Evaluation and Assessment of Leg Muscle Activity and Fatigue Across two Popular Step Test Exercises

D.O.I: https://doi.org/10.4127/jbe.2017.0117

THUKRAL HIMANSHU', CHATTERJEE TIRTHANKAR', BHATTACHARYYA DEBOJYOTI', CHATTERJEE SUBHOJIT', SEN SURANJANA', PAL SUDAN MADHU'

1 Ergonomics Department, Defence Institute of Physiology & Allied Sciences, Lucknow road, Timarpur, Delhi, INDIA

ABSTRACT

Electromyography (EMG) provides inside access to physiological and electrical responses during muscular activity. Step tests [Harvard Step Test (HST) and Queen’s College Step Test (QCT)] appear to be simple to administer, valid method to assess cardiovascular fitness and estimate maximal aerobic capacity (VO$_{2\text{max}}$). The physiological consequences of these tests were not evaluated through assessment of muscular activities and state of fatigue of the active muscles. The study was aimed to examine the muscle activity during two popular step tests. Eight physically fit male university students participated in the study. EMG of leg muscles were recorded by Delsys sEMG system. Four pairs of leg muscles such as vastus medialis, hamstrings, tibialis anterior and gastrocnemius of both legs were evaluated. During HST there was significant increase in amplitude of contraction in both right and left leg muscles. Insignificant decrease in frequency domain was observed during HST in comparison to QCT which predicted chances of fatigue. The study concluded HST puts more strain on musculoskeletal system than QCT, which becomes preferred choice as a mean of evaluating physical fitness in field conditions.

Key Words: Physical fitness, Muscle activity, Fatigue.
INTRODUCTION

Physical fitness and maintaining high quality of health is a required component for all the parts of our societies. Physical activity may impact quality of life in several ways: it can be used to improve self-image and self-esteem, physical fitness and health. ‘Physical fitness’ is ability to bear or withstand stress and pressure under difficult circumstances where an unfit person would be ineffective or would quit (20). Researchers had designed and developed various step tests for the assessment of physical fitness of individuals based on the various physiological variables. Among many step test, two of the most popular tests are - The Harvard step test (HST) which was introduced by Brouha et al., (1943) (6) and Queen’s College step test (QCT) by McArdle et al., (1972) (23). Harvard Step Test had been equated many times based on the different physiological parameters to test which is the best physical fitness index for Indian population (2, 13). Queen’s college step test has been tested positively among Indian population by Chatterjee et al., (2005) because of lower stool height and slower cadences (8, 9). Queen’s college step test has also been termed as an alternative to HST by Bandyopadhyay (2008), (3) in Indian population. Both of these tests have not been evaluated on the basis of muscular activity through electromyography (EMG).

During step test exercises adequate hip extension and flexion and knee extension occurs, which makes stability as an essential component of such manoeuvre. The muscular activity and functional characteristics of muscles providing such stability are the point of concern. Muscle activity during physical work or in general is initiated by the transmission of an action potential over the surface of each active muscle fibre and results in the generation of force and the expenditure of energy derived from metabolism. It is reasonable to state, that in graded voluntary contraction the total electrical activity of a whole muscle is related in a simple way to the energy it expends and to the force it exerts. During dynamic contractions Bigland and Lippold, (1954a) (5) found linear relationship between integrated EMG and force for sub-maximal contractions, either when the muscle shortened (concentric contraction) or was being stretched (eccentric contraction) at constant velocity. Using EMG analytical techniques, several investigators studied the action of extensor muscles and abductor of hip during stair climbing (10, 18, and 24). In the step test same combination of contractions occur alternatively.

Electromyography is a fascinating muse that provides inside access to physiological responses that shows the reason behind the muscular activity. It is a technique to capture and quantify the myoelectric signals and changes in the potential generated by the muscle and helps in possibility of analysing the muscular synergies. The myoelectric signal is collected from the prominent bulge (belly) of the muscle is actually the potential generated by the muscular fibres after receiving
nerve impulse from the motor neuron. Several factors influence the recording of the EMG signals such as muscle size, muscle conduction, body temperature, electrode placement etc. Once the myoelectric signals have been captured they are generally analysed on the basis of RMS (Root mean square) for the force generated by the muscle (4) and MDF (Median frequency) for the frequency of contractions to evaluate muscle fatigue which are widely used. Fatigue in general is defined as decrease in production of force during exercise. It is associated with the effects such as decline in effort, desired force and muscular strength. This in turn leads to reduction in the performance of individuals (28 and 31). In order to induce fatigue various protocols have been developed like isokinetic, isometric and treadmills protocols and this can be calculated by increase in EMG amplitude and decrease in MDF.

Electromyographic evaluations of active muscles during any form of exercise are equally important along with recording of physiological manifestations. It provides an insight of the muscle activation pattern and type of muscular fatigue. In this context recording of electrical behaviour of active leg muscles during step test exercise looks similarly essential. Categorical evaluation and correlation of physiological variables with electromyographic derivatives must provide strong inference about the effectiveness of the test. Signal Analysis which includes amplitude analysis, timing analysis and spectral analysis are common techniques applied to electromyography signals recorded with surface electrodes (7, 14, 15, and 16). EMG studies provide dependable means of computing muscle activity. Hence, evaluation of electromyographic changes during two popular step test exercise focusing only on leg muscular exertion would identify the best fitted field test for evaluation of physical performance. In this way a test may be established as a better mean of investigating the changes in muscle activity when voluntary muscles contract under different physical conditions.

MATERIALS AND METHODS

Participants

Eight asymptomatic male participants (University students) were recruited, with mean age (± SD); 23.8 ± 2.6 years; height 174 ± 3.2 cm; weight 71.5 ± 11 kg; body mass index (BMI) 22.6 ± 3.5 kg/m². Exclusion criteria for the study were any history of musculoskeletal disorders, smoking or alcoholic habits, and respiratory diseases. A written consent was taken from all participants before commencement of the study. All the participants were assessed clinically through history taking and
detailed clinical examination before the study. The study protocol was approved by the Institutional Ethical Committee on the use of Human as an Experimental Subjects and experiment conforms to the principles outlined by the Declaration of Helsinki protocol, 1985.

**Experimental design**

This study incorporated 2 separate exercise testing conditions- HST and QCT with adaptation of muscle activity to physical demand. Activation of muscles was quantified by temporal and spatial features using EMG while stepping up and down. The step tests involved two Step Cadences measured in beats per minute (beats.min⁻¹), two bench heights measured in inches and two durations measured in seconds. This study has mode of exercise as independent variable and electromyographic parameters as dependent variables.

**Test protocol**

After completing the instrumentation participants were asked to relax as shown in figure 1 for 2 minutes while the resting data were taken. Two different stools were used; first one with a height of 18 inches for HST and the second one with a height of 16.25 inches for QCT. The participants were asked to step up and step down on those stools. HST was performed for 5 minutes or till exhaustion at cadence of 120 beats.min⁻¹ (30 cycle’s minute⁻¹) whereas QCT was performed for 3 minutes at 96 beats.min⁻¹ [(24 cycles.minute⁻¹, (23)]. The pace of the exercise was maintained by a metronome. After the completion of test performance the participants’ recovery response were recorded while seated. Harvard step test is ideally carried out on a stool of 50.3 cm or 20 inch height, (6), but in the present study a modified stool height of 18 inch (2) was used. After completion of test the participants were asked to sit on a comfortable chair and their recovery HR was measured from the palpation of carotid pulse. Similarly, carotid pulse from 5 – 20 seconds of recovery period was taken just after completion of QCT. A participant performing QCT is presented in figure 2.
Figure 1. Participant at resting state

Figure 2. Participant performing QCT
Instrumentation

Muscle activities were recorded along the muscle belly (Cram and Kasman., 1998) (12) using multichannel system (Delsys myomonitor IV EMG system, Delsys Inc., Boston, MA). Each participant was instrumented with pre-amplified, single differential surface electrodes (Trigno, Delsys, Inc., Boston MA) on both right and left side of four lower limb muscles such as tibialis anterior (TAR & TAL), gastrocnemius medialis (GMR & GML), vastus medialis (VMR & VML), hamstring (HAR & HAL). Before placement of electrodes, skin was cleansed, shaved and kept moist for proper contact between electrode and skin. Electrodes were placed parallel to the length of muscle. Surface electromyographic signals were recorded at a frequency of 1024 Hz from the above muscles.

The quality of the signal was visually checked and the electrode position was verified when the participants contracted each muscle. The Delsys hardware automatically band pass filtered all the EMG signals (20–450 Hz). For each muscle, the EMG data were fully wave rectified and smoothed by the help of RMS calculation. Median frequency values of frequency domain were also derived with the help of the Delsys analysis software. The window length was 100 ms. Root mean square of EMG raw data is a measure of power of the signal while MDF is the measure of frequencies of activation. The data was exported to excel format. Average of last two minutes of the MDF data was taken for final analysis. Normalization of the EMG raw data or RMS values is usually performed by calculating the percentage of EMG data obtained by doing maximum voluntary contraction (MVC) of the same muscle (1, 25 and 32). A reference EMG values collected. A relative measure of the activations compared to the reference value could be obtained. As per recommendations at least 3 repetitions of the test were performed separated by at least 3 minutes to reduce any fatigue effects. As per the procedure slight warming up exercises were also performed (Stretching, low aerobic exercises) before increasing the force of contraction during the protocol and keeping it for 3-5 seconds and then relaxing. For gastrocnemius the participants were asked to perform unilateral plantar flexion at 90° of the ankle position. For tibialis anterior the participants were asked to perform dorsiflexion in supine position against the force applied. For hamstrings the participants were asked to lie down in prone position and flex the leg at 90° against the force. For vastus medialis the participants were asked to stay in sitting position and extend the leg at 90° against the force. Signal was processed as mentioned above. Root mean square was calculated with the software. Then average of the RMS of the MVC was calculated in excel format and used for normalization. The mean of last two minutes of RMS values of each muscle of each step test experiment were used for normalization.
**Statistical Analysis**

Analysis of EMG data involving normalized RMS and MDF values were performed using paired student’s ‘T’ test. For all tests, differences were considered significant when P value was equal to or less than 0.05. Data are presented mean and SD throughout. The statistical procedure was performed in standard package for statistical software (SPSS v. 20.0, IBM corporation, USA).

**RESULTS**

A descriptive statistics including mean (± SD) of RMS values normalized with MVC for four muscles of both right and left leg during HST and QCT is presented in the table 1. The result of student’s ‘T’ test had shown that gastrocnemius medialis, hamstrings and vastusmedialis right activity is 19%, 47%, 55% higher in HST than QCT, which were statistically significant. The activity of tibialis anterior right did not show any significant change among the two tests. In left side the activity of the same muscle showed 28% higher value in HST than QCT which were significant. Other muscles also showed 36%, 50%, 50% increased activity in HST than QCT. Table 2 shows the fluctuations in MDF (mean ± SD) values of both right and left lower limb muscles. The statistical data showed the greater frequency paradigm in the muscles during QCT than the HST. Gastrocnemius medialis and Hamstrings of left lower limb showed 33% and 36% increased activity (p<0.05) while other tested muscles didn’t show any significant change.
Table 1
*Mean ± Standard Deviation and Difference in percentage of Normalized muscles activity (RMS) of both right and left limb during the performance of HST and QCT (n=8).*

<table>
<thead>
<tr>
<th>Muscles Involved</th>
<th>HST</th>
<th>QCT</th>
<th>Percentage Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tibialis Anterior Right</td>
<td>42.3 ±25.8</td>
<td>42.1 ±27.7</td>
<td>0</td>
</tr>
<tr>
<td>Gastrocnemius Medialis Right</td>
<td>41.6 ±21.3</td>
<td>33.9 ±17.9</td>
<td>19*</td>
</tr>
<tr>
<td>Hamstrings Right</td>
<td>31.5 ±19.0</td>
<td>16.8 ±3.7</td>
<td>47*</td>
</tr>
<tr>
<td>Vastusmedialis Right</td>
<td>78.7 ±12.6</td>
<td>35.8 ±6.0</td>
<td>55*</td>
</tr>
<tr>
<td>Tibialis Anterior Left</td>
<td>38.4 ±9.7</td>
<td>27.6 ±12.8</td>
<td>28*</td>
</tr>
<tr>
<td>Gastrocnemius Medialis Left</td>
<td>39.2 ±13.8</td>
<td>25.2 ±10.4</td>
<td>36*</td>
</tr>
<tr>
<td>Hamstrings Left</td>
<td>28.2 ±5.6</td>
<td>14.2 ±2.3</td>
<td>50*</td>
</tr>
<tr>
<td>Vastusmedialis Left</td>
<td>71.9 ±11.5</td>
<td>36.3 ±9.3</td>
<td>50*</td>
</tr>
</tbody>
</table>

HST- Harvard step test QCT- Queens College step test, (*)- Significance level (p<0.05)

Table 2
*Mean ± Standard Deviation and Difference in percentage of MDF of muscles activity during the performance of HST and QCT (n=8).*

<table>
<thead>
<tr>
<th>Muscles Involved</th>
<th>HST</th>
<th>QCT</th>
<th>Percentage Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tibialis Anterior Right</td>
<td>85.4±30.00</td>
<td>76.5±35.1</td>
<td>10</td>
</tr>
<tr>
<td>Gastrocnemius Medialis Right</td>
<td>91.8±28.9</td>
<td>102.0±15.4</td>
<td>10</td>
</tr>
<tr>
<td>Hamstrings Right</td>
<td>50.2±13.8</td>
<td>51.5±13.2</td>
<td>3</td>
</tr>
<tr>
<td>Vastusmedialis Right</td>
<td>57.1±17.03</td>
<td>58.8±17.6</td>
<td>3</td>
</tr>
<tr>
<td>Tibialis Anterior Left</td>
<td>89.7±45.7</td>
<td>37.1±31.8</td>
<td>59</td>
</tr>
<tr>
<td>Gastrocnemius Medialis Left</td>
<td>66.0±35.4</td>
<td>97.8±10.9</td>
<td>33*</td>
</tr>
<tr>
<td>Hamstrings Left</td>
<td>38.0±13.8</td>
<td>59.0±14.9</td>
<td>36*</td>
</tr>
<tr>
<td>Vastusmedialis Left</td>
<td>58.7±21.1</td>
<td>68.4±9.6</td>
<td>14</td>
</tr>
</tbody>
</table>

HST- Harvard step test QCT- Queens college step test, (*)- Significance level (p<0.05)
DISCUSSION

In the present study, EMG signals (i.e. RMS, MDF values) were recorded in order to portray the activation modalities of TA, GM, VM and HA for both right and left legs and their effects during two test protocols. There were significant decreases in the activities involving three groups of muscles (VM, HA, GM) during QCT. Basmajian et al., 2004, (4) suggested that the bigger muscles may show non-linear relationship because amplitude varied in correspondence to force. In another study it was found that values of hamstring may show increasingly non-linear relationship during exercise (21). The present findings i.e. excessive contraction of HA and VM muscles during HST do not match with the said observations. However, this can be attributed to rhythmic extension and flexion of upper leg and hip to lift the entire body weight and pulling it down on an 18 inch stool during HST. Similar reason is applicable to QCT where the stool height is 16 inch. In the present study GM and VM showed significant difference in the activity as the HST is performed at a greater height than QCT. This phenomenon causes greater knee flexion and more plantar flexion (30). It has been seen that there is almost 30-50% difference in the amplitude of the EMG signals between the two tests which implies that there is more power being generated by the muscle during ‘HST than QCT’. Tibialis anterior right did not show any significant change in activation with both the tests. Role of TA is to keep leg vertical or stabilize the ankle during exercise like step test. TA showed lower activity and had no significant difference between HST and QCT. The average activity of TA remained the same for both exercises which might be attributed to stabilizing the ankle during the exercises. This kind of muscular activation predicted there is continuous ankle planter flexion while stepping which may have altered the mechanism of contraction. Hence with the changes observed in leg muscular activity it can be predicted that HST demanded more effort in terms of muscular activity than that of QCT.

Median frequency values of the EMG signals during both the HST and QCT were also analysed in the study. The results found that there was no significant decrease in the MDF during HST except left gastrocnemius and hamstrings when compared with QCT. This significant difference in GML and HAL may be because of continuous knee flexion leading to decrease in frequency of contraction during HST. This led to delayed depolarization and increase in duration of action potential (26). The frequency domain is the main feature or gold standard which is responsible for assessing the muscle fatigue and recruitment of motor unit. There is a direct link between fatigue and lower frequency of muscular contraction. Time–frequency analyses techniques have evolved in the field of electromyography, as they have in the realm of other biosignals such as ECG and EEG (17). Early among the researchers like Constable et al., (1994) (11) applied these techniques
to the EMG signal and investigated the change in the frequency content of EMG signals during high jumps. Roark et al., (1995) (29) investigated the movement of the thyroarytenoid muscles during vocalization. In both these applications, the time–frequency techniques were essential because the researchers investigated muscles that contracted dynamically and briefly. In the present study there were significant decrease in the MDF during HST (GML and HAL). Studies conducted by Piper (1912), Edwards Lippold (1956) and Maton (1981) postulated that if there is decrease in frequency and increase in amplitude, would ultimately develop fatigue which can be central or peripheral in nature (19, 22 and 27). When there is involvement of spinal cord process in fatigue then it is central and when there is involvement of neuromuscular junction, α-motor and γ-motor neurons and muscles then it can be perused as peripheral fatigue. In the present study the MDF response of few of the leg muscles were lower in case of HST. As per the literature this can be attributed to localised factors. Especially the HAL and GML might have been overused by knee and hip extensions during HST (Stool height 18 inch). Excess lactic acid accumulation during exercise and subsequent decrease in conduction velocities of myofibres might be the cause of downward shift of MDF in those muscles (16). This observation is supported by higher perceived exertion of the participants in the present study. Thus, from the finding it can be assumed that HST demands more muscular effort and to some extent develops fatigue compared to QCT.

CONCLUSION

The present study was designed to find out muscle activation and frequency shift during two popular step tests- HST and QCT. Muscle activity showed significant increase in amplitude which predicted excessive leg muscle activation during HST than QCT. Significant decrease in MDF in GML and HAL were observed along with insignificant decrease in VMR, GMR, VML depicted chances of leg muscle fatigue during HST. The findings of the study postulate QCT puts less strain on musculoskeletal system which makes it preferred test of performance evaluation in field conditions. The study needs to be further validated on a larger group of population with variation in age, ethnicity and sex to have more reliable and practical conclusion and suggestion for future use.
ACKNOWLEDGEMENT

The authors wish to thank the staff members of ergonomics department, DIPAS for their whole hearted support during the study.

REFERENCES

13. Das B, Ghosh T, Gangopadhyay S. A comparative study of physical fitness index (PFI) and predicted maximum aerobic capacity (VO2max) among the


Address for correspondence:

Mr. Tirthankar Chatterjee Sc ‘C’,
Ergonomics Division,
Defence Institute of Physiology and Allied Sciences,
Defence R & D Organization,
Lucknow road, Timarpur,
Delhi-110054
Ph. no. 01123883012
Email. tchatterjee@dipas.drdo.in