Technical Research

Multifunction device for estimating cardiorespiratory fitness in the Step Tests

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ABSTRACT

Cardiorespiratory fitness tests have been always paramount and comprehensive evaluator for the different fitness levels. However, these are sophisticated techniques, time consuming, and usually expensive. Design and manufacture of various sport equipments, especially in the field of cardiorespiratory fitness have exceptional importance. The aim of the present study was to design and manufacture a portable multifunction device for estimating the cardiorespiratory fitness for the Step Tests. 110 physically active young men (age: 18 to 22 years) have been chosen and divided into 11 experimental (Strand-Rhyming, Billi-Mirwald, Techomesh, Cotton, Queens, McArdle, East-Michigan, Hodkins-Scobik, OSU, YMCA, Harvard step test) groups and each group performed a test by the device. Microcontroller-based hardware was designed and programmed with the Basic language. In this device, 11 different standard step test programs designed. In order to assess the agreement of the instrument during the different step tests, the estimated value obtained by the designed device and the routine method (manual procedure and calculations). To assess the reliability of estimated values in different tests, the test-retest method was implemented. Results of statistical method using Bland-Altman and Intraclass Coefficient Correlation (ICC) showed that estimated cardiorespiratory fitness using designed device has very high agreement to the criterion ($P \leq 0.001$). According to the results, it can be concluded that designed multifunction device can be used as an accurate portable alternative system for estimating cardiorespiratory fitness in Step Tests.

Keywords: Design and manufacture, Hardware, Software, Step Tests, Cardiorespiratory fitness.

Introduction

Accurate and updated evaluation of fitness, especially cardiorespiratory fitness is among the issues of interest to researchers in the field of sport science [1,2]. In this regard, designing and manufacturing of various sport equipment including devices for estimating cardiorespiratory fitness have always been important and due to its importance, extensive studies have been conducted [3,4].

One of the most important indicators of health related fitness has been cardiorespiratory fitness that utilized as a criterion for evaluating the functional efficiency of the cardiopulmonary and circulatory systems [2,5]. Maximal oxygen uptake is the best indicator for assessing the aerobic fitness in endurance activities. This indicator is an important parameter accepted by exercise physiologists for estimating cardiorespiratory fitness [1,6,7]. Maximal oxygen uptake can be identified during incremental exercise. By increasing the training load, oxygen consumption is increased with a specific rate, but at one point, oxygen consumption does not increased which indicates cardiovascular health and aerobic capacity of the person according to the definitions of maximum oxygen consumption and Vo_2max is important indicator of physical fitness [8,9]. It can be determined by gold standard methods (including analysis of respiratory gases). However, because these laboratory procedures are costly, and needs highly skilled technicians to carry out the tests, therefore the indirect maximal tests such as Bruce test on the treadmill have been designed to estimate the maximum rate of oxygen consumption per minute during exercise time [3,4].

Field tests are cheaper and operated in less time than laboratory tests for estimating maximal oxygen consumption however, they have low validity. The design of these tests must be operated simply anywhere and easily learn and use it. In this regard, different step tests have been designed for estimating aerobic fitness [10]. It has been demonstrated that the highest Vo_2 max is estimated in running and step tests and lowest rate is in arms Ergometer [11].

The metronome cadence in the step test is directly associated with age and leg strength [12]. Perhaps the inability to maintain step test cadence is related to decrease in fitness factors and that's why strength and endurance are the main components of physical fitness [13]. Since step tests are mainly implemented as a submaximal fitness test or in a few cases maximal fitness test, these tests are superior to other tests like Cycle Ergometer, running, walking, and swimming because they do not need expensive equipment, and they do not require much training space, and its training and implementation is relatively easy and can be easily performed in large population [14]. However, step test needs equipments such as special and standard steps for each step test, sports metronome to operate proper step cadence, sports chronometer to record time, heart rate recording (either manually or by means of heart rate monitoring sensors).
Lack of hardware or software to help researchers to implement many type of step tests necessitated the current device. Hence, this research with the aim of designing and manufacturing multifunction device estimating cardiorespiratory fitness in step tests was conducted.

Material and Methods

Hardware& Software design

In the present study, a microcontroller-based circuit board designed and programmed by the Basic language. Hardware section of the device includes graphic LCD, AVR microcontrollers (ATMEGA8 and ATMEGA128), voltage regulator, buzzer, two color LEDs, micro switches, battery charging port, a 3.7V and 800 mAh Rechargeable Li-Ion battery, 8 MHZ Crystal oscillator, HTM-HNR wireless receiver and transmitter module, finger Infrared (IR) pulse sensor, and plastic box for the device (2.5×8×4 cm). This device has been made of three hardware sections. The first section is part of the device which receives information and data related to heartbeats from the index finger and transferred to the second block.

In this section an IR transceiver has been used which transfers raw data directly to the second section (Figure 1)

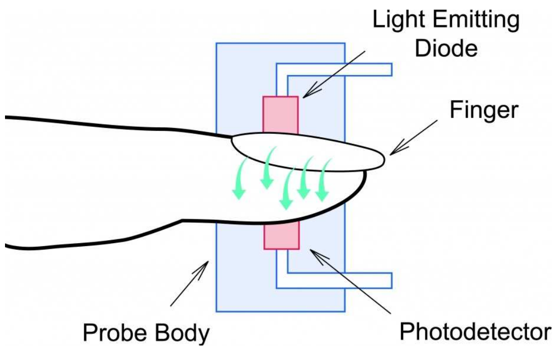

Figure 1. Section 1 of the device.

In the section two of the multifunction device, the finger pulse data wirelessly transmitted from the section one to the section three within several meters away. In the receiver's section, heart rate data directly converted to serial by RS232 format and transmits them by a special radio transmitter (Figure 2).

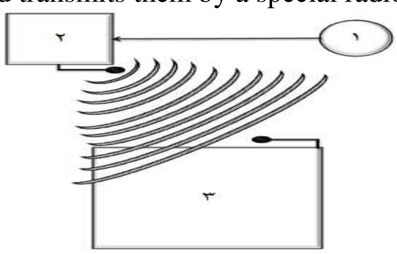

Figure 2. Section 2 of the device (Wireless transmitter).

In this section, heart rate data received by the wireless receiver, then analyzed and sent to the microcontroller. A keypad was implemented for select-a test and also typing the step cadence in the manual mode. Start and Stop buttons used to start and stop the program. Up and down keys are responsible for selecting a program in the program list or increase or decrease the cadence time, or move to the next or previous menu. Selected program displays on the graphic LCD and real-time heart rate demonstrated on 7-segment display. In the current device, 11 step tests are selectable. After running each program, buzzer produce beep sound for each cadence and subject performance easily synchronized with the selected program. An LED blinks with each beep to be useful for subjects with hearing impairment. This device can be used in group training or exercise.

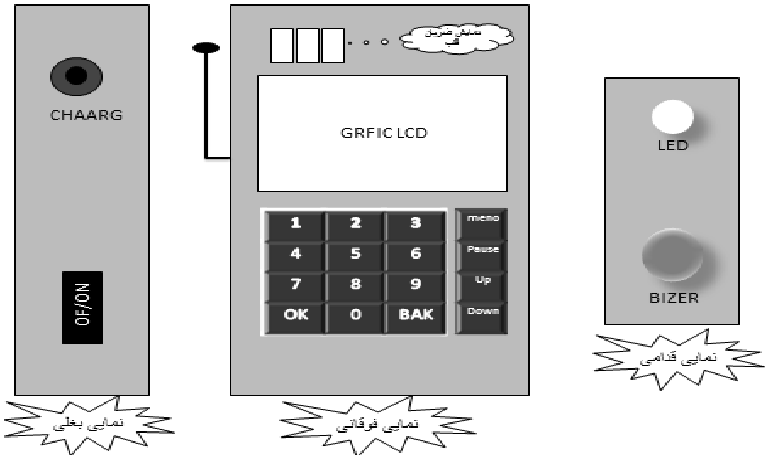

Figure 3. Section 3 of the device.

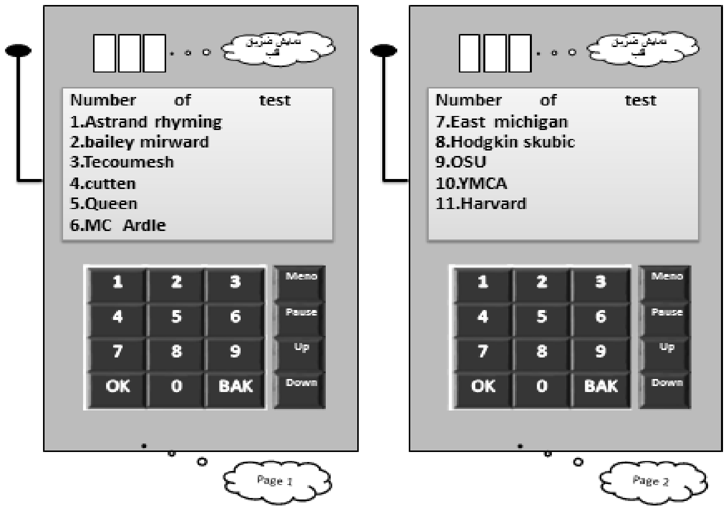

Figure 4. Step test program selection menu**.**

Device Evaluation

In order to evaluate the efficiency and performance of the designed multifunctional device based on specific aims of this research, 110 physically active young men (age: 18 to 22 years) have been chosen and divided into 11 experimental groups and each group performed a test by the device. Bland-Altman plots as well as the Intraclass Correlations (ICC) are extensively used to evaluate the agreement between two measurements techniques (manual procedure vs. calculations). Reliability evaluation of the estimated values of cardiorespiratory fitness by the designed device and routine method was done by test and retest method.

Results

Results of Bland-Altman model using designed device and routine manual methods demonstrated that there is a high agreement between these methods. Similarly, the results highlighted a narrow range of differences between the means of estimated cardiorespiratory fitness by the designed device and manual routine method in ±1.96 SD (95% confidence interval; Table 1).

Table 1. Agreement between the designed device and routine manual methods.

Step Test	Designed device (ml/kg/min)	Routine manual methods (ml/kg/min)	95% CI Values (ml/kg/min)	Mean differences (ml/kg/min)	Agreement
Strand-Rhyming	35.4	35.1	-0.561 to 0.253	0.249	High
Billi-Mirwald	31.1	31.3	-1.225 to 2.269	0.184	High
Techomesh	39.6	39.9	-0.504 to 0.743	0.361	High
Cotton	33.5	32.2	-0.832 to 0.427	0.952	High
Queens	41.1	41.1	-0.328 to 0.555	0.053	High High
McArdle	31.3	31.3	-0.824 to 0.171	0.083	High
East-Michigan	46.5	46.8	-1.013 to 0.565	0.221	High
Hodkins-Scobik	40.6	40.7	-0.89 to 0.637	0.172	High
OSU	39.6	39.5	-0.841 to 0.787	0.094	High
YMCA	34.1	34.1	-0.923 to 0.162	0.061	High
Harvard	44.5	44.5	-0.153 to 0.381	0.071	High

Reliability assessments were done by using test-retest results of estimated cardiorespiratory fitness by the means of the current device in different step tests. Results have shown a high intraclass coefficient between the two consecutive tests (Table 2).

Table 2. Intraclass Correlations (ICC) values in the Test-Re-test of cardiorespiratory fitness device.

Step Test	Test (ml/kg/min)	Re-Test (ml/kg/min)	ICC values
Strand-Rhyming	35.4	36.8	0.875
Billi-Mirwald	31.1	30.9	0.916
Techomesh	39.6	37.5	0.812
Cotton	33.5	34.1	0.853
Queens	41.1	44.6	0.785
McArdle	31.3	35.1	0827
East-Michigan	46.5	42.8	0.791
Hodkins-Scobik	40.6	43.6	0.831
OSU	39.6	42.2	0.846
YMCA	34.1	38.6	0.765
Harvard	44.5	45.8	0.952

Discussion

Multifunction device estimating cardiorespiratory fitness using step test was designed and manufactured to be a portable and able to do many standard and common step tests. The battery of the device is chargeable and can be used for three hours continuous application. It is designed be useful for hearing-impaired people.
The device is able to display the heart rate during activity or rest. It can transfer the heart rate wirelessly; therefore, the heart rate can be used for heart rate monitoring and other physiological research applications. There are 11 step tests on the program section that is operated independently and automatically estimating the precise results. This device has a special timer to show elapsed time of activity. However, the application of this device is not limited to the step test and can be utilized in other applications where a precise metronome is required either in the lab or field.

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References

1. Sui, X., et al., Cardiorespiratory fitness and adiposity as mortality predictors in older adults. Journal of the American Medical Association, 2007; **298**(21): 2507-2516.

2. Cooper, K.H., A means of assessing maximal oxygen intake: correlation between field and treadmill testing. Journal of the American Medical Association, 1968; **203**(3): 201-204.

3.Pollock, M.L., et al., Comparative analysis of physiologic responses to three different maximal graded exercise test protocols in healthy women. American Heart Journal, 1982; **103**(3): 363-373.

4. Myers, J., et al., Exercise capacity and mortality among men referred for exercise testing. New England Journal of Medicine, 2002; **346**(11): 793-801.

5. Teoh, O.H., et al., Exercise testing in children with lung diseases. Pediatrics Respiratory Reviews, 2009; **10**(3): 99-104.

6. Robbins, A.S., et al., Predictors of low physical fitness in a cohort of active-duty US Air Force members. American Journal of Preventive Medicine, 2001; **20**(2): 90-96.

7. Egwuogu, H., et al., The effect of urinary cadmium on cardiovascular fitness as measured by VO_2max in white, black and Mexican Americans. Environmental Research, 2009; **109**(3): 292-300.

8. Haskell, W.L., et al., Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. Circulation, 2007; **116**(9): 1081.

9. Bales, D.W., et al., The influence of supporting the Oxylog instrument on estimated maximal aerobic capacity during a step test and heart rate in a lifting test. Applied Ergonomics, 2001; **32**(4): 367-377.

10. Teh, K.C. and A.R. Aziz, A stair-climb test of cardiorespiratory fitness for Singapore. Singapore Medical Journal, 2000; **41**(12): 588-594.

11. Shin, S. and S. Demura, The relationship of age and leg strength in the step test with stipulated tempo in the elderly. Archives of Gerontology and Geriatrics, 2009; **49**(2): 311-316.

12. Slinger, J., et al., The effect of body build and BMI on aerobic test performance in school children (10-15 years). Journal of Sports Science & Medicine, 2006; **5**(4): 699.

13. Chatterjee, S., P. Chatterjee, and A. Bandyopadhyay, Validity of Queen's College Step Test for estimation of maximum oxygen uptake in female students. Indian Journal of Medical Research, 2005; **121**(1): 32-5.

14. Chakravarty, E.F., et al., Reduced disability and mortality among aging runners: a 21-year longitudinal study. Archives of Internal Medicine, 2008; **168**(15): 1638-1646.

15. Selig, S.E., C.M. Gosling, and J.S. Carlson, A multi-stage step test protocol for people with low exercise capacity. Clinical Kinesiology, 2000; **54**(3): 67-71.

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