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Biomechanical Evaluation of the Burpee Test Battery

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ABSTRACT

This study was aimed at evaluating the performance level of strength, endurance, agility, balance, and coordination with biomechanical factors of youth in Sri Lanka. Most of the available test batteries were designed for particular groups of people, in relation to their anthropometric measurements, Geographic Variation, and socio-cultural factors. Therefore, the modified Burpee test (the 30s, with push-up and vertical jump) was introduced to the subject (n=383, male and n=327, female) to design a test battery. The percentile method was used to distinguish the performance levels. The average number of Burpees of males and females are 9 (SD=3.4) and 6 (SD=2.5), respectively. University students (68), whose, physical fitness levels (satisfactory level or above) were tested for four times through the Eurofit test, were selected to observe their performance levels under the new protocol. Hence, nearly 56 students have demonstrated the average level (or above) of performance. The space of exercise presentation for each performer was defined as the fraction of body height: $0.776^{o}H_{F}^{o} \leq d \leq 1.390^{o}H_{F}^{o}$ and $0.782^{o}H_{M}^{o} \leq d \leq 1.389^{o}H_{M}^{o}$. In addition, the vertical displacement of the C.G during a Burpee exercise can measure through the biomechanical model ($0.6389^{o}H_{F}^{o}$ and $0.6310H_{M}$) in any condition.

Keywords: Kinaesthetic exercise, Burpee protocol, Full-body workout.

INTRODUCTION

The procedure of the original Burpee was introduced by Mr. Royal H Burpee in the 1930s. And it was designed to measure agility and coordination [1]. In the 1940's, American Army used Burpees as an exercise under the toughening-up programme. Even the rawest recruit can do this exercise a few times slowly. But the Army doesn't consider him fit for the rigors of war until he can do it 40 or 50 times, in an easy rhythm, without pausing, for the test. In testing men with this exercise, the American Army considers those eight Burpees done in the 20s as poor, 10 Burpees as fair, 12 as good, and 13 or more as excellent. As per the original Burpee exercise protocol, the Burpee is done in four counts. A man first assumes a standing position with arms at his sides, and feet a couple of inches apart. At the count of 'one,' he goes down to a squatting position, with arms inside his knees [1]. At 'two' he throws feet back to the erect position (Jump your legs straight out to the rear: Plank). At 'three' he comes to the squatting position again. At last 'four' he stands on the floor [2]. At present, the Burpee test is modified (may include push-up or jump or both) and used as High-Intensity Interval Training (HIIT) programmes for athletes. Also, the Burpee test uses modern strength and conditioning programmes [3].

Mostly, the Eurofit physical fitness test battery has been used to evaluate the fitness level of people in Sri Lanka. However, the Eurofit test battery was designed considering geographical, social, and cultural variables of 23 counties

in the European region [4]. The average heights of males and females in Sweden are 177.9 cm and 164.6 cm, respectively [5]. Those values for Sri Lankans are 163.6 cm and 151.4 cm [6]. Energy expenditure of the Burpee depends on body height and mass. Hence, in this situation, the result of the Euro fit test battery will not interact with the anthropometric variable of Sri Lankan people [7].

The Burpee test battery will help to design HIIT protocol and fitness programs. Here, the original Burpee test is modified adding a pushup (upper body muscular strength and endurance) and a vertical jump: building both endurance and explosive power [8]. However, muscular endurance will develop when the volume of both exercises is increased associated with muscular strength [9]. In practice, some people perform Burpees moving back and forth and also from side to side. It influences the evaluation of physical components such as agility and coordination. Therefore, the exercise presentation area poses a question for the coaches and designers of HIIT programs [10].

In this research, the Burpee test battery was introduced to evaluate the performance level of the strength, endurance, agility, balance, and coordination of young people in Sri Lanka. Further, two Biomechanical models were introduced to evaluate the mechanical energy of concentric movement and exercise presentation area of the Burpee for the youth.

METHODS

The study sample included healthy participants 383 males (age= $21 \pm 6y$) and 327 females (age= $20 \pm 5y$) in Sri Lanka to test strength, endurance, agility, balance, and coordination through the Burpee test. All participants had no known or apparent musculoskeletal injuries and were able to perform the exercise correctly. A suitable warm-up is essential for optimal performance during the test (Bompa & Gregory Haff, 2009) [11]. Therefore, candidates were advised to do an optimal warm-up session before commencing the test. Modified-Burpee test protocol (Figure 1a and b) stand erect with the arms by the side (i): bend the knees and place the hands on the floor in front of the feet (squat position) (ii): thrust the legs back to assume a push-up position with a straight line from the shoulders to the heels (iii): push-up (iv): return to the squat position (v): vertical jump (shoulder flexion at the peak of the jump) (vi): finally stand on the floor (i): perform maximum repetition within the 30s.

Biomechanical models were designed to define exercise presentation space and mechanical energy expenditure for a Burpee. Body segment parameters: lengths (arm, ankle to shoulder, wrist to shoulder, and foot), [12] mass and the C.G of body segments were considered for the calculation [13]. The total vertical displacement of the C.G of the Burpee is represented by the following formula (A).

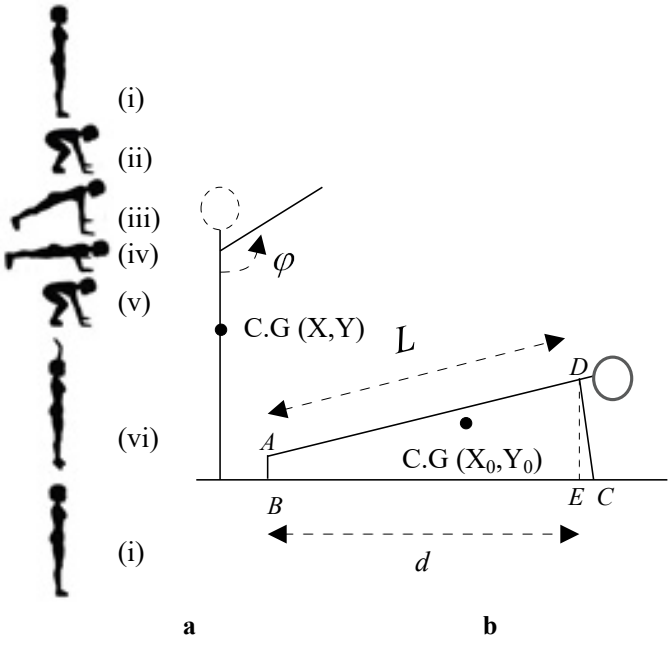

Figure 1(a). Sequence of modified Burpee represented from (i) to (vi) [8]. (**b**). Illustrated plank position of the Push-up on the sagittal frame[3] of the athlete and standing position when zero jump. A: Ankle Joint; B: Distal End of the 1st Metatarsal of the Foot; C: Wrist Joint; D: Shoulder Joint; C.G (X,Y): the coordinates of the Center of Gravity of an athlete; AB=l, CD=l_{arm}; AB and ED are perpendicular to the BC horizontal straight line; $C\hat{D}E = \vartheta$

Total vertical displacement=(Y-Y_0)+vertical jump height (Δh) (A)

$$Y_O = \frac{1}{M}\begin{vmatrix} 2m_A \\ m_{TH} + 2m_{LE} \\ m_{TH}l_{ST} + 2m_{LE}(l_{SH} + l_{HLE}) \\ 2m_F \end{vmatrix}_{1X4} \left| l_{AD}\cos\vartheta, l_A\cos\vartheta, (-\cos\gamma), l_{FD} \right|_{4X1} \quad \text{(B)}$$

$$Y = \frac{1}{M}\begin{vmatrix} 2m_A \\ m_{TH} \\ 2m_{LE} \\ 2m_F \end{vmatrix}_{1X4} \left| (L - l_{AP}\cos\varphi), (L - l_{ST}), (L - l_{SH} - l_{HLE}), (-l_{FP}) \right|_{4X1} + l_{FD} \quad \text{(C)}$$

Where m_A, m_{TH}, m_{LE}, m_F, *and* M represent masses of arm, trunk and head, lower extremity, foot, and mass of the athlete, respectively and l_{AD}, l_{AP}, l_{ST}, l_A, *and* l_F represent the lengths accordingly: The C. G's from distal and Arms from proximal ends; shoulder to the C.G of trunk and head segment; shoulder to hip; arm (shoulder to wrist); foot. l_{HLE}: hip to the C.G of the lower extremity; and l_{FP}: ankle to the C.G of the foot; l_{FD}: the C.G of the foot from the distal end; $\cos^{\gamma} = (\frac{lA}{L})$, and $E\hat{C}D = \vartheta$.

The required concentric energy (E_C) was defined and calculated based on the elite players' performance. A high-speed camera system (Qualisys, 100 Hz) was employed to observe the coordinates of the C.G [5].

RESULT AND DISCUSSION

The distribution of the Burpee test performance of the youth is displayed in the table 2. The average values of the performance of males and females are 9 (SD=3.4) and 6 (SD=2.5), respectively. Participants who performed zero repetition (female 103 and male 61) were not considered for the calculation Figure 2.

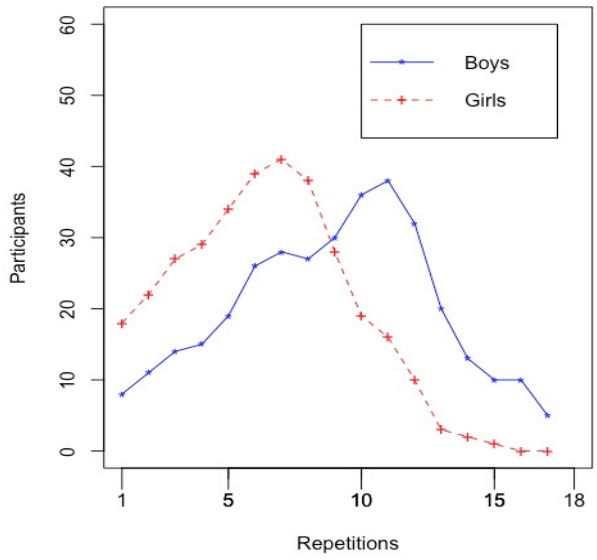

Figure 2. Burpee test (30 s) performance of participants: solid line indicates the males whereas female is represented by the shaded line.

They were in a poor level for a push-up and vertical jump and couldn't complete at least one modified Burpee. Hence, the Burpees repetition (R) range of males is $1 \le R \le 15$ and females, is $1 \le R \le 11$.

It was assumed that the geographic variation and socio-cultural factors of participants in Sri Lanka are nearly unique.

Test battery for burpee

The Burpee test battery represented by Table 1 and Table 2 were used to evaluate the strength endurance, agility, balance, and coordination of the youth.

All participants were given a verbal and visual demonstration (online) of each Burpee condition and allowed to practice the condition. Incorrect procedures such as plank position, elbow flexion in the push-up, foot movements from the floor, and degree of knee flexion at the squat position were monitored by the investigators. Therefore, the maximum repetition was reduced by few best performers. Hence, maximum repetition was counted as 21 and 16 for males and females, respectively.

Table 1: The performance levels of males (Burpees, 30 s), i^{th} percentile represented by P_i symbol

P_i	Participants	Repetition	Points	Level of Category
10	38	1-3	1	Very Poor
20	77	4-5	2	Poor
30	115	6-7	3	
40	153	8	4	Below Average
50	192	9-10	5	Average
60	230	11	6	Above Average
70	268	12	7	Good
80	306	13	8	
90	345	14	9	Excellent
-	-	≥ 15	10	

Table 2: The performance levels of females (Burpees, 30 s), i^{th} percentile represented by P_i symbol

P_i	Participants	Repetition	Points	Level of Category
10	33	1-2	1	Very Poor
20	65	3	2	Poor
30	98	4	3	
40	131	5	4	Below Average
50	164	6	5	
60	196	7	6	Average
70	229	8	7	Above Average
80	262	9	8	Good
90	294	10	9	
-	-	≥ 11	10	Excellent

Most of the researchers suggest that the original Burpee test is suitable mainly to evaluate muscular strength, endurance, and body coordination. The modified Burpee test improved the sequence of movements adding push-up and vertical jump. The protocol covered all features to measure the target physical qualities of youth.

University students (68) who have passed the physical test under the Eurofit test were selected to perform the modified Burpee test interact with the above mentioned protocol. Nearly 56 students displayed satisfactory (average) level performance or above. Other 12 players were below the average level in the push-up test performance under the Eurofit test. Hence, they displayed a poor level for the modified Burpee test. To check the reliability of the maximum level of performance, six national level gymnastics players (youth, male=3, female=3, who got adopted for this test) were requested to perform the test under the new protocol. All players reached an excellent performance level competitively.

To improve the validity of the test, National level (NL) and University level (UL) athletes (n=42, all were University students) were invited to perform the Burpee test. Figure 3 shows the distribution of average performances

of all the athletes based on their sport.

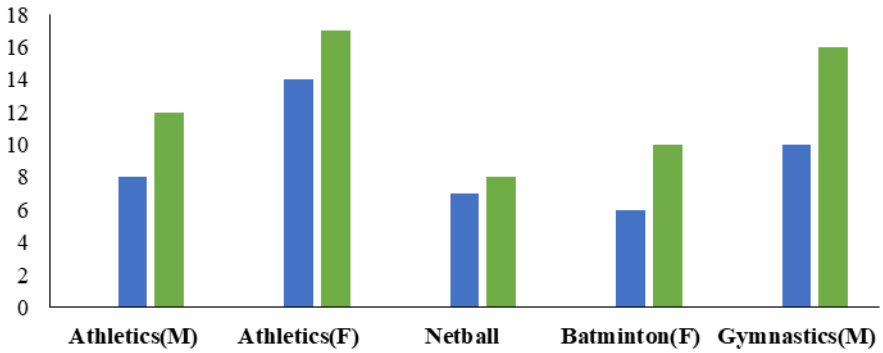

Figure 3. Blue and Green colours represent University level and National level male athletes, respectively. Athletics (M) players (UL, NL):4,2; Athletics (F) players:14,3; Netball: 3,2; Batminton:2,2; Gymnastics:2,2.

As displayed in the Figure 3 all National level athletics players are at excellent performance level. Generally, majority of Netball, Badminton, and Swimming female players were not in excellent performance level for the push-up test. Therefore, they have not shown proper body coordination and balance at the last few seconds of the Burpee test. Also, Rugby and basketball players did not complete the sequence of movement patterns properly in the last few seconds. They failed to maintain the balance and displayed a poor level of body coordination. Therefore, the 30s modified Burpee test battery under the new protocol provides reliable performance levels of the youth in Sri Lanka. It represents standard validity of the test [10].

Biomechanical evaluation of the burpee

To achieve an average or above performance level, an athlete has to consider the movement concept of the Burpee, which is associated with the body awareness, spatial awareness, and effort awareness in a specific space. Therefore, the 2D biomechanical model of plank posture on the Sagittal plane was considered (Figure 1 b). Balance and agility (direction of movement changes 90˚) will be measured in this test only if an athlete performs it in a relevant range of space: can be defined according to the specific *d* of an athlete. Specially to keep the rhythm of movement pattern in a specific space, an athlete has to concentrate on whole-body coordination. Hence, a specific space has to be identified for each athlete to normalize the performance of the group of people in the same age group.

The minimum value for *d* can be defined when AB and CD (ϑ=0^0) body segments are perpendicular to the BC straight line. Therefore, the d_{min} is $\sqrt{L^2+(l_{arm}-l)^2}$. The $d_{\max} = d_{\min} + l_{arm} + l_{foot}$ when B, A, D, and C are on a straight line (If the player falls down on the floor from the plank position of the Push-up). Then *l* goes to l=l_{foot}, hence, *d* will be d_{max}. Therefore, the affective exercise presentation space can be decided from range of d; $d_{\max} \le d \le d_{\max}$. Body segment lengths for male $(L = 0.776H_M, l_{arm} = 0.462H_M \text{ and } l_{foot} = 0.152H_M)$ can be expressed as a fraction of male body height (H_M).

For the male athlete, the range of *d* is $0.776H_M \le d \le 1.390H_M$*L*, l_{arm}, and l_{foot} lengths can be expressed as a fraction of female body height $0.782H_F$, $0.455H_F$, and $0.152H_F$, respectively.

For the female athlete, the range of *d* is $0.782H_F \le d \le 1.389H_F$.

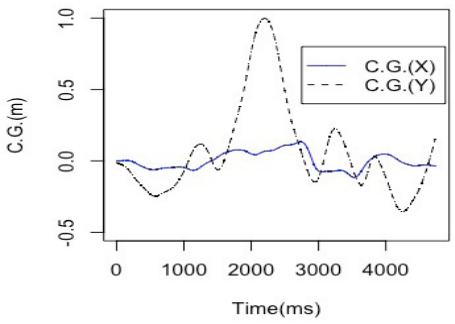

Figure 4. Vertical displacement (Y in meters) and Horizontal displacement (X in meters) of the C.G of the athlete. Sequence starts from iii (Figure 1 a).

Mechanical energy expenditure (concentric movement) for a Burpee takes a very high value because of the fact that the vertical displacement of the C.G of an athlete is more than 1 m for youth. The Figure 4 shows vertical displacement of the C.G of a female athlete (51 kg, height 1.61 m, total displacement of $Y_{C.G}$=1.22 m) during the concentric movement of the first Burpee. The minimum mechanical energy (potential energy 610 J) is required to move the C.G from iii to vi (see Figure 1 a). This energy depends on the height and the mass of the athlete.

Formulas (B) and (C) can be represented in terms of height (H) of the athlete as in the following Table 3.

Table 3: Vertical displacement of the C.G of athletes from plank position to stand on the floor as shown in (Figure 1 b)

C.G	Male	Female	Shoulder Flexion φ=180^0	Shoulder Extension φ= 0^0
Y_0	$(0.3204\cos\vartheta - 0.1034)H_M$ At $\vartheta = 0^0$, $0.2170\ H_M$	$(0.3409\cos\vartheta - 0.0950)H_F$ At $\vartheta = 0^0$, $0.2459\ H_F$	-	-
Y	$(0.6137 - 0.0173\cos\varphi)H_M$	$(0.6205 - 0.0154\cos\varphi)H_F$	$0.6130H_M - 0.6389H_F$	$0.5965H_M - 0.6021H_F$

Generally, the required minimum energy in concentric movement (against the gravity in iii to vi in the sequence of the Burpee movement pattern) can be represented by $E_{C\max} = Mg(Y - Y_0)$. Maximum eccentric energy in order to improve based on vertical jump height $(\triangle h)$ and vertical displacement of the C, G at maximum level of eccentric movement of Push-up ($h_{\min}$). Hence, the total vertical displacement of the C.G will be improved. Therefore, $E_{C\max} = Mg(Y + \triangle h - h_{\min})$ best two players were selected to calculate the E_c as shown in the Table 4.

Table 4: Players: male:23 Years, 175 cm, 68 kg, 400 m Runner; female: 23 Years, 161 cm, 51 kg, Huddler. Average values of first 10 repetitions of 30s Burpee test were taken to calculate $\triangle h$ and $h_{\min}$

Gender	$Y_0(m)$	$Y(m)$	$\Delta h(m)$	$h_{min}(m)$	$E_{Cmin}(J)$	$E_{Cmax}(J)$
Male	0.380	1.104	0.48	0.121	483.0	975.9
Female	0.396	1.029	0.43	0.104	316.7	677.9

The quantity values of E_C, Y_0, and Y reflect the distinguish performance level of players or general youth corresponding to their anthropometric measurements specially height and mass of the body.

CONCLUSION

The Burpee test has been identified as a test to measure people's five physical components: strength, endurance, agility, balance, and coordination, altogether. Exercise presentation-space and concentric energy are defined in terms of body height and mass. Therefore, individual performance is described with quantitative results of the performance level of the Burpee test and concentric energy. Further, it will be helpful to distinguish players' current performance levels of physical components based on the Burpee test.

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