Journal of Data Acquisition and Processing
ISSN: 1004-9037
https://sjcjycl.cn/
DOI: 10.5281/zenodo.9854879

EFFECT OF FOOTWEAR ON RELIABILITY OF ELECTROMYOGRAPHIC FEATURES OF LEG MUSCLES IN FLEXED KNEE HEEL RISE ACTION

Gupta Sanjeev
Professor – Physiotherapy, Faculty of Allied Health Sciences, Manav Rachna International Institute of Research & Studies, Sector – 43, Faridabad – 121004

Aggarwal Saanvi
Student – MBBS 2021 Batch, SVIMS - Sri Padmavathi Medical College for Women, Alipiri Road, Tirupati, Chittoor Dsitrict, Andhra Pradesh, India 517507

Corresponding Author:
Prof. (Dr.) Sanjeev Gupta, E-mail - sanjivgupta_india1@yahoo.co.in

Abstract

Background - Surface electromyographic data (SEMG) was acquired from leg muscles Soleus, Tibialis Anterior and Lateral head of Gastrocnemius to study effect of footwear on heel rise action while knee kept in flexion. Surface electromyography signals were synchronously acquired from different subjects on separate occasions for this purpose. Reliability of surface electromyography data was required to be established prior to analyze the intended footwear influences on leg muscle in heel rise action. Therefore, so acquired SEMG signal data was tested for intra-session & intra-rater reliability analysis of surface electromyographic outcome measures. **Aim** – The study was undertaken to analyze intra-session, intra-tester reliability of frequency as well as time domain outcome measures extracted from SEMG signals. **Design & Setting** – Experimental approach was adopted to acquire simultaneous SEMG signals from leg muscles from 40 participants. Each participants performed three repetitions of heel rise action with knee maintained in flexion, both in barefoot (experimental) and shod (control - flip flop) conditions. The order of the experimental and control condition was assigned randomly. Common SEMG features Mean Frequency MNF, Root Mean Square RMS & Time to Peak TTP were extracted from the SEMG signal data so acquired. **Statistical Analysis** – reliability analysis was performed for RMS, MNF & TTP features from individual dataset of all three trials in the two foot conditions (barefoot & shod). Intra-class Correlation (ICC) was computed for corresponding dataset to test the reliability of the SEMG data drawn features. **Results** – Good intra-rater reliability (ICC > 8.0) was found for Mean Frequency and Root Mean Square for all three leg muscles in both barefoot and shod conditions; however very poor reliability was demonstrated by Time To Peak (TTP) feature for all muscles in both conditions. In general reliability was better in barefoot condition than shod; ICC was observed higher in footwear condition only in case of Tibialis Anterior for RMS feature. **Discussion** – The result establish the fact that intra-session, intra-rater reliability of SEMG based outcome measures is affected (reduced) by footwear as compared to the barefoot. Grossly ICC analysis affirm good reliability for Mean Frequency and Root Mean Square features while it is very poor (unreliable) for the Time to Peak (TTP) feature. These results were found consistent with respect to each

muscle and shod condition. **Conclusion** – Flip Flop (footwear) alters (reduces) intra-session intra-rater reliability of SEMG outcome measures. Frequency domain (MNF) outcome measure when extracted during concentric action of muscle give most reliable dataset as compared to the other SEMG features. Further three repetitions are reasonably sufficient for averaging purpose of SEMG data without compromising reliability of sEMG variables.
KEYWORDS – SEMG, RELIABILITY, FOOTWEAR, SOLEUS, HEEL-RISE

INTRODUCTION

Despite the widespread exploitation of flexed Knee Heel Rise[1,2,3] (FKHR) Task for diagnostic and interventional purposes especially in the fields of physiotherapy and sports rehabilitation, a standardized technique for it, is lacking[4]. Among different environmental variables, influence of footwear is a vital one, which needs to be investigated for its effect on performance and efficacy of FKHR task. Understanding variable environmental conditions and their influences on motor strategy / muscle behavior is critical in physiotherapy clinical practice. Surface electromyography (sEMG) captures electrical activities prevailing in muscle environment that precede kinematic manifestations to produce movement[5]. sEMG has been successfully employed to capture muscle activity in various stages of recovery to evaluate performance and even injury risk. sEMG data has also been used to establish criteria to relate to different (ACL) injury[6] risk. Therefore, a study was undertaken to investigate influence of Flip Flop footwear on leg muscles sEMG; time and frequency domain features were extracted to throw light on possible influence of FF on electro-mechanical behavior of muscles under shod conditions during FKHR. The sEMG signal grossly reflects the sum of the motor unit action potential (MUAP) trains that can be interpreted by mathematical algorithms in light of available literature and evidences[7,8]. sEMG is reported to be a practical and cost effective[9] method for evaluating underlying muscle activity, however, there are challenges regarding the validity of the surface EMG signals due to risk of 'crosstalk' besides other noises and signal contaminations[5]. sEMG based studies necessarily investigate controlled (experimental) muscle activities that may not represent the real events of activities experienced by individuals /athletes. One obvious challenge in sEMG based studies is that subjects cannot be blinded and they are psychologically cautious about sensors being attached overlying the muscles under investigation. Furthermore in shod situations this subjective consciousness may be more pronounced challenging applications of results of such studies in real life situations. Raw sEMG data can be digitally processed for computation of several features that can be related to neuromuscular status of muscle under investigation. The Mean Frequency (MNF), root mean square (RMS) value and TTP are common[10] sEMG features used to analyze electrical activities of the muscles. While amplitude characteristics of the sEMG signals have been employed for investigating muscular activity, it presents several drawbacks especially when dealing with force and fatigue-related issues[11,12,13]; on the other hand, frequency domain-based analysis are found to be more effective for characterizing[14,15,16] type of motor recruitment, synchronization, and fiber dimensions. These features are further interpreted to reflect the physiological activities of the motor unit during muscle contraction. For interpretations based on these sEMG features to be meaningful, they should exhibit consistency such that any changes in the signal can be attributed to the independent variable under study. It is has been reported in literature that for consistent sEMG parameters, necessary to optimize reliability and precision of sEMG studies, subjects are required to reach a physiological[17] and thermoregulatory[18,19] steady-state. Due to stochastic[20] nature of an EMG signal, in order to muster the closest representation of underlying muscle environment, the average of sEMG features captured from consecutive repetitions is a universally adopted approach. There has been a lack of consensus across studies about the optimum number of repetitions to be averaged. Previous studies have used sEMG signals from three[21] consecutive repetitions that were post-hoc averaged for data analysis. Reliability of the sEMG feature extraction is hence fundamental requirement for validation and application of sEMG studies. It cannot be assumed that a given sEMG parameter has the same degree of reliability and precision for all muscles. Despite many published papers describing changes in sEMG parameters, there is very little reporting on the reliability and precision of many of these variables Measurement of sEMG typically involves localized skin preparation, electrodes /sensor placement (SENIAM[22]) and computer- dock based data acquisition setup in appropriation with the muscle activity and context under question. Therefore, test-retest reliability study involving data capturing on different occasions is not reasonable due to inter-session variability "data acquisition technique" related confounding, in addition to Flip Flop condition i.e. the variable under study. Nonetheless, it was concluded that intra-rater (within-session) reliability is a prerequisite for accurately quantifying influence of FF on leg muscle during FKHR task. An appropriate reliability estimate would be one that reasonably measures correlation as well as agreement between measurements. Intraclass correlation coefficient (ICC) is such a measure of reliability which is calculated by mean squares (ie, estimates of the population variances based on the variability among a given set of measures) obtained through analysis of variance[23]. The ICC is typically used as a measure of relative consistency[24] (reliability). Therefore, the objective of this study was to investigate influence of FF on intra-rater (within-session) reliability of sEMG features in matched subjects, where the sensors were not re-applied throughout the data acquisition process. We hypothesized FF would lower the intra-rater reliability of sEMG feature measurement in FKHR task due to unpredictable / inconsistent perturbation of foot due to elastic (EVA) flip flop sole. The outcome of this study is likely to add necessary knowledge towards standardization of technique for assessing leg muscles sEMG measurements using FKHR (similar) Task. This will also create evidence for most reliable sEMG features, providing opportunity of their preferential selection as outcome measures in future research.

MATERIALS AND METHODS

Design

The study followed cross sectional within-subject experimental design, where data was collected from each subject for several successive repetitions in both experimental (FF) and control (BF) condition to investigate acute effects of Flip Flop on sEMG activity. The study was in accordance with Declaration of Helsinki and approved by Independent Ethical Committee of Indian Fertility Society, Approval No. F.1/IEC/IFS/2021/No.03, Dated: 21/07/2021, and registered on Clinical Trials Registry- India (CTRI) vide trial Registration. No. CTRI/2021/08/035321.

Participants

Forty healthy subjects; 14 males and 26 females, *(Mean ± SD : Age 20.41 ± 1.3 years, with 1.60 ± 0.1 m height and weight 53.75 ± 7.8 kg, Foot size UK 6.45 ± 1.7)* participated in the study. The inclusion & exclusion criterion for subject recruitment is mentioned in Table 1.

Table 1

Inclusion criteria	**Exclusion criteria**
▪ Healthy, active able-bodied male and female individuals. ▪ Individuals between 18 - 25 years of age. ▪ Familiar to wearing Thong Style Flip Flop Footwear.	▪ Any Neuro-musculoskeletal condition e.g. Fracture, deformity, nerve injury, multiple sclerosis, motor neuron disease etc. ▪ Pre-existing injury / pain / Fatigue /DOMS in lower extremities ▪ Any lower limb joints insufficiency ▪ Any history of Ataxia / balance disorder or vertigo ▪ Individuals under medication for neuro-muscular pain ▪ Individuals under any such medication which have side- effects on neuro-muscular capacity of any type.

Procedure - Subjects performed Flexed Knee heel rise Task[25] (FKHR) while standing on dominant[26] leg with knee maintained in flexion. This FKHR task was worked upon by taking cues from the technique as described in "Flexion Heel Rise Test[27]" and feedback from participants of the preliminary trials. The surface electromyographic signals were recorded using a Trigno EMG System (Delsys Inc, United States); Avanti sensor's consisting of bar shaped bipolar electrodes (99.9% Ag) of 5 × 1 mm dimension, with Inter Electrode Distance - 10 mm. Data collection protocol was custom designed using "Test Configuration" feature in Delsys EMGworks Acquisition software (Delsys Inc.). Three SEMG sensors synchronously captured signals from Soleus (SOL), Tibialis anterior (TA), and Gastrocnemius lateral (GML) of dominant leg, at a sampling frequency of 4000 Hz each. Data acquisition protocol "Test Run" was turned "ON" in the Delsys EMGworks Acquisition Software. Instructional "Audio command prompts" were sequentially generated as per the predetermined experiment workflow design of the "Test Configuration" in the Delsys software. The subjects followed these audio commands to complete the experimental Trial (Table 2). These computerized software generated voice commands ensured standardized instant and duration of different event of the FKHR task. While doing the heel rise, subjects were given "continuous feedback" to maintain knee in minimum 30^0 flexion. The duration of one complete task trial was 20 seconds consisting of several events specified on timeline as per Table 2.

Table 2 Indicative Scheme of One Complete Trial Of Flexed Knee Heel Rise Task (FKHR)

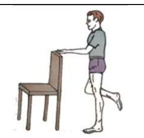
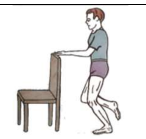
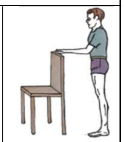
							
Event on Timeline	**1st second**	**5th second**	**8th second**	**15th second**	**18th second**	**18th - 20th Second**	**20th second**
Event Description	Bilateral balanced standing	Progressing to Dominant side sinlgle limb standng with knee extended	Progressing to Dominant side sinlgle limb standng in knee flexed 30^0	Heel Rise of dominant side in position No. 3 With Brief isometric pause at peak	Heel down back to Position No. 3	Back to Position No. 2	Back to Position No. 1

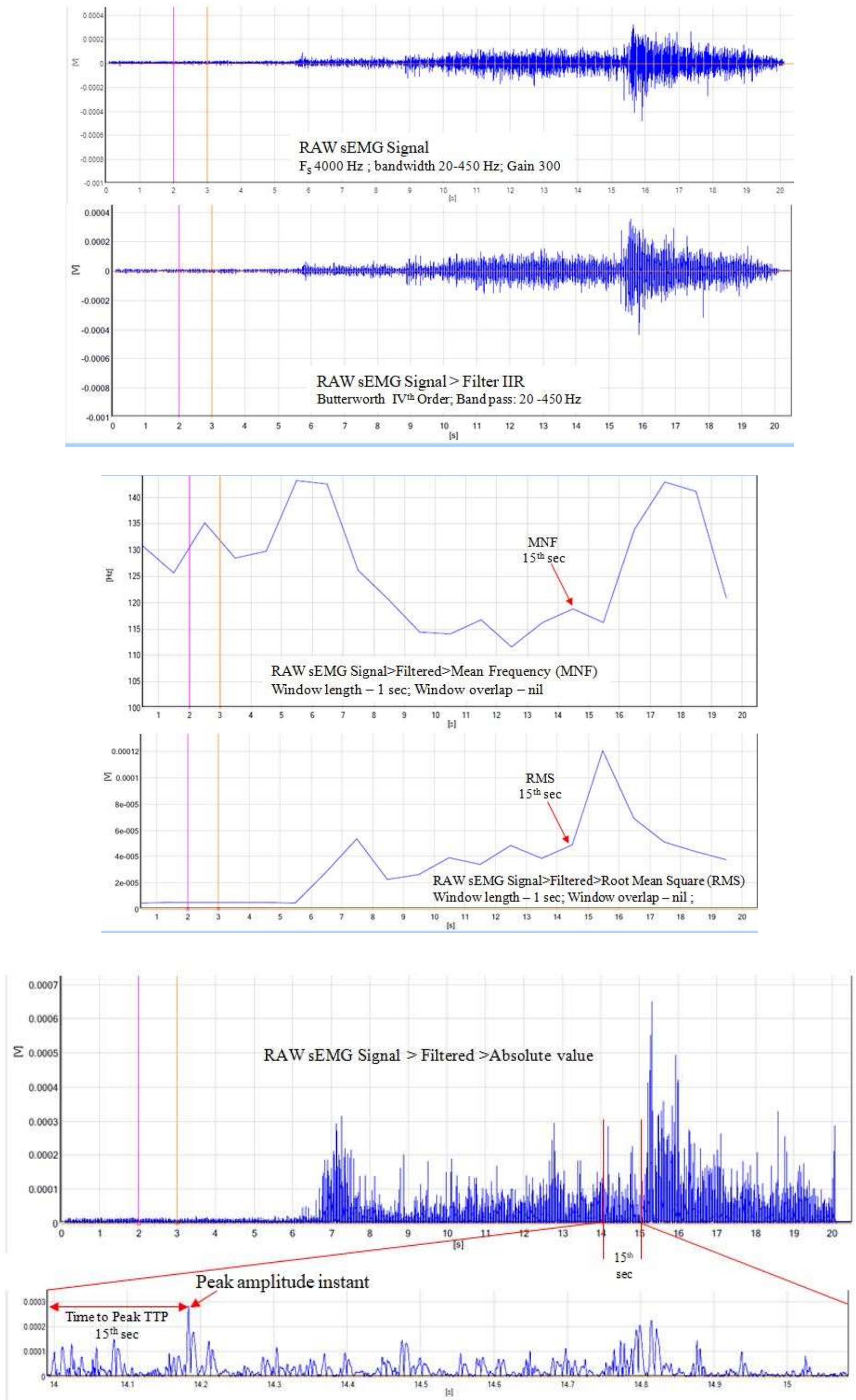
Fig 1 - Flip Flop Footwear

Flip Flop Footwear (Intervention) - Thongs style Flip Flop FF (Fig 2) used in the study consisted of three layered ethyl-vinyl-acetate (EVA) sole. The indicative measurements of Flip Flop for size UK 7: Length: 271mm, Width: 109 mm, Single piece weight 125 gm, thickness: upper sole 10 mm & mid and Lower sole 5 mm each.

sEMG Feature Extraction

All digital signal processing and feature extraction was done by built-in calculation scripts of “Delsys EMGworks Analysis” software. The raw sEMG signals from each muscle were corrected for DC offset, rectified after band-pass filtering by “Filter IIR” script (Butterworth IVth order; cut-off frequencies 20-450 Hz). Data was analyzed for 15th second of the 20 second data series; that corresponds to the start of heel rise activity during the test run. The Mean Frequency (MNF) – centroid frequency estimated over a window of 1 sec, over which the raw signal spectrum is estimated; Root Mean square (RMS) - the square root of the mean square value of amplitude estimated over a window 1 sec; and Time to peak (TTP) – interval between the instant of auditory command and instant of peak amplitude was calculated from the band-pass filtered rectified signals for 15th second of each trial data. The schematic description of feature extraction is presented in Table 3.

Table 3. Schemata of sEMG Signal processing and Feature extraction



Statistical Analysis

MNF, RMS and TTP data so extracted was exported to Microsoft Excel spreadsheet for reliability testing and analysis. All statistical calculation & testing were done in SPSS v 26.0. Intra-class correlation coefficients (ICC) were calculated for MNF, RMS and TTP for three data corresponding to three trials for each muscle in both barefoot and flip flop conditions. Intra-class correlation coefficients[23] (ICC) were calculated with Two-way mixed effects (model), Mean of 3 measurements (type) and Absolute agreement (definition[22]); with 95% confidence interval and Level of significance set a priori at $p = 0.05$. Intra-class correlation coefficients greater than 0.80 & 0.90, were considered to indicate good & excellent reliability respectively, for research[28] and clinical[29] applications. Additionally Cronbach's alpha (measure of internal consistency) was also calculated by the reliability analysis calculation by SPSS.

Results

Table 4 Reliability Statistics - Intraclass Correlation (N=3)

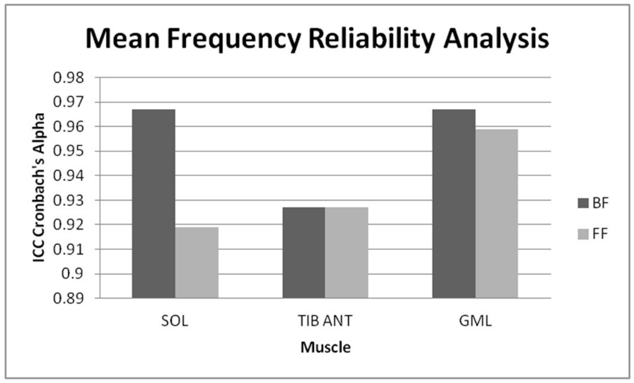
Variables	Cronbach's Alpha (N = 3)	Intraclass Correlation ICC (Average Measures)	95% Confidence Interval		F Test with True Value 0			
			Lower Bound	Upper Bound	Value	df 1	df 2	Sig
M1_MNF_BF	0.967	.965	0.940	0.980	30.112	39	78	0.000
M1_MNF_FF	0.919	.919	0.864	0.955	12.286	39	78	0.000
M1_RMS_BF	0.932	.926	0.873	0.959	14.618	39	78	0.000
M1_RMS_FF	0.883	.879	0.796	0.932	8.582	39	78	0.000
M1_TTP_BF	0.313	.314	-0.159	0.614	1.456	39	78	0.080
M1_TTP_FF	-0.479	-.478	-1.505	0.170	0.676	39	78	0.910
M2_MNF_BF	0.927	.928	0.878	0.959	13.611	39	78	0.000

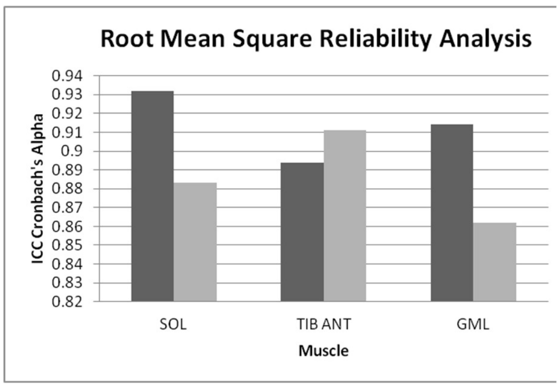
M2_MNF_FF	0.927	.927	0.877	0.959	13.726	39	78	0.000
M2_RMS_BF	0.894	.894	0.821	0.940	9.391	39	78	0.000
M2_RMS_FF	0.911	.911	0.851	0.950	11.264	39	78	0.000
M2_TTP_BF	0.301	.305	-0.186	0.612	1.430	39	78	0.090
M2_TTP_FF	-0.218	-.207	-0.984	0.308	0.821	39	78	0.748
M3_MNF_BF	0.967	.966	0.943	0.981	29.969	39	78	0.000
M3_MNF_FF	0.959	.959	0.931	0.977	24.254	39	78	0.000
M3_RMS_BF	0.914	.911	0.850	0.950	11.589	39	78	0.000
M3_RMS_FF	0.862	.865	0.771	0.924	7.253	39	78	0.000
M3_TTP_BF	0.090	.091	-0.547	0.491	1.099	39	78	0.356
M3_TTP_FF	-0.082	-.083	-0.849	0.394	0.924	39	78	0.599

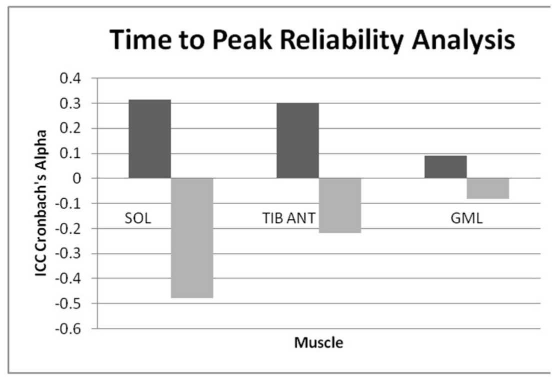
M1: Soleus (SOL), M2: Tibialis Anterior (TA), M3: Gastrocnemius Lateral (GML);

MNF: Mean Frequency, RMS: Root Mean Square, TTP: Time to Peak

BF: Barefoot FF: flip flop







a) ICC statistics for MNF, RMS and TTP sEMG parameter for Soleus (SOL), Tibialis anterior (TA), and Gastrocnemius lateral (GML) are displayed in Tables 4.
b) ICC was found to be greater than 0.80 (good to excellent) for all three muscles for MNF, RMS in both barefoot and flip flop conditions; p value < 0.001
c) ICC was found to be in range of 0.3 to -0.479 (poor to unreliable) for all three muscles for TTP in both barefoot and flip flop conditions (p value > 0.05).
d) The order of all variables in decreasing value of Cronbach's Alpha is found to be: M1_MNF_BF=M3_MNF_BF>M3_MNF_FF>M1_RMS_BF>M2_MNF_BF>M2_MNF_FF>M1_MNF_FF>M3_RMS_BF>M2_RMS_FF>M2_RMS_BF>M1_RMS_FF>M3_RMS_FF>M1_TTP_BF>M2_TTP_BF>M3_TTP_BF>M3_TTP_FF>M2_TTP_FF>M1_TTP_FF
e) ICC was found to be greater in bare foot condition than flip flop for MNF, RMS and TTP for respective muscles; except for RMS feature for TA where the ICC was higher in case of flip flop condition
f) Overall MNF was the most reliable feature followed by RMS and TTP being the least reliable feature.
g) The sEMG frequency domain variable provided better ICC compared to the time domain variables

DISCUSSION

The aim of our study was to investigate influence of FF on within session repeatability of sEMG features. To the best of our knowledge no study has preferentially focused on leg muscles behavior in flip flop shod conditions during FKHR task. The primary assumption at the core of this study was that flip flop would mediate inconsistent neuro-mechanical consequences on leg muscle activity due to its unaccustomed elastic (EVA) sole. Results of present study cannot be directly compared with previous studies as diverse footwear and tasks are being studied previously[30, 31] with a very less commonality among the objectives and outcomes. Foremost the analysis of present study confirmed our first hypothesis that FF reduces within-session intra-rater repeatability of sEMG features. Such influences can be more cumulative in cyclic movements (walking / running) where carry over effects and variable foot positions are more pronounced. However, overall ICC values provided good to excellent[23] intra-rater reliability for MNF and RMS features, regardless of muscle/ footwear condition. On the basis of present findings, it can be suggested that the three consecutive trials is a reasonable number that should be averaged for trustworthy computation of MNF & RMS sEMG variables. This may also be helpful to avoid unnecessary fatigue due to more repetitions and thus a consistent feature can be made available for reliable synthesis of information / evidence. We observed that frequency domain feature is MNF is most robust on reliability testing than the time domain feature RMS. The reliability analysis of TTP feature deserves a special mention in light of the results of the present study; overall TTP values showed very poor (even negative) reliability across muscles and shod conditions. Considering TTP also a time domain feature, strikingly contrast reliability of it as compared to RMS is quite challenging. One possible answer to this puzzle may be drawing a new dimension that is parallel to both MNF and RMS but not to TTP. Going into the calculation method of these three features has suggested a new way of thinking at this problem. The MNF and RMS are not "instantaneous values" and are defined and calculated over a "1 second" window implying they are "averaged values" over a time length "epoch"; while TTP is the value of time period corresponding to instant of highest amplitude in the same length of data series i.e. 15th second. While MNF and RMS are averaged values TTP is "instantaneous value", this might have resulted in high variability of TTP which went faded in case of MNF and RMS being averaged ones. Hence the takeaway message would be that "window/epoch" averaged sEMG features being more consistent should be of choice while planning sEMG feature as the outcome measures. Muscle-wise there is no clear message about ICC differences in the present findings; the ICC is quite high for both concentric (SOL & GML) and eccentric (TA) work. However if not attributed to simple chance, highest value of ICC in case of MNF for both SOL & GML in barefoot condition may be taken as a clue that "frequency domain feature in concentric task" is the most reliable combination for sEMG based studies.

Limitations - The study was done in experimental context, real world situation may have changed performance and results for similar tasks. There was variability in the knee flexion maintained by subjects as it was based upon the verbal feedback only without any other control. FKHR task being a balance requiring activity, there may be inter-participant variability that can potentially affect FKHR task performance especially in FF conditions. The testing procedure involved only three repetitions to avoid fatigue, higher / lesser number of repetitions might have put more light on present findings. The study was performed during an isolated FKHR task; direct application of its findings may not be fair to the cyclic activities like gait &

locomotion due to carry over effects of preceding events on latter repetitions. The study focused only on intra-rater within session reliability of MNF, RMS and TTP sEMG variables; reliability of other popular features remains elusive and therefore necessitates future research in this direction.

Future scope - a wide range of functional movements and sEMG features should be studied in future to establish global reliability of sEMG studies. In addition, we suggest analyzing the reliability of sEMG wavelet features that combine both time-frequency domains as one. Another extension of this work may be to evaluate test-retest (inter-session) repeatability of sEMG features. With such future research, it is possible that the more reliable sEMG features may stand out as preferred outcome measures for sEMG based studies and more appropriate experimental task may be designed by the investigators.

Conclusion – Footwear affects reliability of sEMG feature extraction, sEMG features show lesser intra-rater reliability in flip flop conditions as compared to barefoot. Frequency domain features during concentric work yield better reliability. Investigators and therapists are suggested to consider these finding while designing testing protocol for optimization of sEMG measurements and obtain trustworthy results. It can be suggested that the three consecutive repetitions can reasonably be considered for averaging purpose without compromising intra-session reliability of sEMG variables. Present study validates possibility of sEMG studies of leg muscles in intra-session repeated-measures study designs in physiotherapy research.

REFERENCES

1. Hislop, Helen J. Daniels & Worthingham's Muscle Testing: Techniques of Manual Examination. St. Louis, Mo.: Saunders Elsevier, 2007.
2. Clarkson, Hazel M. 2013. Musculoskeletal assessment: joint motion and muscle testing. Philadelphia, PA: Wolters Kluwer/Lippincott Williams & Wilkins Health.
3. Gupta S, Sen ED, Gupta D, Kumar D. Surface Electromyographic Analysis of Soleus muscle activity in different shod conditions in Healthy Individuals – Systematic review. Journal of Arthroscopy and Joint Surgery. 2021 Oct;8(4):333-9
4. Hébert-Losier K, Newsham-West RJ, Schneiders AG, Sullivan SJ. Raising the standards of the calf-raise test: A systematic review. Journal of Science and Medicine in Sport. 2009 Nov;12(6):594-602.
5. DeLuca, C.J. (1997); The use of surface electromyography in biomechanics Journal of Applied Biomechanics 13, 135-163.
6. Zeller, B.L., McCrory, J.L., Kibler, W.B. and Uhl, T.L. (2003) Differences in kinematics and electromyographic activity between men and women during the single-legged squat. American Journal of Sports Medicine 31, 449-456.
7. Day, S.J., Hulliger, M. (2001) Experimental simulation of cat electromyogram: evidence for algebraic summation of motor-unit action potential trains. Journal of Neurophysiology 86, 2144-2158.

8. Keenan, K.G., Farina, D., Maluf, K.S., Merletti, R. and Enoka, R.M. (2005) Influence of amplitude cancellation on the simulated surface electromyogram. Journal of Applied Physiology 98, 120-131
9. Marshall P, Murphy B. The validity and reliability of surface EMG to assess the neuromuscular response of the abdominal muscles to rapid limb movement. J Electromyogr Kinesiol. 2003 Oct;13(5):477-89. doi: 10.1016/s1050-6411(03)00027-0. PMID: 12932422.
10. Al-Mulla, M. R.; Sepulveda, F. and Colley, M. (2012b). sEMG Techniques to Detect and Predict Localised Muscle Fatigue, In: EMG Methods for Evaluating Muscle and Nerve Function, Mark Schwartz, pp. 157-186, InTech, ISBN 978-953-307-793-2, Rijeka, Croatia
11. Farina D, Mesin L, Martina S, Merletti R (2004) A surface emg generation model with multilayer cylindrical description of the volume conductor. IEEE Trans Biomed Eng 51(3):415–426
12. Farina D, Cescon C, Negro F, Enoka RM (2008) Amplitude cancellation of motor-unit action potentials in the surface electromyogram can be estimated with spike-triggered averaging. J Neurophys 100(1):431–440
13. Merletti R, Farina D (2016) Surface electromyography: physiology, engineering, and applications. IEEE Press and J.Wiley, New York
14. Larsson B, Kadi F, Lindvall B, Gerdle B (2006) Surface electromyography and peak torque of repetitive maximum isokinetic plantar flexions in relation to aspects of muscle morphology. J Electromyogr Kinesiol 16(3):281–290
15. Solomonow M, Baten C, Smit J, Baratta R, Hermens H, D'Ambrosia R, Shoji H (1990) Electromyogram power spectra frequencies associated with motor unit recruitment strategies. J Appl Physiol 68(3):1177–1185
16. Wakeling JM, Rozitis AI (2004) Spectral properties of myoelectric signals from different motor units in the leg extensor muscles. J Exp Biol 207(14):2519–2528
17. Poole DC, Schaffartzik W, Knight DR, et al. Contribution of exercising legs to the slow component of oxygen uptake in humans. J Appl Physiol 1991;71: 1245–53.
18. Borrani F, Candau R, Millet GY, Perrey S, Fuchslocher J, Rouillon JD. Is the VO2 slow component dependent on progressive recruitment of fast-twitch fibers in trained runners? J Appl Physiol 2001;90:2212–20.
19. Saltin B, Gagge AP, Stolwijk JAJ. Muscle temperature during submaximal exercise in man. J Appl Physiol 1968;25:679–88.
20. Reaz MBI, Hussain MS, Mohd-Yasin F. Techniques of EMG signal analysis: Detection, processing, classification and applications. Biol Proced Online. 2006; 8: 11–35. https://doi.org/10.1251/bpo115
21. Alkner BA, Bring DKI. Muscle Activation During Gravity-Independent Resistance Exercise Compared to Common Exercises. Aerosp Med Hum Perform. 2019; 90: 506–512. https://doi.org/10.3357/AMHP. 5097.2019
22. H. J. Hermens, B. Freriks, R. Merletti et al., SENIAM: European Recommendations for Surface Electromyography: Results of the SENIAM Project, Roessingh Research and Development, Enschede, Netherlands, 1999.

23. Koo TK, Li MY. A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. J Chiropr Med. 2016 Jun;15(2):155-63. doi: 10.1016/j.jcm.2016.02.012. Epub 2016 Mar 31. Erratum in: J Chiropr Med. 2017 Dec;16(4):346..
24. Weir J. Quantifying Test-Retest Reliability Using The Intraclass Correlation Coefficient And The Sem. J Strength Cond Res. 2005; 19: 231–240. https://doi.org/10.1519/15184.1
25. Sanjeev, G., Sen Elina, D., Dhananjay, G., & Dinesh, K. (2022). Electromyographic frequency spectra analysis to investigate influence of flip flop footwear on leg muscles during flexed knee heel rise task. International Journal of Health Sciences, 6(S1), 10040–10053. https://doi.org/10.53730/ijhs.v6nS1.7433
26. Schneiders AG, Sullivan SJ, O'Malley KJ, Clarke SV, Knappstein SA, Taylor LJ. A Valid and Reliable Clinical Determination of Footedness. PM&R. 2010 Sep;2(9):835-41.
27. Hébert-Losier K, Schneiders AG, Sullivan SJ, Newsham-West RJ, García JA, Simoneau GG. Analysis of Knee Flexion Angles During 2 Clinical Versions of the Heel Raise Test to Assess Soleus and Gastrocnemius Function. J Orthop Sports Phys Ther. 2011 Jul;41(7):505-13
28. Sleivert GG, Wenger HA. Reliability of measuring isometric and isokinetic peak torque, rate of torque development, integrated electromyography and tibial nerve conduction velocity. Arch Phys Med Rehabil 1994;75:1315–21.
29. Currier DP. Elements of research in physical therapy. Baltimore: Williams and Wilkins; 1984.
30. Spudić D, Smajla D, Šarabon N. Intra-session reliability of electromyographic measurements in flywheel squats. PLoS One. 2020 Dec 3;15(12):e0243090. doi: 10.1371/journal.pone.0243090.
31. Jang MH, Ahn SJ, Lee JW, Rhee MH, Chae D, Kim J, Shin MJ. Validity and Reliability of the Newly Developed Surface Electromyography Device for Measuring Muscle Activity during Voluntary Isometric Contraction. Compute Math Methods Med. 2018 Aug 29;2018:4068493. doi: 10.1155/2018/4068493.