Original Article

The Sit-Up test battery: Calculation of the energy expenditure

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ABSTRACT

Sit-Up tests have been involved to measure the abdominal strength and endurance of youth and elite players in training sessions and specific skill tests. This study was aimed at evaluating the fitness level of the muscular strength and endurance of the abdominal and hip-flexor muscles of youth people corresponding to the body segment parameters: height and weight. The test battery and biomechanical model of the dynamic movement of Sit-Up were designed. The 30s Sit-Up test was performed by youth people: n = 1373 male and n = 1160 female. The percentile method was used to distinguish the performance levels. The average numbers of Sit-Up of males and females are 17 (SD = 2.17) and 12 (SD = 1.98), respectively. University students (68), who have already tested their fitness levels (satisfactory level or above) of muscular strength and endurance of abdominal and hip-flexor muscles by the Euro-fit test, were selected to show the validity of the test battery. Nearly 90% of students were at the average level or above relevant to the new Sit-Up test battery. The biomechanical model described the main active muscles' forces (Rectus Femoris: 0-900 N, Psoas 0-300 N, and Iliacus 0-295 N) and total mechanical energy expenditure (132.66 J: 70.72 J, 61.94 J concentric and eccentric movements, respectively; player: mass 67.5 kg and height 1.66 m) for any player. The new '30s Sit-Up test battery' is affective to evaluate reliable fitness levels for muscular strength, endurance of abdominal and hip-flexor muscles of youth. The biomechanical model demonstrates the energy expenditure for anyone (EAvg = 0.317 + 0.002 Cal).

Keywords: Biomechanics, Biomechanical model, Hip flexor, Youth people.

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INTRODUCTION

Most of countries, physical fitness test batteries (Council of Europe, 1993) use to evaluate the physical fitness level of people. However, the Eurofit test batteries were designed considering geographical, social, and cultural variables (Tomkinson & Olds, 2007) for the European region (23 counties) people. The average heights of males and females in Germany are 178 cm and 165 cm, respectively (Federal Statistical Office, 2021). Those values for Sri Lankans are 163.6 cm and 151.4 cm (Ranasinghe et al., 2011). Therefore, anthropometric measurements of the human body in Europe are exactly different compared to Sri Lanka. Basically, for a Sit-Up exercise, torque around the hip joint depends on the mass and height of the upper body. Consequently, the maximum repetition will be varied with these variables. In this situation, the Eurofit test batteries will not be reliable to evaluate the accurate fitness level of youth people who are outside the European region.

Physical fitness tests have been used to observe physically fit people for recruitment. Moreover, it will play a critical role to screen the best athletes for team sports in a competitive situation. Especially, the level of performance of Sit-Up exercise will be a good measurement of the strength and endurance of abdominal and hip flexor muscles. Three types of variation can be seen when lifting the upper body such as trunk flexion (Lehnert et al., 2015), hip flexion, and spontaneous Sit-Up (combination of trunk and hip flexion) (Andersson et al., 1997). Most of the previous studies discussed the patterns of muscle activity corresponding to the EMG signals. The EMG signals from a Sit-Up are displayed for Sternocleidomastoideus, Rectus Abdominis, External Obliquus, Tensor Facia Latae, Pectineus, Rectus Femoris, and Bicep Femoris (Cordo et al., 2003). However, the pattern of Psoas and Iliacus muscles activity is still not clearly identified.

Most athletes, trainers, coaches, physiotherapists, scientists (Wibowo et al., 2022) (Guerrero-Mendez et al., 2021) and doctors recommend doing Sit-Up exercises to strengthen abdominal muscles rather than hip flexors. Further, they believe that Sit-Up exercise will help to develop six packs and fat burn. Therefore, people include the Sit-Up exercise in their training or physical fitness sessions (El-Ashker, 2018). The volume and intensity of Sit-Up vary from one to another. There are no scientific protocols or relevant test batteries to justify the workload based on calorie burn.

In this research, the method of calculation of required mechanical energy to perform a Sit-Up for any player has been discovered based on the biomechanical model of knee bend Sit-Up. Therefore, kinetic factors of relevant muscles have observed through the biomechanical model of the Sit-Up exercise to justify the argument. Further, the test battery was introduced to evaluate the performance level of the muscular strength and endurance of abdominal and hip-flexor muscles of youth people in Sri Lanka.

MATERIAL AND METHODS

The study sample included healthy participants 1373 males (age = 21 ± 6 years) and 1160 females (age = 20 ± 5year) in Sri Lanka to test the muscular strength and endurance of abdominal and hip-flexor muscles through the Sit-Up test. All participants had no known or apparent musculoskeletal injuries and were able to perform the exercise correctly.

According to the moment pattern of the Sit-Up, abdominal muscles are mainly activated (Lamb et al., 1988). The relationship between the degree of knee flexion and activation of the hip flexors has been increased (Andersson et al., 1997; McGill, 1995). Therefore, the following protocol was introduced to perform the Sit-Up exercise.

The protocol for Sit-Up on a flat surface

Lie down on your back, knee flexion about 90° and stabilize the lower body, feet are touching entire performance period, keep hands behind your ears without pulling on your neck, lift your head and shoulder blades from the ground, and perform maximum repetition within the 30s.

The maximum repetitions (two sets) performed by each participant and average values of performance of participants were standardized according to the percentile of the performance. Also, the relatability and validity of data were tested through the standard Eurofit test battery.

The Sit-Up exercise was performed (maximum repetitions, two sets) by each participant, and the average values of performance of participants were standardized considering the percentile of the performance. Further, the relatability and validity of data were tested by using the standard Eurofit test battery. Assumed that geographic variability for performance is negligible for the selected sample.

Biomechanical model of the Sit-Up exercise

Consistent with the kinematics of the Sit-Up, the pattern of muscle activity was complex, with the pattern exhibiting both serial and parallel components (Cordo et al., 2003). Therefore, to observe active muscle movements to perform Sit-Up exercises, the 2D biomechanical model on the sagittal plane (Figure 1) was designed.

The rectus abdominis (C_cH: distance between 5th to 7th Costal Cartilages and Xiphoid Process) will be activated in the initial part of the Sit-Up (Curl-Up). Gradually dynamic contraction of C_cH is released and further, it acts as the stabilizer of the trunk. The Iliacus ($L_vL_{t.f}$) and Psoas ($I_FL_{t.f}$) major muscles (strongest flexor of the hip joint) will be activated with the Rectus Femoris (A_{iis}K). Where $L_vL_{t.f}$, $I_FL_{t.f}$, and A_{iis}K are lengths of 1st to 4th Lumbar Vertebrae to the Coastal Processes of Lumbar Vertebrae, Iliac Fossa to Lesser Trochanter of Femur, and Anterior Inferior Iliac Spine to Lesser Trochanter of Femur, respectively.

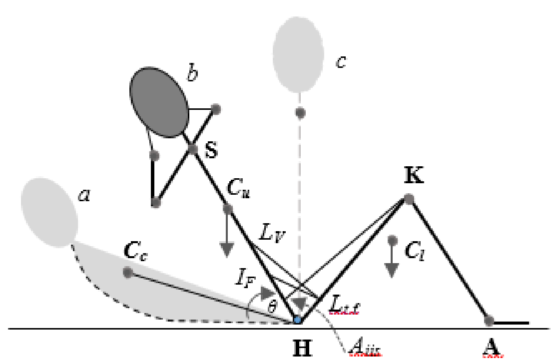

Figure 1. The 2D view of Sit-Up exercise on the flat horizontal surface (sagittal plane): (a). Curl-Up: spine flexion (Guerra et al., 2019); (b). a dynamic position of the body at t = *t*; (c). completion of the concentric movement of the Sit-Up.

Kinetics of the Sit-Up exercise

Tensions of the Psoas ($I_FL_{t.f}$) major, Iliacus ($L_vL_{t.f}$), and Rectus Femoris (A_{iis}K) are represented from T_1, T_2, and T_3 respectively. Iliacus, Psoas major muscles connect to a point on the femur (Lesser Trochanter). Assumed the direction of the resultant forces (T_1, T_2, and T_3) on a sagittal plane move towards the $L_{l.t}$ (The middle point of the two Lesser Trochanters). H is an imaginary point that will be fixed relative to the body in a dynamic situation.

Where $HL_{l.f} = p$, $HCu = d_1$, $HLv = d_2$, $HI_F = d_3$, $HK = L_T$, and $K\widehat{H}I_F = K\widehat{H}I_V = \beta$.

T_1, T_2, and T_3 were derived using the standard Lagrange equation (Robertson et al., 2014).

$$\begin{pmatrix} T_1 \\ T_2 \\ T_3 \end{pmatrix} \begin{pmatrix} X_1 & X_2 & X_3 \\ Y_1 & Y_2 & Y_3 \\ Z_1 & Z_2 & Z_3 \end{pmatrix} = \begin{pmatrix} P \\ Q \\ R \end{pmatrix} \quad (1)$$

P, Q, and R torques are,

$$P = -M_L g(q + L_T \cos\theta),$$
$$Q = I\ddot{\theta} + M_U g l_{CU} \cos\theta, and$$
$$R = -M_U L_T \left[g\cos(\theta+\beta) + l_{C_u} \dot{\theta}^2 \sin\beta + l_{C_u} \ddot{\theta} \cos\beta \right]$$
$$-M_L gq.$$
$$X_1 = L_T \cos(\alpha_1 + 2\beta) - (L_T - p)\sin(\alpha_1 + \beta)$$
$$Y_1 = d_1 \sin\alpha_1$$
$$Z_1 = -(2L_T - p)\sin(\alpha_1 + \beta)$$
$$X_2 = L_T \cos(\alpha_2 + 2\beta) - (L_T - p)\sin(\alpha_2 + \beta)$$
$$Y_2 = d_2 \sin\alpha_2$$
$$Z_2 = -(2L_T - p)\sin(\alpha_2 + \beta)$$
$$X_3 = L_T \cos(\alpha_3 + 2\beta)$$
$$Y_3 = d_3 \sin\alpha_3$$
$$Z_3 = -L_T \sin(\alpha_3 + \beta)$$

The change in muscle length (Jiroumaru et al., 2014)(Hawkins & Hull, 1990) of Rectus Femoris and Iliopsoas ($\Delta A_{iis}K$, $\Delta I_F L_{t.f}$, $\Delta L_v L_{t.f}$) based on Limb position were used to calculate d_1, d_2, and d_3 values (Figure 1).

$\Delta A_{iis}K$ = [1.107-0.0015(180-β) + 0.00199(180-γ)] x length of thigh.

$\Delta I_F L_{t.f} = \Delta L_v L_{t.f}$ = 0.215-0.00076(180-β) x length of thigh.

Centre of gravities (COG) of body segments

The Dempster body segment parameters (Dempster, 1995) and Anthropometric segment length of human body as a function of body height (Winter, 2009) (Karimi & Jahani, 2012)were used to derive the COG of the upper body from the H point: C_u.

$C_u = \dfrac{0.427 l_{Trunk} + 0.081 l_{Head}}{0.5780}$ Assumed COG of arms (Upper extremity) is located near point S.

COG of the lover body is denoted by C_l

$$C_l = (C_{lx}, C_{ly})$$
$$C_{lx} = \frac{0.3463 l_{Leg} \cos(\theta + \beta - \gamma) - 0.6533 l_T \cos(\theta + \beta) + 0.0725 l_{Foot}}{0.5795} \quad (2)$$
$$C_{ly} = \frac{0.1868 l_{Leg} \sin(\theta + \beta - \gamma) + 0.5228 l_T \sin(\theta + \beta)}{0.5795}$$

The free fall technique (Figure 2: c to a) was used to determine the moment of inertia (*I*) of the upper body (Upper extremity; Trunk; and Head-Neck).

$$I = 2Mgl_{CU}\left(\frac{\sin\theta - 1}{\dot{\theta}^2}\right) \quad (3)$$

The mechanical energy (W) was calculated considering concentric $(x \in [a,b))$ and eccentric $(x \in [b,c])$ movements of the Sit-Up. Where x is the change of length of the Iliacus, Psoas, and Rectus Femoris muscles.

$$W = W_{Spine\ Flexion} + \sum_{i=1}^{3} W_i \quad (4)$$

where $W_i = \int_a^b T_i\, dx_i + \int_b^c T_i\, dx_i$

The dynamic Sit-Up exercise was captured using six high-speed camera (100Hz) setups (Chandana & Gang, 2020). It is used to measure segmental kinematics in the sagittal plane (Chandana et al., 2018). Kinematic variable calculated aid of Movement analysing software (Qualisys).

RESULT AND DISCUSSION

The Sit-Up test performance of Sri Lankan youth people has been distributed as shown in Figure 2. The average values of the performance of males and females are 17 (SD = 2.17) and 13 (SD = 1.98), respectively.

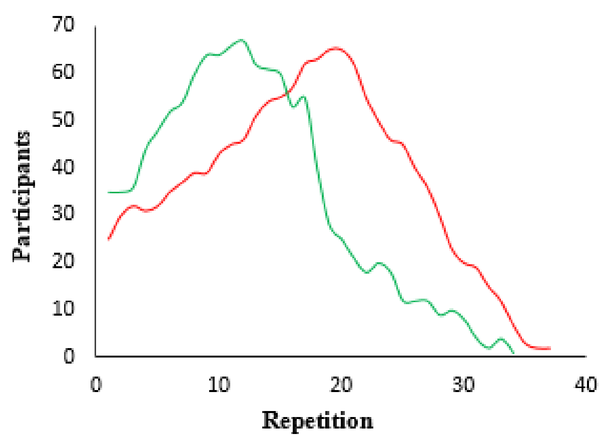

Figure 2. Sit-Up (the 30s) performance of participants: green colour indicates female and male represent by red.

Assumed the geographic variation and socio-cultural factors of participants in Sri Lanka are negligible.

Test battery for Sit-Up

The Sit-Up test battery represents in Table 1 and Table 2 to evaluate the muscular strength and endurance of abdominal and hip-flexor muscles of youth people.

Table 1. The performance levels of males (Sit-Up, the 30s).

%	Participants	Repetition	Points	Level of Category
10	137.3	1-5	1	Poor
20	274.6	6-9	2	
30	411.9	10-12	3	Below average
40	549.2	13-15	4	
50	686.5	16-17	5	Average
60	823.8	18-19	6	
70	961.1	20-21	7	
80	1098.4	22-24	8	Good
90	1235.7	25-27	9	
-	-	≥ 28	10	Excellent

All participants were given a verbal and visual demonstration (online) of each Sit-Up condition and allowed to practice the condition. Incorrect procedures such as excessive shoulder protraction and retraction, foot movements from the floor, separation of knees, and degree of knee flexion depending on the activation of lower abdominal stabilizers (Parfrey et al., 2008) were monitored by the investigators. Therefore, the maximum repetition was reduced by a few best performers. Hence, the maximum repetition counted as 37 and 34 for males and females, respectively.

Table 2. The performance levels of females (Sit-Up, the 30s)

%	Participants	Repetition	Points	Level of Category
10	116	1-4	1	Poor
20	232	5-6	2	
30	348	7-8	3	Below Average
40	464	9-10	4	
50	580	11-12	5	Average
60	696	13-14	6	
70	812	15-16	7	
80	928	17-18	8	Good
90	1044	19-22	9	
-	-	≥ 23	10	Excellent

Most of the research describes the Sit-Up test as suitable for mainly evaluating muscular strength and endurance of abdominal muscles when foot non-fixe situation. If the foot is fixed, hip flexor muscles are activated. Therefore, this protocol covered all features to measure the muscular strength and endurance of abdominal and hip flexor muscles.

University students (68) who have gone through the Eurofit test to perform the Sit-Up test under the above-mentioned protocol. Nearly 61 students displayed satisfactory (average) performance level or above. The reasons for the difference between performance levels for the same group for Eurofit and the new test battery are Geographic variation, socio-cultural factors, and anthropometrics measurements of European people (specially height and mass).

The Cur-Up is a specific part of the early stage of the movement pattern of the Sit-Up exercise. Initially, the rectus abdominis will be actived for spine flexion ($S\widehat{C_c}H$ angle between 30^0 and 40^0) as shown in Figure 3.

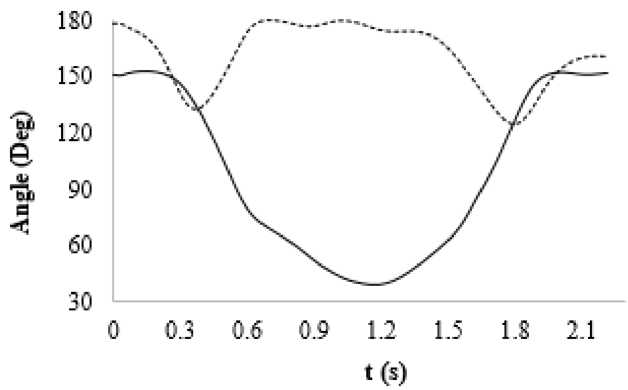

Figure 3. Angles: β(-) and $S\widehat{C_c}H$(--) change from concentric to eccentric movements of the Sit-Up exercise.

The butterfly shape of velocities of S, Cc, and H are illustrated in Figure 4. Concentric movement and eccentric movements of a Sit-Up are represented in the periods of 0s-1.2s and 1.2s-2.1s, respectively. Even though the velocity of H is small with compare to the velocity of S, it has about 20m displacement on the floor. Therefore, the force activation has to consider relative to point H (see Equation 1 and Figure 5).

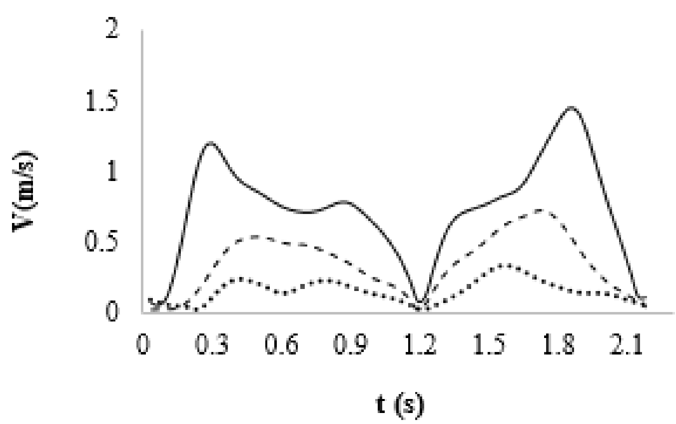

Figure 4. Kinematics of Sit-Up (the 30s): Velocities of S(-), Cc(--), and H(··) of a player (mass 67.5 kg, height 166 cm) who was adopted for Sit-Up exercise.

Though Rectus Femoris and Psoas muscles are activated the same way, Rectus Femoris is dominated to move the upper body throughout the Sit-up exercise. The Iliacus muscle is activated when the other two muscles' tensions are gradually reduced.

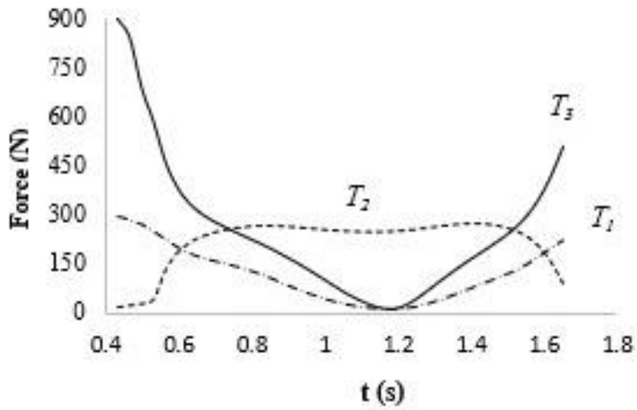

Figure 5. Muscle force throughout the concentric and eccentric movement. The tension of active muscles: Psoas major (T_1), Iliacus (T_2), and Rectus Femoris (T_3).

According to Equation 4, the mechanical energy was calculated (Table 3). This method will be useful to calculate the energy expenditure of an athlete who is doing a Sit-Up exercise. Hence, the volume of the exercise can be predicted based on the mentioned energy expenditure.

Table 3. Work done by the main active muscles to complete a Sit-Up (Player: 67.5 kg mass, height 166 cm). Metabolic equivalent of task (Ainsworth et al., 2000)(MET = 4.184 $\frac{E}{m\,t}$ where E:0.1326 kJ; m:67.5 kg; t: 0.0083 hr.) for a Sit-Up is 9.86 $kJ.kg^{-1}.hr^{-1}$.

Movement of Sit-Up	Mechanical Energy (132.66 J)			Calories
	Rectus Femoris (J)	Psoas(J)	Iliacus (J)	
Concentric	41.38	16.94	12.40	0.317 ± 0.02
Eccentric	34.47	16.35	11.12	

CONCLUSION

The findings of this study have practical applications when selecting a test for of abdominal performance or prescribing an abdominal exercise program for youth people. Especially, this result provides a reliable evaluation of the muscular strength and endurance of the abdominal and hip-flexor muscles of youth people.

The biomechanical model of the Sit-Up is useful to predict exercise load based on the energy expenditure and demand for any athlete.

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DISCLOSURE STATEMENT

No potential conflict of interest were reported by the author.

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