7.1 programs (The Mathworks Inc., Natick, Massachusetts, USA). EMG signals were corrected for bias and converted to microvolts, full wave rectified and low-pass filtered (Butterworth, 4th order, Fc-6Hz). A 100ms moving-average window, advancing one sample at a time (99ms-overlap between two adjacent windows) identified the maximal EMG amplitude for each muscle in both trials of all eight MVIC exercises [Hubley-Kozey et al, 2006].

Statistical Analysis

Student t-tests evaluated group differences in age, height, body mass and body mass Index (BMI). Maximal electromyographic amplitudes were identified from three quadriceps, two gastrocnemius and two hamstring muscle sites for each exercise. The single highest EMG amplitude, regardless of trial and exercise was utilized to represent absolute maximum activity for each muscle. Activity levels for each exercise were normalized to this maximum amplitude and were reported as a percentage of MVIC (%MVIC). For each muscle, a two-factor mixed model Analysis of Variance, for group (asymptomatic or knee OA) with repeated measures for exercise was employed to test main effects and interactions. Bonferonni adjusted post-hoc testing was utilized on all significant findings. Significance was determined with alpha = 0.05. Frequency counts for exercises that elicited the absolute maximum activity were recorded for each muscle for each subject group.

Results

Participants with asymptomatic knees were significantly younger than those with moderate knee OA, had lower BMI, mass and were shorter ($p<0.05$). Six participants with knee OA presented with KL grade of I, 27 with KL II, 25 with KL III and five with KL IV radiographic scores. Scores were not available for five participants, two had OA confirmed with MRI and three X-rays were not available in digital form at the time of KL scoring. Group demographics and KL scores were used for descriptive purposes.

Mean normalized amplitudes in percent MVIC for each exercise, group and muscle are shown in Table 2. For LG and MG an exercise main effect was found with standing plantarflexion eliciting the greatest activation ($P<0.05$) at over 86% MVIC for both groups, with knee extension exercises eliciting the lowest activation ($P<0.05$).

Table 2: Relative muscle activation (in percent) normalized to absolute maximum amplitudes for each exercise [Mean (standard deviation)]. Greatest relative maximal activations for each muscle are indicated in **bold** (P<0.05).

	LG		MG		VL		VM		RF		LH		MH	
	AS	OA	AS	OA	AS	OA	AS	OA	AS	OA	AS	OA	AS	OA
KE45	14.2 (11.9)	12.4 (8.8)	12.0 (9.7)	12.6 (11.2)	**84.1 (19.7)**	**86.0 (18.4)**	**80.7 (21.0)**	**85.2 (17.7)**	84.2 (15.4)	82.4 (17.1)	15.7 (12.4)	16.3 (11.4)	8.7 (6.1)	9.7 (6.6)
KE15	14.8 (11.3)	13.9 (13.3)	15.7 (14.2)	17.2 (18.2)	**86.0 (19.0)**	**85.6 (16.8)**	**86.5 (19.5)**	**86.0 (19.2)**	**89.2 (16.0)**	**89.4 (14.5)**	17.1 (11.5)	16.5 (13.7)	9.7 (6.1)	10.0 (9.4)
KEHF	32.7 (28.3)	36.6 (27.3)	29.3 (24.7)	30.1 (24.8)	42.7 (24.0)	56.6 (27.2)	44.0 (25.2)	57.0 (25.6)	82.5 (19.3)	82.7 (16.1)	19.8 (18.5)	15.3 (9.8)	21.5 (20.0)	15.9 (11.7)
KF55	63.4 (25.8)	70.4 (24.3)	57.1 (27.2)	61.4 (22.8)	9.9 (8.5)	11.0 (14.8)	14.6 (15.2)	12.5 (11.4)	9.6 (6.1)	9.12 (8.8)	69.3 (21.5)	59.1 (20.1)	73.3 (21.1)	70.8 (21.9)
KF15	59.9 (26.9)	64.9 (23.1)	62.8 (27.3)	68.4 (23.5)	11.4 (8.7)	13.1 (14.1)	14.9 (13.0)	15.0 (14.7)	8.9 (6.1)	8.9 (6.3)	**91.7 (10.1)**	**90.2 (14.4)**	81.1 (18.4)	83.4 (16.8)
PKF55	53.4 (26.2)	50.1 (23.5)	56.4 (26.0)	57.1 (22.4)	8.9 (5.9)	9.3 (9.3)	13.5 (12.9)	14.8 (15.6)	8.2 (5.1)	8.4 (7.4)	**89.6 (13.5)**	**86.4 (14.5)**	**93.5 (12.3)**	**93.0 (10.5)**
PF Sit	71.0 (27.7)	74.2 (25.1)	71.5 (25.1)	75.2 (22.4)	13.3 (19.4	20.1 (22.7)	13.1 (16.3)	22.1 (24.5)	10.5 (12.3)	14.3 (16.3)	13.4 (10.5)	15.9 (11.4)	13.0 (9.9)	13.1 (11.0)
PF Stand	**85.6 (19.4)**	**88.7 (16.2)**	**91.9 (15.3)**	**93.2 (13.6)**	39.6 (24.3)	49.5 (25.3)	49.6 (31.2)	51.9 (28.5)	32.9 (19.9)	38.7 (21.6)	24.8 (17.8)	37.6 (23.2)	15.2 (16.7)	18.6 (15.7)

Exercises: KE45 (knee extension at 45° knee flexion), KE15 (knee extension at 15° knee flexion), KEHF (knee extension-hip flexion at 45° knee flexion and 90° hip flexion), KF55 (knee flexion at 55° knee flexion), KF15 (knee flexion at 15° knee flexion), PKF55 (knee flexion at 55° knee flexion in prone position), PFsit (plantarflexion at neutral ankle, knee extended, hip flexed), PFstand (unilateral plantarflexion in standing).**Muscles:** LG (lateral gastrocnemius), MG (medial gastrocnemius), VL (vastus lateralis), VM (vastus medialis), RF (rectus femoris), LH (lateral hamstrings), MH (medial hamstrings)
Groups: OA (moderate knee OA), AS (asymptomatic knee)

For VL and VM, a significant interaction was found (P<0.05). Post hoc results were the same for both muscles. In both groups, KE45 and KE15 produced higher activation (84% MVIC or higher) than the other exercises (P<0.05) with no differences between groups (P>0.05). Individuals with knee OA had greater levels of activation during KEHF compared to participants with asymptomatic knees (P<0.05). Lowest levels of activity occurred during knee flexion and sitting plantar flexion exercises (P<0.05) where no differences existed between participants with asymptomatic knees and those with knee OA (P>0.05). For RF, no group differences existed (P>0.05) only an exercise main effect (P<0.05). The greatest activity (89% MVIC or higher) was recorded during KE15 (P<0.05) where no differences were found between KE45 and KEHF (P>0.05). Rectus femoris activity was lowest during knee flexion and sitting plantar flexion exercises (P<0.05).

A significant interaction was found for the LH ($p<0.05$) where an exercise main effect was found for MH ($p<0.05$). For LH, KF15 and PKF55 elicited significantly higher activity than all other exercises ($P<0.05$) with no differences between these two exercises or between groups ($P>0.05$). In both groups, LH activity during KF55 (59-69%MVIC) was lower than KF15 and PKF55 ($P<0.05$) but was greater than all other exercises. Lateral hamstring activity during KF55 was less, and during standing plantarflexion was greater in the group of participants with knee OA compared to LH activity in participants with asymptomatic knees ($P<0.05$). The greatest MH activity occurred during PKF55 ($p<0.05$). Medial hamstring activity during KF55 was lower (71-73%MVIC) than during PKF55 and KF15 and greater than all other exercises ($P<0.05$). The lowest activity was found in both groups during KE45, KE15 and sitting plantarflexion exercises ($P<0.05$).

For each muscle, Table 3 contains the number of participants that produced maximum activation for each exercise. These results are consistent with the relative amplitudes produced in Table 2. Exercises where maximum activations were obtained were similar between groups. The standing plantarflexion exercise was the single most effective exercise eliciting maximal activations for MG in 48 (70%) of the participants with knee OA. Clearly, a single exercise was not found that could be deemed as the best exercise for achieving maximal amplitudes.

In summary, the greatest activation for gastrocnemius occurred during standing plantarflexion, for vastii muscles during KE45 and KE15, for rectus femoris during KE15 and for hamstring musculature during both PKF55 and KF15. No differences in maximum normalized values from these exercises were found between participants with asymptomatic knees and those with knee OA.

Table 3: MVIC exercises that produced maximum activations for each muscle. The numbers of individuals, separated by group are shown.

Exercise	Muscle													
	LG		MG		VL		VM		RF		LH		MH	
	AS	OA	AS	OA	AS	OA	AS	OA	AS	OA	AS	OA	AS	OA
KE45	0	0	0	0	28	30	23	28	17	19	0	0	0	0
KE15	0	0	0	0	33	28	35	29	32	32	0	0	0	0
KEHF	1	3	0	0	2	6	2	3	19	16	0	0	0	0
KF55	7	13	2	3	0	0	0	0	0	0	8	4	12	10
KF15	7	4	8	3	0	0	0	0	0	0	30	38	16	23
PKF55	3	2	3	1	0	0	0	0	0	0	30	24	39	35
PF sit	17	14	12	13	2	0	1	1	0	0	0	0	0	0
PF stand	33	32	43	48	3	4	7	7	0	1	0	2	1	0

Exercises: KE45 (knee extension at 45^o knee flexion), KE15 (knee extension at 15^o knee flexion), KEHF (knee extension-hip flexion at 45^o knee flexion and 90^o hip flexion), KF55 (knee flexion at 55^o knee flexion), KF15 (knee flexion at 15^o knee flexion), PKF55 (knee flexion at 55^o knee flexion in prone position), PFsit (plantarflexion at neutral ankle, knee extended, hip flexed), PFstand (unilateral plantarflexion in standing).
Muscles: LG (lateral gastrocnemius), MG (medial gastrocnemius), VL (vastus lateralis), VM (vastus medialis), RF (rectus femoris), LH (lateral hamstrings), MH (medial hamstrings)
Groups: OA (moderate knee OA), AS (asymptomatic knee)

Discussion

This study provides new information on how exercise selection influences EMG amplitudes obtained during maximal voluntary isometric testing in those with confirmed knee OA compared to those with asymptomatic knees. Consistent with findings of Vera-Garcia et al.,[2009] on trunk musculature, the current investigation found that no single exercise elicited a maximum voluntary activation for all lower extremity musculature even for a given muscle group. Maximum amplitudes occurred with similar frequency for the exercises in those with asymptomatic knees and those with knee OA.   Therefore, the presence of pathology did not alter which exercise elicited a maximum for a given muscle grouping.

As shown in Table 3, maximum activations were elicited in 3-6 different exercises for the seven muscles tested. The largest number of maximum activations was attained during standing plantarflexion for both gastrocnemii muscles (Fig.1F), although this exercise was more effective for the medial gastrocnemius. The effectiveness of this standing plantar flexor exercise is supported by the significantly higher relative activation amplitudes compared to the other exercises in Table 2 for both groups (86% MVIC or greater). Despite this finding over 50% of the absolute maximum activations for the lateral gastrocnemius were achieved from other exercises illustrating that relying on standing plantar flexion only would result in an underestimation of the maximum amplitude and potentially introduce a bias between medial and lateral sites.

Normalization exercise details are not often reported although one protocol described normalizing gastrocnemius amplitudes to amplitudes obtained from MVIC in prone lying plantarflexion where ankle position was neutral and the knee and hip extended [Childs et al, 2004; Rudolph et al, 2000]. The knee and ankle positions in those studies were similar to the sitting plantarflexion exercise utilized in the current study, which produced maximum activation in only 23 percent of individuals. The description of the protocol employed by Rudolph et al. [2000] includes the provision of using the maximum amplitudes obtained during the dynamic walking, stepping or jogging trials indicating that amplitudes were often higher in these dynamic trials than in the MVIC trials. This supports that perhaps this prone exercise was not effective at eliciting maximum amplitudes and is consistent with our findings. The present study attempted to utilize the series of standardized exercises to elicit maximums rather than relying on the assumption that maximum amplitudes would be achieved during walking or other dynamic tasks in which we have less control over the absolute amplitude. To the best of our knowledge, a standing plantarflexion exercise is not usually utilized for normalization however; the results of the present study suggest that this should be considered for inclusion in MVIC protocols. Peak normalized amplitudes reported during walking even for those with severe knee OA using this protocol are well below 100% MVIC supporting the effectiveness of standing plantarflexion to be used for MVIC normalization [Hubley-Kozey et al, 2009].

Knee joint angles of 45^{o} to 60^{o} during open kinetic chain MVIC testing are commonly employed and testing with only one knee joint angle is typical [Rudolph et al, 2000; Zeni et al, 2009;Childs et al, 2004]. Absolute maximum values were achieved with similar frequency in both KE45 and KE15 for VL and VM (Table 3) and they were equally effective at producing a similar relative activation as a percentage of MVIC (Table 2). Clearly, choosing only one exercise would result in an underestimate of the maximum activity in a large number of subjects. Differences between KE15 and KE45 may be partially explained in the knee OA group, based on variability in location of joint pathology (tibiofemoral versus patellofemoral), effusion presence, extension range of motion limitations and articular surface contact mechanics. The explanation for this finding in the asymptomatic group is less clear, and while joint mechanics and muscle mechanics may play a role, it may simply be that a variety of exercises are needed as was shown for the abdominal muscles to provide a best estimate of maximal activity [Vera-Garcia et al, 2009].

The desire to target rectus femoris, a bi-articulate muscle using the knee extension-hip flexion exercise was not as successful as expected with 27% of the asymptomatic controls recruiting absolute maximal activity. The majority of subjects in both groups recruited maximal activities in rectus femoris for KE45 and KE15 with the greatest activity recorded during KE15. Perhaps the motor control requirements of this KFKE task and the inability to monitor torque output (feedback) during this exercise resulted in the lower number of subjects recruiting maximal rectus femoris activations. Therefore KE45 and KE15 provided the best estimate of maximal activity for all three quadriceps.

The majority of participants obtained maximum hamstring activity during KF15 and PKF55 as shown in Table 3. In fact, only 12.5 percent of the maximum activities were obtained during KF55 in sitting, and the relative amplitudes were 73%MVIC or lower suggesting this exercise was not as effective in eliciting maximal activations. Therefore, studies that utilize similar exercises for maximal normalization would most likely underestimate their maximum reference amplitudes. The presence of knee OA did not alter the results as no differences in percent MVIC were found between groups. The KF15 and PKF55 elicited similar relative activation amplitudes, but more participants produce absolute maximal amplitudes in MH during PKF55 whereas the KF15 was most effective for the LH. These results are generally consistent with previous studies. Onishi et al. [2002] found that during maximum isokinetic knee flexion, semitendinosus and semimembranosus (MH) presented with the lowest activity at angles closer to full knee extension with a continued increase in activity as knee flexion increased. In contrast, activity of the long head of biceps femoris (LH) was greatest between 15-30 degrees. Mohamed et al. [2002] found that during maximal isometric knee flexion performed in nine different positions, EMG activity did not consistently change with muscle length however; semitendinosus activity was lowest while the subject was positioned in 0 degrees knee flexion and 90 degrees of hip flexion. While understanding global muscle group maximal activation levels are of interest, there is an increasing importance of understanding differential MH:LH activation during gait in knee OA [Lewek et al, 2004; Ramsey et al, 2007b], therefore the choice of normalization exercise may introduce a differential recruitment bias in the normalized EMG amplitudes if only one position were used.

Most knee OA EMG studies use open kinetic, mid-range knee flexion/extension during sitting [Childs et al, 2004; Zeni et al, 2009] whereas others do not report or reference their normalization procedures [Lewek et al, 2004; Ramsey et al, 2007b; Rudolph et al, 2007] making it difficult to compare relative amplitudes across studies. While comparing EMG results across studies can be a challenge given the lack of detail on procedures, it should be noted that for those studies reporting maximal-effort normalization procedures, similarities in amplitude-based measures (co-contraction indices) have been reported [Hubley-Kozey et al, 2009; Lewek et al, 2004; Ramsey et al, 2007a]. This is encouraging, as it supports the value of using maximum activations as a standard reference for comparative purposes. Even if a common protocol is not universally accepted, the present results show that understanding how specific exercises affect these relative amplitudes and that similarities exist between asymptomatic individuals and those with knee OA can help interpret findings from studies that utilize different maximal normalization protocols

The present study was limited to examining a finite series of MVIC exercises for the lower extremity musculature and thus we cannot determine whether other joint positions, or closed kinetic chain exercises would be more or less effective. These exercises were based on pilot work and represented a manageable series of contractions for this patient population. There were no adverse effects reported during or after testing. Given the differences in effectiveness among exercises, this study supports the need for reporting details on exercise positions for MVIC testing. While BMI measures were higher for those with knee OA, this difference in tissue volume would affect the raw EMG amplitudes, but not the normalized values. The exercise where the maximum occurred would also not be affected. Individuals with knee OA were older, however; the difference was less than seven years and this age difference would not likely alter the relative amplitudes. The lack of differences in relative amplitudes and exercise eliciting maximum amplitudes between groups supports this assumption.

Despite these limitations, this study provides novel information regarding MVIC exercises utilized for EMG normalization on a relatively large sample, and most important showed that those with asymptomatic knees and those with OA responded in a similar manner. Our findings illustrate the importance of presenting and potentially standardizing MVIC normalization protocols in the study of neuromuscular function in individuals with knee OA and further refining these voluntary techniques may be more effective. Further work could examine other positions and exercise modes, but caution regarding the number of exercises to include and ensuring that positions are attainable and comfortable for the patient population is needed. Examining the re-test reliability of these measures on sub-maximal activity profiles (i.e. gait waveforms) using this series of exercises is required to further substantiate their effectiveness for normalization procedures.

Conclusion:

This study provides evidence to support employing a series of exercises rather than a single exercise to increase the likelihood of recruiting maximal activity in the lower extremity muscles. No single exercise produced a maximum activation for all muscles for all individuals. Greatest activation for gastrocnemius muscles occurred during standing plantar flexion, for vastii muscles during KE45 and KE15 and for rectus femoris during KE15. KF15 and PKF55 produced the greatest hamstrings muscle activation, where a tendency existed for the lateral hamstrings to be influenced by the former and the medial hamstrings influenced by the latter. Furthermore, the findings illustrate that those with asymptomatic knees and those with medial joint knee OA were not different with respect to relative activation amplitudes for the majority of exercises or for which exercise was most effective at eliciting a maximum activation. This study provides an important first step in standardizing normalization criteria for understanding levels of sub-maximal activity produced during functional tasks in individuals with knee OA.

Conflict of Interest

Authors disclose that there are no conflicts of interest pertaining to this manuscript

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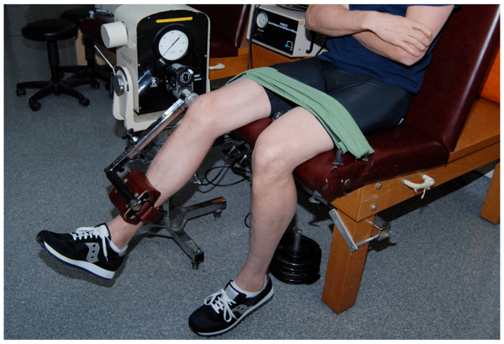
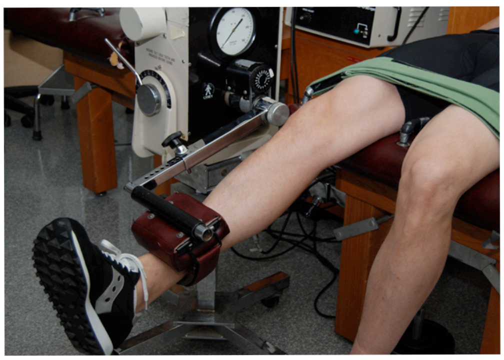


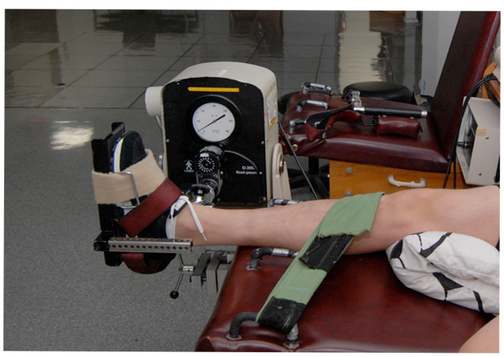
B)

C)



D)

E)



F)

G)

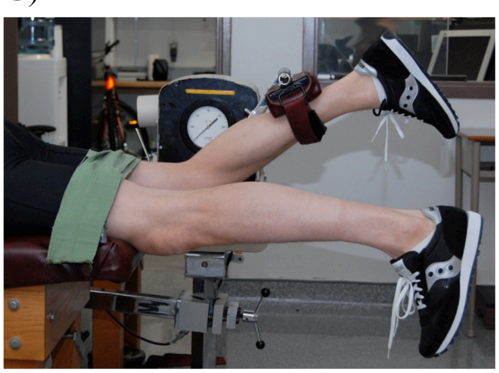


Figure 1: Standard positions for the series of maximal voluntary isometric contraction exercises. A) Knee extension at 45 degrees of knee flexion in sitting (KE45), B) Knee flexion at 55 degrees of knee flexion in sitting (KF55), C) Knee extension at 15 degrees of knee flexion in supine (KE15), D) Knee flexion at 15 degrees of knee flexion in supine (KF15), E) Plantar flexion at neutral in supine, F) Plantar flexion in standing and G) Knee flexion at 55 degrees of knee flexion in prone (PKF55). Note: combined knee extension and hip flexion was performed as per position A) (KEHF). With standard instructions, participants were asked to provide a maximal effort for a period of three seconds during each exercise. The thigh was secured with Velcro straps for all seated testing and participants were required to keep their hands crossed over their chest. For prone testing, a single pillow was placed under the hips and the thigh was strapped to the table. During seated plantarflexion, the leg was strapped to the table.

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