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QUANTIFICATION AND COMPARISON OF ECCENTRIC AND CONCENTRIC MUSCLE ACTIVITY OF THE LOWER LEG MUSCLES DURING UNCHALLENGING TYPES OF LEVEL AND DOWNHILL WALKING

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Abstract: Various types of walking are characterized through the predominant fractions of eccentric and concentric muscle contractions. Walking in part can be more efficient by the function of muscle works and the superior efficient of eccentric versus concentric contractions. Muscle activations during eccentric and concentric contraction during different mode of walking determined in many different ways and different methods. Nonetheless, the experimental measures are not always repeatable and/or identical as no all quantifications of muscle activations can be entirely accurate. On this basis, accordingly, our finding has provided a critical approach for synchronous sEMG and 2-D high – speed camera in quantification of the eccentric and concentric muscle activations of rectus femories muscle (RF) and bicep femories (BF) synergic muscles on unchallenging level and downhill walking. In fact, tracking the muscular electromyography (EMG) with kinematic mode did not yield a reliable outcome. To meet this challenge experiment different approaches such as musculoskeletal modelling might be useful technique in these quantifications and in understanding of distinct walking characteristics.

Keywords: Level walking, downhill walking, concentric contraction, eccentric contraction.

INTRODUCTION:

Muscle force production and adaptation are influenced by a range of factors but important to these are the length, and rate of change of length, of the active fibres involved in the activity (Rassierand Pun, 2010; Rassier and Herzog, 2002). When fibres are extended - usually by an external joint moment caused by a ground reaction force -the activity is termed eccentric. Similarly, when the muscles are shortening the activity is termed concentric. Although it is not always possible to measure the length of fibres using the ultrasound apparatus modes (Arnold and Delp, 2011, Fukunaga et al., 1997) and its subsequent related dynamic changes, it is common practice in biomechanics research to infer the type of contraction using kinematic analysis. More simply, fibres of knee (e.g. Rectus femoris) extensors muscles are considered to be acting simultaneously eccentrically when the knee under a negative angular velocity is moving into flexion moments. Similarly, the fibres of hamstring muscles (e.g. Semitendinosus) are acting eccentrically when the flexed knee with positive angular velocity is undergoing into a more extended moment.

These specific types of muscle activity can differ between individuals and between seemingly similar activities such as different modes of walking. Nevertheless, the specific mechanisms underpinning the beneficial changes due to walking interventions are not clear. Walking can take many forms, including level walking, downhill walking, uphill-walking, stair-descent and stair-ascent. Subsequently, the biomechanical/ physiological responses to the various spatio-temporal parameters during walking terrains could differ quite substantially. For example, in level walking the rate of positive mechanical work due to the acceleration of centre of mass (COM) in ascending moment is respectively counter balanced with equal mechanical negative work associated with the acceleration of centre of mass in descending period (Donelan et al., 2002;Minetti et al., 1993).

Whereas, downhill-walking and stair-descent involve longer and larger phases of deceleration of the COM, are considered to promote mainly eccentric activities that apply higher mechanical stress in the lower limb muscles, leading to the greater improvements in maximal strength and contraction velocity (Paschalis et al., 2013; Navalta et al, 2004). Landing during downhill locomotion at which lower limbs muscles act to decelerate the COM minimizes the kinetic of energy per unit of vertical displacement compared to the walking on the level surface (Lee et al., 2013; McIntosh et al., 2006).

In contrast, uphill-walking or stair-ascent exerts predominantly concentric loads on the lower-limb muscles (Asmussen ,1953; Padulo et al., 2013) to raise the COM against gravity are far more energetically demanding than the eccentric loads exerted during downhill slopes (DeVita et al., 2007).This suggest that there is a certain angle or angular range at different inclination from level walking to the different hill walking causing to the distinct mechanical energy dissipation in dynamic movements (Rieneret al., 2002).Inevitably, the concentric and eccentric muscle contraction as being verified to distinguish exercise types including walking modalities based on the most dominated contractions parts. Nevertheless, the exact magnitude of this quantification remains to be elucidated. In addition to the differential in volume of contraction during different locomotion, other noticeable differences distinguish the efficiency of human skeletal muscle contractions. In addition, a few studies have quantified the muscle works in part from biauricularmuscle (e.g. quadriceps and hamstring) in lower limbs extremities.

Recent research reveals that eccentric loads can elicit highly desirable changes in the neuro-mechanics, enabling the muscles to respond more effectively and with greater control to varying (or even unexpected) load requirements (Elmer et al., 2012). On this basis it is plausible to suggest that the promotion of downhill-walking or stair-descent by increasing the eccentric loads on the leg musculature may be a useful adjunct to populations for whom power and control are diminished, for example in older adults or patients suffering sarcopenia. Moreover, available evidence demonstrated that exercise, which typically involve eccentric workout, has helped to enhance concentric and isometric abilities (Maeo et al., 2015). Eccentric muscle action by attaining higher force production with lower electromyography (EMG) activity also induced more site-specific osteogenic response in lower limbs muscle than concentric muscle action(Hawkins et al., 1999).Advancing age however, notably affect the leg mechanic to walk on different inclines (Franz and Kram, 2013). For this reason, maintaining lower limbs eccentric strength is important for preserving functional independency and mobility (Roiget al., 2010). Eccentric strength also is an influential factor in the most of the competitive sports (e.g. Alpine ski) (Vogt and Hoppeler, 2014).

The aim of this study will be to quantify and compare modes of delivering eccentric and concentric loads via walking to the lower weight – bearings limbs to identify a feasible and meaningful eccentric training stimulus for specifically older adults. Distinct pattern of eccentric and concentric human muscle actions can provide an effectiveness technique for muscle behaviour on functional performances such as maintaining gait.

MATERIAL AND METHODS:

Participants:

Nine male participants with the mean (±sd) age: 29.00 ± 6.14 years; height: 175.48 ± 5.88 cm; body weight: 71.53 ± 11.13kg, volunteered to take part in this study. The study was approved by Teesside University Committee of Ethics and was in agreement with the ethical standard of Helsinki declaration on the use of human research. The participant completed the health and physical activity (*Booth*, 2000) questionnaires and signed the informed consent form. The subjects were in a good health and did not have injuries and lower limbs diseases over the 6 months prior to the study. They did not involve in any kind of systematic exercise or training.

Design of Research:

The design of this study is a within-subject repeated measures using a cross-over to balance out order effects to explore the inter-relationship between biomechanical variables (2-D-kinematic and sEMG data) and their reliability to observe how these are affected by changing the type of exercise.

Experimental Protocol:

Participants undertook two visits to the laboratory in total. The first visit devoted to the anthropometric measurements and providing the opportunity for the participants to become familiar with using the apparatus. Notably, it has been suggested that familiarization is important for motorized treadmills (Isner-Horobeti et al., 2013) in order to reduce the risk of injury. The height using a standard audiometer (Seca, 247, Birmingham, England) and weight by a standard weighing scales (Seca Weighing and Measuring Systems, 869, Birmingham, England) were measured and the subjects were familiarized with apparatus and testing procedures. The second visit took place for testing purposes which was composed of level treadmill walking (0%), two sets of downhill treadmill walking (-5% and -10%) on a motorized treadmill (Woodway, ELG70, Germany). Surface electromyography (sEMG) and 2-D kinematic data were synchronized using an external trigger to record the unilateral sagittal plane motion in the right leg. The external trigger allowed to a simultaneous recording.

Data collection and processing:

Surface electromyography measurement: Muscles elcrtomyographic activities were obtained using eight - channels wireless system at sampling rate of 2000 Hz, pre-amplifier gains 1000 V/V ±1%, input impedance of $>10^{15}$ Ω//0.2pf) (Cometa SRL, Wave Wireless, Milan, Italy).To record sEMG signal two muscles rectus femoris (RF) and bicep femoris (BF) on the right leg were selected. Palpation of each isolated muscle to ensure an appropriate position for electrode placement used according to the SENIMA guidelines (Hermenset al., 2000) (Table 2). Then, the intended muscles shaved and cleaned with medical alcohol wipe. Subsequently, the sensors (Noraxon Inc., USA) and electrodes placed and taped on the skin for each muscle securely. The participants were performed three separate 5-seconds maximum voluntary contraction for each muscle with 1-minutes rest between every muscle using the Burden protocol (2010) (Table 3). Prior to perform MVCs the subjects fully instructed by the researcher on the proper performance and the suitable knee angle to perform during maximum voluntary extension and flexion was determined using a bubble inclinometer (White Plains, New Yourk, 10602, USA). While performing MVCs the participant verbally encouraged to do their best.

The EMG data processed between two onset and offset time points (Figure 1) (Hibbs et al., 2011). In signal processing, the signals were band pass filtered with a fourth-order Butterworth algorithm and a cut-off frequency of 20 - 400 Hz. After removing of any bias, the raw EMG signals were smoothed using a root mean square (RMS) option with 20-ms moving window to make full wave positive. The data after that saved in laboratory computer (Aurion Zero Wire EMG Software, Wave EMG 1.1, Cometa SRL, Milan, Italy) for further analysis (Figure 2).To analyse the data, the peak value of MVCs for each muscle were identified and the highest of three MVCs was used for normalization process (Bolgla and Uhl, 2007; Benoit et al., 2003). To normalize MVCs that was expressed as a percentage of maximum voluntary contraction (%MVC), equation 1was used.

% MVC = 100* peak during activity / peak during MVC exercise (Equation 1)

Table 1: Determination selected anatomical landmarks according to the SENIMA guidelines

Muscle groups	Placements
Quadriceps femoris (QF)	In the section of rectus femoris from the distance of 50% on the line from the anterior spina ilica superior to the superior part of the patella
Bicep femoris (BF)	At the 50% of the ischial tuberosity to the lateral epicondyle of the tibia

Table 2: MVC performances (Burden, 2006)

Exercise	Muscles	Descriptions	Duration	Sets	Diagrams
Extension	RF	Participant sit on a chair with suitable extended knee angle(almost 60 ^{0}degree) and attempts to extend the knee against a resistance	5s	3 sets	
Flexion	BF	Participant sit on a chair with a knee angle of 90^o degree and attempts to flex the knee against a resistance	5s	3 sets	

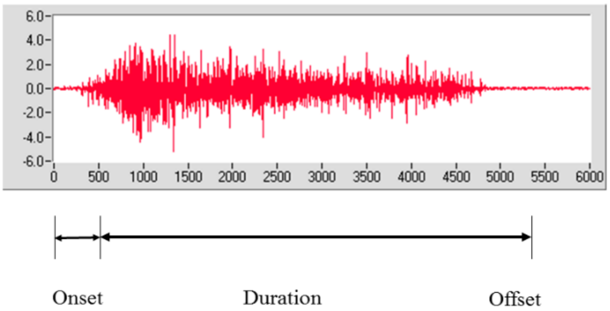

Figure 1: Signal processing: The EMG data processed between two onset and offset time points

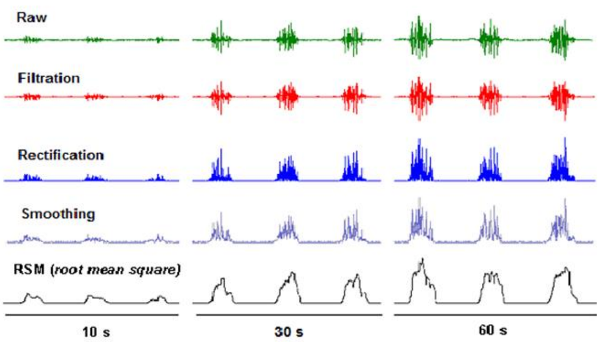

Figure 2: The method processing the EMG signals

2-D-Kinematic measures: Two-dimensional (2-D) kinematic data using a high-speed camera (Sports Cam, 250 Colour, Lake Image Systems, Herts, v1.4 England) recorded the vertical right knee angle at sample frequency of 125 Hz during different level (0%) and downhill (-5% and -10%) treadmill tests (Maykut et al., 2015).To allow this, three anatomical locations from hip, knee and ankle on right leg were marked to record various walking motions (Table 4) (Figure 3) and the film was captured sagittal plan kinematic from the right leg. The 2-D data then was analysed via a commercially available software (Quintic, Biomechanics v26, Ltd., West Midlands, UK).To obtain the data, the video was opened in Quintic software and digitisation option was used to set the frames and calibrate the file. Then, the short films using the automatic digitisation procedure tracked the centre of 3 joints on hip, knee and ankle with the use of the reflective markers. Once kinematic data digitised, the Butterworth filter in single - video option was used to optimally smooth the raw data for position, velocity and acceleration of the hip (10- 21.5 Hz), knee (15-18.5Hz) and ankle (18.50-31Hz) in angular analysis. Finally, the kinematic data directly exported to the Microsoft Excel for further analysis.

Table 3: Anatomical land markers for 2-D-kinematic measures (McLean et al., 2005).

Land markers	Placements
Hip	Placed the marker over the greater trochanter
Knee	Placed on the lateral epicondyle of the knee
Ankle	Placed on the lateral malleolus along an imaginary line that passes through the transmalleolar axis

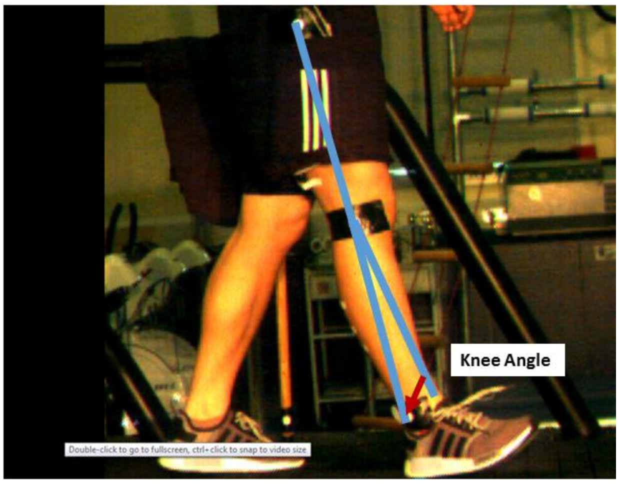

Figure 3: Anatomical land marks for EMG and 2-D-kinematic measures. Snapshot of video image showing the marker location and the knee angle (determined as the angle subtended by the long-axes of the distal relative to the proximal segment) captured during treadmill walking

Exercise details:

After determining MVCs for each muscle, the participants walked 1 minutes at light intensity on treadmill for preparation time prior performing the main testing. Subsequently, after warming up the subjects performed four distinct bouts of exercise (level walking, 2 set of downhill walking at similar self – selected walking speed (SSWS) (2.83 ± 0.74) on the treadmill) for 5 second while EMG and 2-D high speed camera recorded all efforts during tests periods simultaneously using an external trigger. To perform level treadmill walking the participant walked on a treadmill at 0% incline and downhill walking were performed at -5% and -10 % inclines (Minetti et al., 1993; Navalta et al., 2004). The trials for level and downhill walking were included 5 landing phases of the right leg during 5 gait Cycles (right heel strike -to- the next right heel strike) respectively.

Quantification of the eccentric and concentric muscle actions using 2-D- kinematic and sEMG measures:

To estimate the eccentric and concentric muscle action of RF and BF muscles, the linear interpolation method used to fill the gaps between the 2-D - kinematic and sEMG data using a designed programme in Microsoft Excel. Specifically, to match up the data in this method, the EMG code rates at 2000Hz was divided by kinematic codes rate at 625 Hz and the outcome was multiplied by each code rate at kinematic data to unite all data in a parallel sequence. These measurements are proxy measures of eccentric and concentric muscle contraction form RF and BF and unfortunately we could not use of optoelectronic motion capture and force plate to help determine joint moments, which together with EMG could determine the eccentric or concentric muscle actions. Following that, to determine the eccentric and concentric muscle actions, the knee extension-flexion moments at different terminal stance and swinging phase per each gait cycle during each treadmill walking (0%, -5%, -10%) were used. Ultimately, the eccentric and concentric muscle actions for RF and BF muscles, during each trails from equation 2 and 3 were obtained.

Eccentric muscle contraction from each muscle = IF (angular velocity >2, average % MVC, 0) (Equation 2)

Concentric muscle contraction from each muscle = IF (angular velocity < -2, average % MVC, 0) (Equation 3)

Statistical analysis:

Analysis of crossover (repeated measures) trails for multiple subjects:

The within – subjects (Crossover trails) protocol of eccentric and concentric components from muscle RF and BF were standardized using mean differences with 90% confidence limits (CL) per Altman and Bland (2011). The threshold values of effect size between0-0.19, trivial; 0.2–0.59, small; 0.6-1.19, moderate; 1.2-1.99, large; 2.0–3.99, very large; >4 extremely large with the relevant magnitude-based interference < 0.01, trivial; 0.01–0.05, very unlikely; 0.05 – 0.25, unlikely; 0.25 – 0.75, possibly; 0.75 – 0.95 likely; 0.95 – 0.99 very likely; >0.99, certainly; according to the Hopkins et al. (2009) classifications were applied to analyse the data. The clear mechanistic effect (the 5% chance of CL which are overlapped between negative and positive threshed) were qualified in this scale. Subsequently, the within-subject correlation between different exercise tails for each muscle calculated with CL 90 %. To interpret the data, the magnitude correlation coefficients: <0.1, trivial; 0.1 – 0.3, small; 0.3 – 0.5, moderate; 0.5 – 0.7, large; 0.7 – 0.9, very large; >0.9, nearly perfect in agreement with Hopkins and colleagues (2009) were used.

The inter-and intra-session variability for a single and multiple subjects:

To determine the repeatability data, the within- subject coefficient of variation (CV) with for a single subject equation stated 4 was used. The value of CV <26% has been considered to be acceptable for each muscle actions during each walking trails as previously many studies used of this value for complex exercise using lower extremities (e.g. quadriceps muscle) (Hibbs et al., 2011). Confidence limits (CL) 95% for single subject variability was used per any muscle actions. In this process, the CV measures expressed as reliability using standard deviation on the magnitude mean values for each muscle actions (i.e.ECC and CON) based on the magnitudes of %MVC angular velocity (AV).

CV = (SD / mean) × 100 (Equation 4) (Hibbs et al., 2011)
Subsequently, the between–day design spreadsheet (Hopkins, 2000) using the interclass correlation coefficient (ICC) was applied to quantify the between subjects' reliability for each muscle actions (i.e. ECC and CON based

on %MVC and AV). The CL 90% for between –subjects' reliability per each muscle actions applied.

RESULTS:

The raw MVCs and % MVCs for both RF and BF muscles during each walking trails (0%, -5% and -10%) are presented in Table 4. The average range of sEMG RMS of MVCs for RF muscle was between 201.04 to 983.73uVand the average ranges sEMG RMS of MVCs for BF muscle was between 167.96 to 784.28uV. This indicates that in overall RF of knee extensor muscle was more active ≥ than BF of knee flexor muscle MVCs static activities. The normalised MVCs to the peak amount however did not show a consistence outcome during level walking (0%), downhill walking (-5%) and downhill walking (-10%). The %MVCs for RF muscle except two cases were higher for downhill walking (-10%) in comparison with those two level (0%) and downhill walking (-5%) and the %MVC for BF muscle had huge rate of discrepancy between different modes of walking. Table 5 displays the raw ECC and CON muscle contractions in terms of produced force during each distinct walking trails. It shows that both ECC muscle contraction of RF (1.73 ± 1.73) and BF (7.29 ± 6.31) muscles were higher during downhill walking (-10%) than other level walking (0%) and downhill walking (-5%). Similarly, CON muscle contraction for RF (3.69 ± 4.89) and BF (11.40 ± 8.13) muscle was higher for downhill walking (-10%) compared to the level (0%) and downhill walking (-5%). More importantly, Table 5 reveals that both ECC and CON muscle actions of BF muscle were higher than ECC and CON muscle actions of RF muscle during downhill walking (-10%) and downhill walking (-5%) but it was not the same for level walking (0%).

The crossover trails protocol of ECC, CON muscle actions for both RF and BF muscles are exhibited in Table 6 and Figure 2, and Table 7 and Figure 3.In contrast with the raw data, Table 6 showed ECC RF muscle were not significantly different between level walking (0%) versus downhill walking (-5%) and downhill walking (-5%) versus downhill walking (-10%) whilst there was to be likely a small difference between level walking(0%) and downhill walking (-10%). Further, Table 6 has demonstrated that only downhill walking (-10%) was moderately different from level walking (0%) and there was a small difference between two modes downhill walking (-5% and -10%) and no difference between level walking (0%) and downhill walking (-5%). Table 7 also reveals that both mode of downhill walking (-5% and -10%) had small differences with level walking (0%) and two mode of downhill walking (downhill walking (-5%) vs downhill walking (-10%) were not different from each other at all (Trivial). Similarly, Table 7 showed that there was a small difference between level walking (0%) and downhill walking (-5%) and downhill walking (-10%) while there was a moderate difference between level walking (0%) and downhill walking (-10%).

The within - day CV for a single subject is presented in Table 8. The total within day variability for a single subject was varied ranged between 10% to the 58% for different type of muscles actions during each walking trails. The between-day variability for multiple subjects, which has expressed by ICC with 95% CL has been shown in Table 8. As can be found from Table 8the eccentric (ECC) muscle contraction of RF muscle had the highest value of repeatability for LTW (0%) with ICC = 0.86% and DTW-5% with ICC =0.90% and DTW-10% with ICC= 0.55 that CON contraction of RF as well as BF muscle contractions. In contrast, ECC (ICC = -0.44) and CON (ICC = -0.57) muscle actions of BF muscle during LTW 0% had the lowest value for repeatability in comparison with other muscle activities during the other walking trails (5% or 10%).The remaining ECC or CON muscle actions for both RF and BF muscle during different types of walking trails had poor value for reliability.

Table 4: The MVCs (uV) and % MVCs for RF and BF muscles derived from subjects (n= 8)

Participants	RF				BF			
	MVCs	%MVCs			MVCs	%MVCs		
		LTW0%	DTW-5%	DTW-10%		LTW0%	DTW-5%	DTW-10%
1	795.37	0.75	0.83	0.96	784.28	8.85	8.15	6.70
2	212.98	4.45	3.65	5.24	375.81	5.29	3.72	3.29
3	282.50	1.72	1.70	2.46	347.34	4.69	15.39	25.69
4	983.73	24.37	7.20	18.26	569.47	5.14	10.93	16.65
5	439.93	0.87	1.05	1.03	167.96	5.46	11.80	36.20
6	201.04	6.63	6.82	11.57	413.49	26.99	11.49	24.42
7	318.65	2.45	2.66	3.35	703.58	2.25	2.83	2.93
8	271.68	0.89	1.02	0.93	349.47	0.20	45.14	39.61

Abbreviations: MVC, maximum voluntary contraction; %MVC, percentage of maximum voluntary contraction; RF, rectus femoris; BF, bicep femoris; LTW, Level treadmill walking; DTW, Downhill treadmill walking

Table 5: The raw data of ECC and CON muscle contractions (Mean ± SD) from multiple subjects (n = 8)

Raw Data (Mean ± SD)	RF		BF	
	ECC	CON	ECC	CON
LTW0%	1.10 ± 0.85	1.36 ± 1.33	4.05 ± 4.75	3.12 ± 3.48
DTW-5%	1.24 ± 1.00	1.66 ± 1.60	5.50 ± 5.42	7.69 ± 7.76
DTW-10%	1.73 ± 1.73	3.69 ± 4.89	7.29 ± 6.31	11.40 ± 8.13

Abbreviations: ECC, Eccentric contraction; CON, Concentric contraction

Table 6: The within – subjects (Crossover trails) protocol of ECC and CON muscle actions of RF

Comparison	Raw Difference (mean ± 90% CL)	% Difference (mean ± 90% CL)	Qualitative inference
ECC RF			
LTW0% vs DTW-5%	0.22 ± 0.38	17.83 ± 23.22	Trivial
LTW0% vs DTW-10%	0.66 ± 0.78	37.55 ± 30.68	Likely small
DTW-5% vs DTW-10%	0.44 ± 0.69	16.73 ± 21.45	Trivial
CON RF			
LTW0% vs DTW-5%	0.42 ± 0.60	23.70 ± 28.08	Trivial
LTW0% vs DTW-10%	2.60 ± 3.47	152.16 ± 229.88	Likely moderate
DTW-5% vs DTW-10%	2.17 ± 2.88	103.86 ± 176.74	Likely small

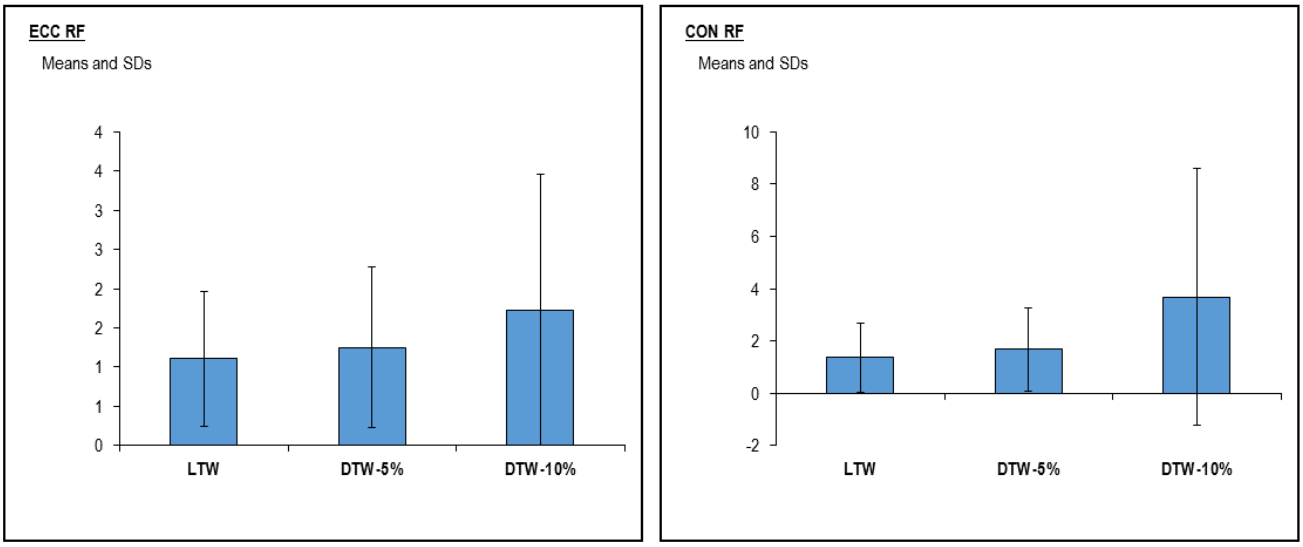

Figure 2: The ECC and CON muscle actions of RF according to the %MVC and Angular velocity (AV)

Table 7: The within – subjects (Crossover trails) protocol of ECC and CON muscle actions of BF

Comparison	Raw Difference (mean ± 90% CL)	% Difference (mean ± 90% CL)	Qualitative inference
ECC BF			
LTW0% vs DTW-5%	1.74 ± 6.61	106.30 ± 476.06	Possibly small
LTW0% vs DTW-10%	3.75 ± 6.01	166.75 ± 524.27	Likely small
DTW-5% vs DTW-10%	2.01 ± 3.10	29.31 ± 56.89	Trivial

CON BF			
LTW0% vs DTW-5%	2.06 ± 3.29	83.18 ± 131.19	Likely small
LTW0% vs DTW-10%	7.70 ± 6.28	231.18 ± 345.60	Very likely moderate
DTW-5% vs DTW-10%	5.64 ± 4.18	80.79 ± 86.71	Likely small

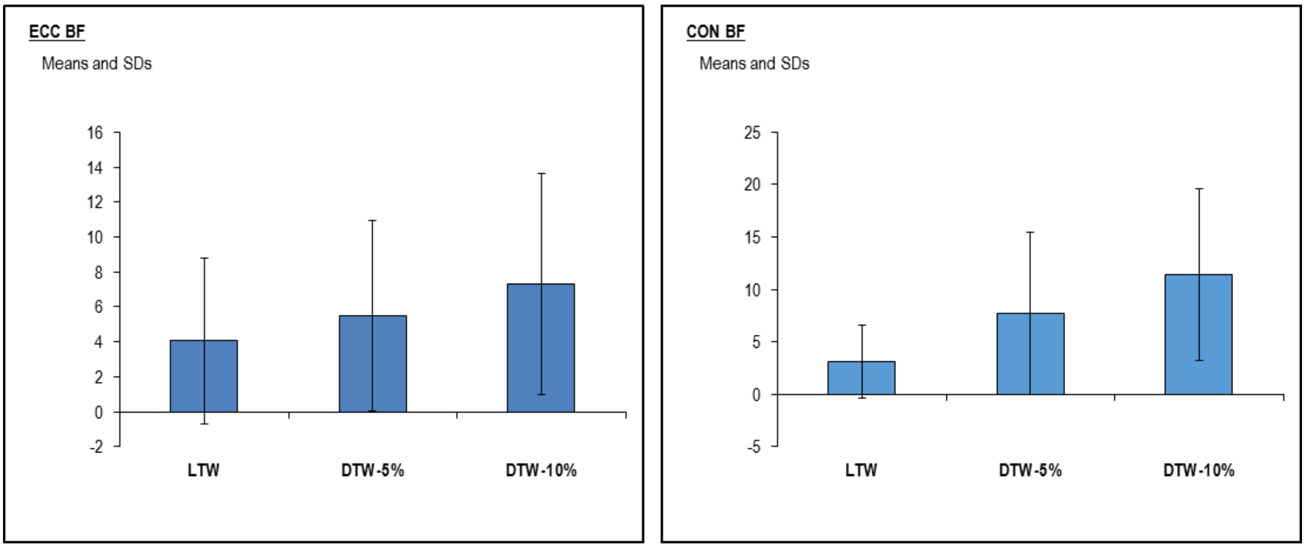

Figure 3: The ECC and CON muscle actions of BF according to the %MVC and Angular velocity (AV)

Table 8: Within – day %CV with 95% CL derived from one subjects (n=1) for ECC and CON muscle actionsof RF and BF muscles

Muscle / Trail	RF		BF	
	ECC	CON	ECC	CON
LTW0%	10.51%*	20.13%*	26.96%	21.34%*
DTW-5%	26.69%	16.85%*	57.12%	58.87%
DTW-10%	10.31%*	23.31%*	46.40%	10.78%*

**The value of CV<26% was acceptable for repeatability*

Table 9: Between- day ICC with 95% CL derived from multiple subjects (n=8) for ECC and CON muscle actions of RF and BF muscles

Muscle / Trail	RF		BF	
	ECC	CON	ECC	CON
LTW0%	0.86 (0.30 – 0.95)	0.48 (-0.33 – 0.77)	-0.44 (-1 – 0.24)	-0.57 (-1 – 0.15)
DTW-5%	0.90(0.57 – 0.96)	0.53 (-0.21 – 0.80)	0.31 (-0.61 – 0.69)	0.16 (-1 – 0.65)
DTW-10%	0.55 (-026 – 0.70)	0.16 (-0.83 – 0.62)	0.29(-0.65 – 0.68)	0.71 (0.16 – 0.88)

DISCUSSION:

To wide range of knowledge, this is the first study to quantify and compare the concentric (positive work) and eccentric (negative work) muscle actions of knee extensor and flexor joint from lower extremities during three mode of walking gaits. To this objective, asynchronous of sEMG and 2-D high-speed camera using an external trigger was applied to quantify the concentric and eccentric muscle contractions of rectus femories muscle (RF)and bicep femories (BF) muscle during 5-second of disparate level walking (0%), downhill walking (-5%) and downhill walking (-10%) in this investigation. It was speculated that the quantification of concentric and eccentric muscle actions of keen extensor (RF) and flexor muscles (BF) would assist to estimate and compare the amount of mechanical muscle forces during distinctive walking tasks. Knowledge regards the magnitude of exerted forces in terms of eccentric and concentric muscle contractions driven from lower limbmuscles in part around the knee joint in fact could have distinguished particular walking patterns in more details. Walking in general can be more efficient by the function of muscle works and the superior efficient of eccentric versus concentric contractions. In accordance with this this, the level and downhill walking fundamentally are different biomechanical tasks in terms of muscle functions and activation levels (Kuster et al., 1995).

DeVita et al. (2007) for example using the kinematic and GRF measures in five conditions of walking (level walking, up-and downhill walking and stair accent and decent) stated that all walking terrains contained the concentric and eccentric muscle actions but the magnitude of these activities were varied. In more detail they reported, uphill walking and stair ascent had more magnitude of concentric muscle components than level and downhill walking. Subsequently, downhill walking and stair decent involved more eccentric muscle contractions than level and uphill walking. However, this quantification established based on hip, knee and ankle joint power vs time curves and was not based on particular knee flexor (BF) or knee extensor (RF) muscle activations. Similarly, Eg and Winter (1995) individualized the total of concentric and eccentric muscular works using three-dimensional (3-D) model and from joint power at each lower extremity joint in level walking.

Activation differences between concentric and eccentric maximum voluntary contractions at different levels , which is possibly due to the changes in the muscle fibre length , has been evident in some studies (Grabiner and Owings , 2002; Linnamo et al., 2001). More evidence also showed longer muscle length leads to a greater force productions at higher level of muscle activation and compliance (Arnold et al., 2013; Arnold and Delp, 2011). Seger and Thorstensson (2005) stated greater increase in surface EMG activity during maximal voluntary contractions (MVCs) following eccentric training interventions compared to the concentric contraction. More specifically, it has been documented that downhill walking which contains more eccentric contraction component has elicited greater maximal contractions than walking on a flat surface or other mode of walking in healthy individuals. Maeo et al., (2015) reported higher relative gain MVCs knee extension for eccentric torque (+ 24% on average) than isometric (+ 13%) and concentric (+ 12% on average) torques following 40 -min low frequency downhill walking. Rodio and Fattorini (2014) also have shown greater MVCs only following downhill walking for both right and left legs in contrast with walking on level or other uphill surfaces. Franz and Kram (2012) similarly reported a greater knee extensor muscle activation and knee loading when young adults walked on downhill surface.

Current study, however, have not fully corroborated the functional significancy for muscle works in terms of eccentric and concentric muscle contractions for level and downhill walking trails. This indicates that there was not any remarkable weight- bearing differences between levels (0%) and downhill walking at -5% and -10% gradients. Eccentric contraction of RF muscle, for example, only had small differences between levels (0%) and downhill walking at -10% while this was not different between other types of walking (Trivial). This was followed with inconsistent within-day subject variability for RF muscle during each level walking (CV = 10.51%), downhill walking -5% (CV = 26.69%) and downhill walking -10% (CV = 10.31%). The between-day repeatability equally was inconsistent between each level walking (0%) (ICC =0.86) and downhill walking -5 % (ICC = 90%) and downhill walking-10% (ICC = 0.55).

Subsequently, concentric contraction of RF muscle was only moderately different between level walking (0%) and downhill walking (-10%) with small or no differences between other walking trails. The within – day variability during various walking terrains showed acceptable repeatability for concentric muscle contraction of RF muscle for level walking (0%) with CV = 20.13%, downhill walking at -5% with CV = 16.85% and downhill walking at -10% with CV = 23.31%. In contrast, the between- day subject showed low value of repeatability of concentric muscle contraction for level walking (0%) with ICC = 0.48 and downhill walking -5% with ICC= 0.53 and downhill walking -10% with ICC = 0.16.

Distinctive changes in BF from hamstring muscle activity have also been observed. There was a small difference between eccentric muscle contraction of different level walking (0%) versus downhill walking (-5%) and level walking (0%) versus downhill walking (-10%) while two mode of downhill at -5% and -10% were not different at all. Correspondingly, neither the within-day repeatability and nor the between-day showed a reliable value for eccentric contraction of BF muscle for none of the level (0%) (CV= 26.96%, ICC = 0.44), downhill walking at-5% (CV= 57.12%, ICC = 0.31) and downhill walking-10% (CV= 46.40%, ICC = 0.29%).

Concentric muscle contraction of BF was moderately different between level (0%) and downhill walking (-10%) but this differences were small between level walking (0%) versus downhill walking (-5%) and downhill walking at -5% and 10%.In the same way, the within – day and between-day subjects variability for concentric BF were different for each level (0%) (CV = 21.34%, ICC = -0.57), downhill walking (-5%) (CV = 58.87, ICC = 0.16) and downhill walking (-10%) (CV = 10.78%, ICC = 0.71) which was an indication of poor repeatability for this contraction from BF.

More importantly, when MVCs normalised to the peak value as a %MVC, downhill walking (-10%) did not elicit the highest values for %MVC for all cases in comparison with level walking (0%). Although ,some studies have shown that downhill walking paradigms, induced greater maximal voluntary contractions compared to the level or other uphill walking conditions in terms of mechanical force productions (e.g. MVCs) (Maeo et al., 2015; Rodio and Fattorini, 2014; Hussain et al., 2009; McHugh, 2002). However, changes in %MVC of RF from quadriceps muscle and BF from hamstring muscle at the current study because

of the variations between different level (0%), downhill walking (-5%) and downhill walking (-10%) were not comparable with previous literature.
Based on given outcomes of this investigation changes in muscle activity and muscle geometry in terms of eccentric and concentric muscle activities at different surfaces were not fully significant though. It can be assumed that a synchronisation of sEMG and kinematic signal could not certainly provide a reliable estimation of the volume of the recruited lower limbs muscle activations during each distinct level (0%) and non-level (-5% and -10%) walking surfaces. Although the recruited muscle could specify variable eccentric and concentric contractions during different walking tasks, one plausible biological bias may was sample size. The participants in the present study were not homogeneous as they were selected from different races. A heterogeneous sample size made not any differences in EMG amplitude waveforms and the raw kinematic signals at different walking surfaces. Consequently, there were not specific differences between eccentric and concentric muscle actions of RF and BF even though there was a moderate difference in both concentric muscle contractions of RF and BF during level walking (0%) and downhill walking (-10%). However, it was not reliable enough. Furthermore, statistically a large sample size is required to obviate the large variations among different individual (Hopkins 2000).Apart from this, the bias in EMG and 2-D kinematic data may have been affected by several, biomechanical, ecological, environmental and physiological factors.

A complex EMG and kinematic data may be inferred by many experimental paradigms in biomechanical setting. Taking the feature of methodological mechanism, to acquire the synchronized EMG and kinematic data, the external trigger using multiple connection was applied to elicit the functional load between distinct level and downhill walking. In this approach, the action-potential signal, measured through the cable connection to the input socket from EMG amplifier and camera. Nonetheless, the output signals may have been transferred inappropriate way owing to many wire connections in varying distances and thus the pattern of RF and BF muscle activities form quadriceps and hamstring muscles throughout the level (0%) and downhill walking (-5% and -10%) did not reflect accurately.

More importantly, when collecting the sEMG and kinematic signal there are some interferences, called 'noises'. The noises account for the largest determinant of signal level and in fact the quality of mechanical signal in different exercises (i.e. gait) may depended upon to these noise depletions (Raez et al., 2006). This unwanted interference could have led to the false interpretation in genuine muscle activations of RF and BF in present study. The noises could have induced from both intrinsic and extrinsic factors. The sources of this unwanted variability in this study maybe were power line and cable motions artifact from EMG spectrum, electrode amplification process during MVCs collection, retraction of electrodes and skin during dynamic tasks (i.e. level and downhill walking). Drastic changes in light radiance from high – speed camera may have increased the shot noises in an image also. Likewise, the thermal noise form skin, devices and ambient, may have affected the signals. Therefore, different noises could have influenced the overall signal acquisitions and its susceptibility in various situations.

Indeed, in some occasions the EMG signal does not represent the function of muscle of interest as it can be contaminated from the adjacent neighbour muscle or an opposing antagonist (Hug, 2011.). These mimic signals are called the EMG cross talk and the extent of contaminations in crosstalk is varied by different exercise intensities (Farina et al., 2004; Türkerand Miles 1990).Crosstalk can also lead to the misinterpretation of data, as the amplitude of EMG signals can be stochastic (quasi -random- waveform) in nature. More precisely, it can cause the muscle to be considered active when it is not. Barr et al. (2010) have recently suggested that sEMG incorrectly interpreted the vastuslateral is to rectus femoris (vasti-to-rectus) muscle activities during different stance and swing phases of gait because of vasti-to-rectus crosstalk. Kohand Grabiner (1992) similarly reported the crosstalk in sEMG of human hamstring muscle. They suggested that double differential technique appears to be a more efficient technique than the bipolar technique while recording EMGs from muscles with highly active neighbours.

However, to maximize the quality of mechanical signal and minimize baseline noises and movement artifacts in current study, the Butterworth band pass filter with cut-off frequency between 20 - 400 Hz of RMS form EMG and Butterworth filter with cut-off frequency between 10-30Hz form kinematic smoothing(2-D-digitiser Quintic software) were applied. In spite of this, neither the band pass filter from EMG and nor spatial filtering from lower limbs kinematic from a digitised technique did resulted a reliable method for noises removal. This means that synchronised sEMG and video-kinematic may contained variable specific of error systems (e.g. RMS and 2D-digitizer errors).

Furthermore, under certain conditions, sEMG records the skin surface signal and not solely the target muscle origin which electrode is placed. Thus, the produced EMG signal can be weak or unreal neuromechanicphenomenon and if this bias has happened in the current study, the sEMG signal was not the appropriate signal to unify with kinematic signals. For this reason, Byrne et al. (2005) have stated that sEMG may not suitable for obtaining information from an isolated single muscle.

Pervious evidence has shown that individualized familiarization method reduces the variability and error in measurements and database in the laboratory setting (Schellenbach et al., 2010). In the current study, the participant had experience of becoming familiar with exercise performances (i.e. MVCs, level and downhill treadmill walking). A familiarisation session can exclude the learning effect and optimize the outcome of measurements. Literally, a substantial period of familiarisation with equipment and training procedures has been shown to enhance the reliability of measurements. Without familiarisation, Waldron et al., (2016) have noted more lower-limbs (vastus lateralis (VL) and biceps femoris (BF)) EMG variability in adolescent cyclists. However, reliable data is not always assured. This because there is no specific regulation for body motion among individual due to uncertain muscles configurations. Thus, in this investigation, the mechanical signal (combined sEMG and kinematic signals) was not as perfect as depicted in many other investigations. Although sEMG data was normalised to peak activity for each muscle over all trails and kinematic calibration was performed to improve the accuracy and experimental error reductions, however, it is likely that the sEMG and kinematic signals were not linearly combined to display the proper muscle activations. This is possibly because of the delay in the onset of electrical activity transmission between the sEMG and kinematic reconstructions (Corcoset al., 1992; Cavanagh and Komi ,1979).Further, mechanical signal might not be fully detected the entire concentric and eccentric movements under short- time of 5 second during each static MVCs and dynamic walking trails.

There is also emerging evidence that shows contraction types and muscle length changes would affect the EMG spectrum and neural activation despite the variation in different muscle activations (Arnold et al., 2013; Kellis and Baltzopoulos, 1998). Subsequently, the rate of force development would differ depending on the onset of muscle action and contraction velocity at various exercise levels (e.g. Gaits) (Maffiuletti et al., 2016) .With regard to this, some studies have reported that that the EMG amplitude of MVCs and isokinetic torque were greater for concentric than eccentric muscle action under similar loading conditions. They in fact distinguished the activation pattern between the concentric and eccentric contractions. Consequently, these kinds of finding allow to a comparison between concentrically and eccentrically loads in terms of applied force at during exercises or sports. In reality, the most activities involve both type of muscle actions consecutively depending on the pattern of given tasks (i.e. level walking vs downhill walking). In this study, however, there were no obvious changes in lower limbs muscle activities (RF and BF) between the 3 walking conditions (0%., -5%, -10% grades).Some ecological characteristics such as individual walking velocity (similar walking speeds during level and two downhill walking per person) and stiff steps may have influenced this outcome. Some other environmental features such as surface treadmill belt and footwear might be affected by the neuromuscular control and could have produced misleading results(Stern and Gottschall2012; Dingwell et al., 2001).Along with above issues, physiological factors involving some anthropometric characteristics such as fat layer, blood flow, fatigue onset, the lower limbs body weakness during the tasks that was being performed (i.e MVCs or walking trails), the body temperatures may have influenced the EMG waveforms and 2-D kinematic diagrams (Doud and Walsh, 1995; Kamen and Caldwell, 1996). Certain psychological states such as lack of motivation can affect the way a person could perform the given tasks. This could have suppressed the actual biomechanical signals in gaits distinctions in the current study (Beretta-Piccoli et al., 2015; Dimitrova and Dimitrov 2003). Hence, these factors potentially have influenced the signal integrity and could have interacted with the relative amount of the concentric and eccentric of RF and BF muscular works in level (0%) and two models of downhill walking (-5% and -10% grades).

In short, the obtained results in this investigation are affected by many sources of noises. In this case, presumably due to these server noises and distortion, the real information has been lost, as the proposed method has been influenced by these complex exposures. In fact, tracking the muscular electromyography with kinematic mode (2-D high – speed camera) did not yield a reliable outcome since it was enigmatic. An array of different methods might help to improve the techniques in gait - related research and in quantification of associated parameters. To address this challenge, a new approach is required to differentiate various characteristics of muscle dynamic (i.e. eccentric and concentric contractions) in gait patterns. In this regard, a computational framework of musculoskeletal modelling such as OpenSim may provide more speciation of skeletal muscle geometry. These models of musculoskeletal system permit a broader scientific quantification of musculoskeletal loads, neuromuscular stimulations, join kinematic, muscle length and musclulotendinousforces in human locomotion. Using musculoskeletal computational modelling may be beneficial to overcome the noises from aforementioned natural variability's or technical aspects such as false conditions, sensor movements and cross-talk.

CONCLUSION:

Various types of walking are characterized by the predominant fractions of eccentric and concentric muscle contractions. In fact, estimation of muscular efforts during different walking conditions is an important goal at various athletic sport or clinical states. Muscle activations during eccentric and concentric contraction during different modes of walking have been determined in many different ways and by different methods. Nonetheless, the experimental measures are not always repeatable and/or identical as not all quantifications of muscle activation scan be entirely accurate. The experimental complexity with sophisticated modern devices can be one of the main reasons as one variable error can influence the other variable and on the overall outcome measures because of high level of noises. In this case, the integration of EMG and kinematic signals in the current study did not present a reliable distinctions of eccentric and concentric muscle contractions from RF and BF muscles between different pattern of level walking (0%), downhill walking (-5%) and downhill walking (-10%) possibly owing to variety of noises. The multiple source of noises in this study possibly were the experimental apparatus, calibration error, lightening conditions and the human variability, which inferred the mechanical signals during MVCs and dynamic walking trails. Changes induced by these noises might have altered the result of this experiment and caused no real comparative differences between conventional level walking and walking on downhill surfaces. Consequently, experimental paradigms due to the various technical problems can modify the results incorrectly, which makes it difficult, a true evaluation of types of activities. Accordingly, the present finding has provided a critical approach for synchronous sEMG and 2-D kinematic model in quantification of the eccentric and concentric muscle activations of RF and BF synergic muscles on unchallenging level and downhill walking. To meet this challenge experiment of different approaches such as musculoskeletal modelling might be useful technique in these quantifications and in characterization of distinct walking.

LIMITATIONS:

The sample size of this study due to the complexity of measurements was small. However, the larger sample size required a long-lasting time of measurements, which was beyond of the duration of this study. The inequity usage of force plate and optoelectronic motion capture was another limitation to quantify the eccentric and concentric muscle actions of rectus femoris (one of the quadriceps femoris muscle) and bicep femoris (one of the hamesteringmuscle). The duration of each MVCs and walking trails were short and an optimal training periodisation with longer duration might have the better outcome.

FUTURE DIRECTIONS:

Direct measurements of muscle forces in terms of eccentric and concentric muscle actions are difficult because of its invasive nature. The quantification and comparison of eccentric and concentric muscle activity of the lower leg muscles using an integration of EMG and kinematic model during level and downhill walking in this research was also challenging. The computational musculoskeletal model may solve the highlighted issues in this study. On this basis, the future study is going to be a developing of musculoskeletal model of lower limb that stimulates the smoothed EMG data in integration with 3-D kinematic mode of optoelectronic motion capture to estimate the dynamic muscle forces during unchallenging types of gait.

REFERENCES:

I. Altman DG, Bland JM. How to obtain the P value from a confidence interval.Br Med J.2011; 343.

II. Arnold EM, Delp SL. Fibre operating lengths of human lower limb muscles during walking. Philos Trans R Soc Lond B Biol Sci. 2011; 366(1570):1530-9.

III. Arnold EM, Hamner SR, Seth A, Millard M, Delp SL. How muscle fiber lengths and velocities affect muscle force generation as humans walk and run at different speeds. J Exp Biol. 2013; 216 (Pt 11):2150-60.

IV. Asmussen E. Positive and negative muscular work. Acta Physiol Sc and. 1953; 28(4):364-82.

V. Arnold EM, Delp SL. Fibre operating lengths of human lower limb muscles during walking. Philos Trans R Soc Lond B Biol Sci. 2011; 366(1570):1530-9.

VI. Barr KM, Miller AL, Chapin KB. Surface electromyography does not accurately reflect rectus femoris activity during gait: impact of speed and crouch on vasti-to-rectus crosstalk. Gait Posture. 2010; 32(3):363-8.

VII. Batterham AM, Hopkins WG. Making meaningful inferences about magnitudes. Int J Sports Physiol Perform. 2006; 1(1):50–57.

VIII. Beretta-Piccoli M, D'Antona G, Barbero M, Fisher B, Dieli-Conwright CM, Clijsen R, Cescon C. Evaluation of central and peripheral fatigue in the quadriceps using fractal dimension and conduction velocity in young females. PLoS One. 2015; 10(4):e0123921.

IX. Booth ML. Assessment of Physical Activity: An International Perspective. Research Quarterly for Exercise and Sport.2000; 71 (2): s114-20.

X. Burden A. How should we normalize electromyograms obtained from healthy participants? What we have learned from over 25 years of research. J Electromyogr Kinesiol. 2010; 20(6):1023-35.

XI. Byrne CA, Lyons GM, Donnelly AE, O'Keeffe DT, Hermens H, Nene A.Rectus femoris surface myoelectric signal cross-talk during static contractions. J Electromyogr Kinesiol. 2005; 15(6):564-75.

XII. Cavanagh PR, Komi PV. Electromechanical delay in human skeletal muscle under concentric and eccentric contractions. Eur J Appl Physiol Occup Physiol. 1979; 42(3):159-63.

XIII. Corcos DM, Gottlieb GL, Latash ML, Almeida GL, Agarwal GC. Electromechanical delay: An experimental artifact. J Electromyogr Kinesiol. 1992; 2(2):59-68.

XIV. DeVita P, Helseth J, Hortobagyi T. Muscles do more positive than negative work in human locomotion. J Exp Biol. 2007; 210(Pt 19):3361-73.

XV. Dimitrova NA, Dimitrov GV. Interpretation of EMG changes with fatigue: facts, pitfalls, and fallacies. J Electromyogr Kinesiol. 2003; 13(1):13-36.

XVI. Dingwell JB, Cusumano JP, Cavanagh PR, Sternad D. Local dynamic stability versus kinematic variability of continuous overground and treadmill walking.J Biomech Eng. 2001 ;123(1):27-32.

XVII. Donelan JM, Kram R, Kuo AD. Simultaneous positive and negative external mechanical work in human walking. J Biomech. 2002; 35(1):117-24.

XVIII. Doud JR, Walsh JM.Muscle fatigue and muscle length interaction: effect on the EMG frequency components. Electromyogr Clin Neurophysiol. 1995; 35(6):331-9.

XIX. Eng JJ, Winter DA. Kinetic analysis of the lower limbs during walking: what information can be gained from a three-dimensional model? J Biomech. 1995; 28:753–758.

XX. Elmer S, Hahn S, McAllister P, Leong C, Martin J. Improvements in multi-joint leg function following chronic eccentric exercise. Scan J Med Sci Sports. 2012; 22(5): 653-661.

XXI. Franz JR, Kram R. The effects of grade and speed on leg muscle activations during walking. Gait Posture. 2012; 35:143–7.

XXII. Farina D, Merletti R, Indino B, Graven-Nielsen T. Surface EMG crosstalk evaluated from experimental recordings and simulated signals. Reflections on crosstalk interpretation, quantification and reduction. Methods Inf Med. 2004; 43(1):30-5.

XXIII. Franz JR, Kram R. Advanced age affects the individual leg mechanics of level, uphill, and downhill walking. J Biomech. 2013 Feb 1; 46(3): 535–540.

XXIV. Fukunaga T, Ichinose Y, Ito M, Kawakami Y, Fukashiro S. Determination of fascicle length and pennation in a contracting human muscle in vivo. J Appl Physiol .1997; 82:354–358.

XXV. Grabiner MD, Owings TM.EMG differences between concentric and eccentric maximum voluntary contractions are evident prior to movement onset. Exp Brain Res. 2002; 145(4):505-11.

XXVI. Hawkins SA, Schroeder ET, Wiswell RA, Jaque SV, Marcell TJ, Costa K. Eccentric muscle action increases site-specific osteogenic response.Med Sci Sports Exerc. 1999; 31(9):1287-92.

XXVII. Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. J Electromyogr Kinesiol. 2000; 10(5):361-74.

XXVIII. Hibbs AE, Thompson KG, French DN, Hodgson D, Spears IR. Peak and average rectified EMG measures: which method of data reduction should be used for assessing core training exercises? J Electromyogr Kinesiol. 2011; 21(1):102-11.

XXIX. Hopkins WG (2000). Measures of reliability in sports medicine and science. Sports Medicine 30, 1-15.

XXX. Hopkins W, Marshall S, Batterham A, Hanin J. Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc.2009; 41 (1): 3

XXXI. Hug F. Can muscle coordination be precisely studied by surface electromyography? J Electromyogr Kinesiol. 2011; 21(1):1-12.

XXXII. Hussain MS, Reaz MBI, Mohd-Yasin F, Ibrahimy MI. Electromyography signal analysis using wavelet transform and higher order statistics to determine muscle contraction. J. Knowl. Eng. Expert Syst.2009; 26:35– 48.

XXXIII. Kamen G, Caldwell GE. Physiology and interpretation of the electromyogram. J Clin Neurophysiol. 1996; 13(5):366-84.

XXXIV. Kellis E, Baltzopoulos V. Muscle activation differences between eccentric and concentric isokinetic exercise. Med Sci Sports Exerc. 1998; 30(11):1616-23.

XXXV. Koh TJ, Grabiner MD. Cross talk in surface electromyograms of human hamstring muscles.J Orthop Res. 1992; 10(5):701-9.

XXXVI. Kuster M, Sakurai S, Wood GA.Kinematic and kinetic comparison of downhill and level walking. Clin Biomech (Bristol, Avon). 1995; 10(2):79-84.

XXXVII. Isner-Horobeti ME, Dufour SP, Vautravers P, Geny B, Coudeyre E, Richard R. Eccentric exercise training: modalities, applications and perspectives. Sports Med. 2013; 43(6):483-512.

XXXVIII. Lee M, Kim J, Son J, Kim Y. Kinematic and kinetic analysis during forward and backward walking. Gait Posture. 2013; 38(4):674-8.

XXXIX. Linnamo V, Strojnik V, Komi PV.EMG power spectrum and maximal M-wave during eccentric and concentric actions at different force levels. Acta Physiol Pharmacol Bulg. 2001; 26(1-2):33-6.

XL. Maeo S, Yamamoto M, Kanehisa H. Muscular adaptations to short-term low-frequency downhill walking training. Int J Sports Med. 2015; 36(2):150-6.

XLI. Maffiuletti NA, Aagaard P, Blazevich AJ, Folland J, Tillin N, Duchateau J. Rate of force development: physiological and methodological considerations.Eur J Appl Physiol. 2016; 116: 1091–1116.

XLII. Maykut JN, Taylor-Haas JA, Paterno MV, DiCesare CA, Ford KR. Concurrent validity and reliability of 2d kinematic analysis of frontal plane motion during running. Int J Sports Phys Ther. 2015; 10(2):136-46.

XLIII. McHugh MP, Tyler TF, Greenberg SC, Gleim GW. Differences in activation patterns between eccentric and concentric quadriceps contractions. J Sports Sci. 2002; 20(2):83-91

XLIV. McIntosh AS, Beatty KT, Dwan LN, Vickers DR. Gait dynamics on an inclined walkway. J Biomech. 2006; 39(13):2491-502.

XLV. McLean SG, Walker K, Ford KR, Myer GD, Hewett TE, van den Bogert AJ . Evaluation of a two dimensional analysis method as a screening and evaluation tool for anterior cruciate ligament injury.Br J Sports Med .2005; 39:355-362.

XLVI. Minetti AE, Ardigò LP, Saibene F. Mechanical determinants of gradient walking energetics in man.J Physiol. 1993; 472:725-35.

XLVII. Navalta JW, Sedlock DA, Park KS. Physiological response to downhill walking in older and younger individuals. JEPonline. 2004; 7(6): 45-51.

XLVIII. Padulo J, Laffaye G, Ardigò LP, Chamari K. Concentric and Eccentric: Muscle Contraction or Exercise? J Hum Kinet. 2013; 37:5-6.

XLIX. Pescatello LS, Franklin BA, Fagard R, Farquhar WB, Kelley GA, Ray CA. American College of Sports Medicine position stand. Exercise and hypertension. Med Sci Sports Exerc. 2004; 36: 533–553.

L. Rassier DE, Herzog W. Force enhancement following an active stretch in skeletal muscle. J Electromyogr Kinesiol. 2002; 12(6):471-7.

LI. Rassier DE, Pun C. Stretch and shortening of skeletal muscles activated along the ascending limb of the force-length relation. AdvExp Med Biol. 2010; 682:175-89

LII. Raez MBI, Hussain MS, Mohd-Yasin F.Techniques of EMG signal analysis: detection, processing, classification and applications. Biol Proced Online. 2006; 8: 11–35.

LIII. Riener R, Rabuffetti M, Frigo C. Stair ascent and descent at different inclinations. Gait Posture. 2002; 15(1):32-44.

LIV. Rodio A, Fattorini L. Downhill walking to improve lower limb strength in healthy young adults. Eur J Sport Sci. 2014; 14(8):806-12.

LV. Roig M, Macintyre DL, Eng JJ, Narici MV, Maganaris CN, Reid WD. Preservation of eccentric strength in older adults: Evidence, mechanisms and implications for training and rehabilitation. Exp Gerontol. 2010; 45(6):400-9.

LVI. Schellenbach M, Lövdén M, Verrel J, Krüger A, Lindenberger U. Adult age differences in familiarization to treadmill walking within virtual environments. Gait Posture. 2010; 31(3):295-9.

LVII. Seger JY, Thorstensson A. Effects of eccentric versus concentric training on thigh muscle strength and EMG.Int J Sports Med. 2005; 26(1):45-52.

LVIII. Stern KA, Gottschall JS. Altering footwear type influences gait during level walking and downhill transitions. J Appl Biomech. 2012; 28(5):481-90.

LIX. Türker KS, Miles TS. Cross-talk from other muscles can contaminate EMG signals in reflex studies of the human leg. Neurosci Lett. 1990; 111(1-2):164-9.

LX. Vogt M, Hoppeler HH. Eccentric exercise: mechanisms and effects when used as training regime or training adjunct. J Appl Physiol (1985). 2014; 116(11):1446-54.

LXI. Waldron M, Highton J, Gray A. Effects of familiarization on reliability of muscle-activation and gross efficiency in adolescents and adults. Cogent Medicine (2016), 3: 1237606.