

## BeepShuttle Junior: Software for the Administration of the 20m Shuttle Run Test in Children and Adolescents

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### ABSTRACT

The 20m shuttle run test (20mSRT) is applied for assessing cardiorespiratory fitness, and is included in many fitness test batteries, such as Eurofit, Alpha-fit, FitnessGram, etc.

The aim of this study was to validate software, specially designed by us (BeepShuttle Junior), which administers the 20mSRT, calculates the maximal oxygen uptake ( $\text{VO}_{2\text{max}}$ ) in children and adolescents from 6 to 17 years of age, and classifies them in accordance with comprehensive gender- and age-specific international norms. This software supports the administration of the 20mSRT with an appropriate animation and audio signals. The most recent  $\text{VO}_{2\text{max}}$  reference standards were combined in order to assess cardiorespiratory fitness. The results can be exported in an Excel compatible CSV file for additional analyses.

A total of 63 children (31 girls and 32 boys) from London, aged from 6 to 9, were tested with the BeepShuttle Junior software, which calculated  $\text{VO}_{2\text{max}}$  and percentile scores for each child.

The boys performed significantly better than girls in cardiorespiratory fitness ( $47.7 \pm 3.1$  vs  $45.9 \pm 2.2$  ml/kg/min respectively,  $p < 0.05$ ), but the mean percentile scores for boys and girls were similar ( $53.2 \pm 23.6$  and  $53.9 \pm 22.1$  respectively).

This software computes the percentile score for the exact age (years, months) and the exact  $\text{VO}_{2\text{max}}$  of each participant by linear interpolation. The individual results and assessments completely matched the interpolated normative data tables.

**Key words:** 20m shuttle run test, cardiorespiratory fitness, maximal oxygen uptake, children and adolescents, beep test.

### Introduction

Cardiorespiratory fitness is one of the most important components of physical fitness, and refers to the ability of the circulatory and respiratory systems to supply enough oxygen for working muscles during sustained physical activity [1]. From the health prospective, a good level of cardiorespiratory fitness has been shown to reduce clinical risk factors for cardiovascular disease and metabolic syndrome in children and adolescents [2]. A systematic review, which includes numerous longitudinal studies [3], provides strong pieces of evidence that a higher level of cardiorespiratory fitness, both in childhood and adolescence, is associated with a healthier cardiovascular profile and with a lower risk of developing cardiovascular diseases later in adulthood. Although many terms have been used in the literature to describe this component of physical fitness, e.g. cardiorespiratory fitness, cardiorespiratory endurance, aerobic fitness, maximal aerobic power, aerobic work capacity, and physical work capacity, they are all applied interchangeably for practical purposes [2].

The most valid measure of cardiorespiratory fitness is the maximal oxygen uptake ( $\text{VO}_{2\text{max}}$ ), which reflects the capacity of the heart, lungs, and blood to transport oxygen to the working muscles, and the utilization of oxygen by the muscles during exercise. The  $\text{VO}_{2\text{max}}$  is expressed in absolute (litres of oxygen per minute (L/min)) or relative terms (relative to body weight in millilitres of oxygen per kilogram body weight per

minute (ml/kg/min)) [4]. The rate of aerobic metabolism and oxygen uptake increases as the intensity of physical exercise increases up to the point at which the aerobic capacity is reached. Beyond this point,  $\text{VO}_2\text{max}$  no longer increases proportionally, even though exercise intensity can be increased, and there is a plateau in the relationship between the rate of oxygen uptake and exercise intensity [2].

In a laboratory setting, the  $\text{VO}_2\text{max}$  of children can be accurately obtained by using either the treadmill or cycle ergometer [4]; however, this requires expensive equipment and qualified technicians. It is also time-consuming, requiring about 30 minutes for the administration of the test for just one person. Therefore, the direct measurement of  $\text{VO}_2\text{max}$  is not possible or practical for most field settings, such as schools or sports clubs, where large numbers of people must be tested [2]. On the other hand, field-based tests for estimating  $\text{VO}_2\text{max}$  are easy to administer, involve minimal equipment, have a low cost, and can be utilized on a larger number of participants over a period of time (Romero et al., 2010).

The 20m shuttle run test (20mSRT) has probably been the most widely used means of assessing the cardiorespiratory fitness of children and adolescents [5-8], and is part of the most extensively applied health-related fitness test batteries, such as Eurofit [9], Alpha-fit [10], FitnessGram [2], PREFIT [11] and ASSO-FTB [12]. The 20mSRT appears to encourage maximal effort by children, and the prediction of aerobic capacity from its results is valid for overweight and obese children, as well as those of normal weight [13].

The 20mSRT was first described by Luc Léger [14] with the original 1-minute protocol, which starts at a speed of 8.5 km/h, and increases by 0.5 km/h each minute. Other variations of the test have also been developed, where the protocol starts at a speed of 8.0 km/h and with either 1 or 2-minute stages, but the original protocol is nevertheless recommended [5]. During the test, children run between two lines, which are 20 meters apart, in time with an audio signal. The test finishes when a child fails to reach the end lines simultaneously with the audio signals on two consecutive occasions; otherwise, the test ends when a child stops due to fatigue [10]. Values of gender- and age-specific norms for the 20mSRT in European children (6.0 – 9.9 years old) have recently been published for the first time [15], and although norms in European adolescents (12.5 to 17.5 years old) can also be found [16], there is still a gap between 9.9 and 12.4 which has to be filled in order to establish a comprehensive set of European norms.

The administration of the 20mSRT and the accurate assessment of its results, however, might lead to some difficulties; for instance, it is hard to follow the shuttles and the speed for each individual properly when using only audio signals. Moreover, some test batteries, such as Alpha-fit and ASSO-FTB, do not refer to  $\text{VO}_2\text{max}$ , but only to the completed stages of the 20mSRT, which is not an appropriate way to compare results from different studies. Furthermore, the reference standards of the 20mSRT have gaps in their values for younger children, which makes it more difficult for assessment purposes. The creation of valid software to facilitate the implementation of this test would make it easier to assess the cardiovascular status of each individual.

The aim of this study was to validate software, specially designed by us (BeepShuttle Junior), which administers the 20mSRT, calculates the  $\text{VO}_2\text{max}$  in children and adolescents between the ages of 6 and 17, and classifies them in accordance with comprehensive gender- and age-specific international norms.

## **Material and Methods**

### **Participants**

A total of 63 children (31 girls and 32 boys) from London, aged from 6 to 9, voluntarily participated in this study, which was conducted in 2016. The school review board approved this research prior to the tests, and a consent form was signed by the parent/guardian of all participants before they took part.

## Anthropometry

The standing height of the children was measured to the nearest 0.1 cm with the Leicester Height Measure, which is recommended by the Child Growth Foundation and has been used in the UK's National Child Measurement Program [17]. Body weight was measured to within an accuracy of 0.05 kg with an electronic scale, and the BMI was calculated as: weight in kilograms / height in meters squared. The Z-scores and percentile scores for weight, height and BMI of each individual were calculated and assessed by using specialized software of the World Health Organization, called 'WHO Anthro Plus' [18].

## Cardiorespiratory Fitness Assessment

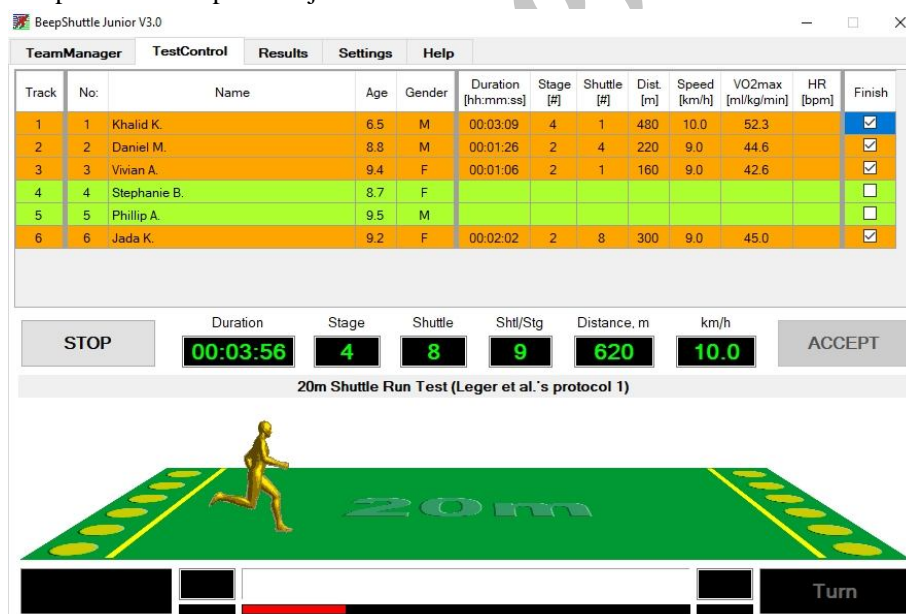
For the purpose of this study, we designed specialized software [19] to improve the assessment and efficacy of the 20mSRT in children and adolescents. All participants performed the 20mSRT and were tested with the BeepShuttle Junior software. The test was performed in the junior playground at St Edmund's Catholic Primary School after a short general warm-up. Children were wearing their PE uniform (T-shirts, shorts and plimsolls) and practised the test to familiarize themselves with it. During the test we followed the standard procedure, and only one trial was performed [10].

## BeepShuttle Junior

This software applies the original 1-minute protocol, which starts at a speed of 8.5 km/h and increases in speed by 0.5 km/h after each minute, as described by Leger et al [14]. BeepShuttle Junior provides a good visualization of the 20mSRT by using an appropriate animation (Figure 1), and it renders customized audio signals in its settings section. The results of the test can be exported in CSV Excel compatible files for additional analyses. The software works on Microsoft Windows XP Service Pack 3, Vista, 7, 8, 10.

A functional demo of the BeepShuttle Junior is available for download at:

<https://www.stk-sport.co.uk/beepshuttle-junior.html>



**Figure 1.** Screenshot of the animated 20m SRT on BeepShuttle Junior

The BeepShuttle Junior provided information relating to the duration of the test (min), stage (number), shuttle (number), distance (m), speed (km/h), VO<sub>2</sub>max (ml/kg/min), percentile score (PRs) and classification (very poor, poor, medium, good, excellent) for each child (Figure 2). Maximal oxygen uptake (VO<sub>2</sub>max, ml/kg/min) was calculated by using the Leger et al [20] equation:

$$\text{VO}_2\text{max (ml/kg/min)} = 31.025 + 3.238 \times \text{speed} - 3.248 \times \text{age} + 0.1536 \times \text{speed} \times \text{age}$$

‘Speed’ in the above equation is the running speed of the final completed stage (km/h), and ‘age’ refers to the age at last birthday. This equation was reported to provide an SE (standard error) estimate of 5.9 ml/kg/min or just 12.1% in a sample of 7000 children and adolescents from Québec between the ages of 6 and 17 [20], and was applied for the most recent international and European reference standards [7, 15].

No.	Name	Age	Gender	H	W	Stg	Shtl	Dist.	Duration	Spd	VO2max	PRs	Rating	HR	StartDateTime
1	Khalid K.	6.5	M	116	19	4	1	480	00:03:09	10.0	52.3	94.1	Excellent	0	2017-07-27 13:58:41
2	Daniel M.	8.8	M	137	38	2	4	220	00:01:26	9.0	44.6	29.0	Medium	0	2017-07-27 13:58:41
3	Vivian A.	9.4	F	165	68	2	1	160	00:01:06	9.0	42.6	10.7	Poor	0	2017-07-27 13:58:41
4	Stephanie B.	8.7	F	143	40	5	1	660	00:04:09	10.5	50.8	92.9	Excellent	0	2017-07-27 13:58:41
5	Phillip A.	9.5	M	144	41	5	5	740	00:04:37	10.5	50.5	72.3	Medium	0	2017-07-27 13:58:41
6	Jada K.	9.2	F	132	36	2	8	300	00:02:02	9.0	45.0	30.0	Medium	0	2017-07-27 13:58:41
7	Kevin S.	8.7	M	127	28	2	1	160	00:01:06	9.0	43.9	23.0	Poor	0	2017-07-27 14:04:51
8	David K.	7.7	M	133	29	2	3	200	00:01:18	9.0	46.4	39.3	Medium	0	2017-07-27 14:04:51
9	Sofia C.	7.6	M	135	32	3	1	320	00:02:04	9.5	48.2	56.6	Medium	0	2017-07-27 14:04:51
7	Kevin S.	8.7	M	127	28	3	1	320	00:02:09	9.5	46.2	45.0	Medium	0	2017-07-27 14:07:16
8	David K.	7.7	M	133	29	3	4	380	00:02:27	9.5	48.8	61.0	Medium	0	2017-07-27 14:07:16
9	Sofia C.	7.6	M	135	32	2	8	300	00:01:56	9.0	47.9	54.4	Medium	0	2017-07-27 14:07:16
7	Kevin S.	8.7	M	127	28	4	5	560	00:03:33	10.0	49.5	66.7	Medium	0	2017-07-27 14:10:33
8	David K.	7.7	M	133	29	4	4	540	00:03:26	10.0	51.0	80.6	Good	0	2017-07-27 14:10:33
9	Sofia C.	7.6	M	135	32	3	7	440	00:02:52	9.5	49.8	68.4	Medium	0	2017-07-27 14:10:33

**Figure 2.** Screenshot of the result section of BeepShuttle Junior

In order to assess children’s VO<sub>2</sub>max, we adopted the most comprehensive and up-to-date available set of gender- and age-specific international norms for the 20 m shuttle run test in children and adolescents between the ages of 9 and 17. These standards were based on 1,142,026 children and adolescents from 50 countries (representing 6 major geographical regions: Africa, Asia, Europe, Latin America and the Caribbean, Northern America and Oceania), extracted from 177 studies over the period from 1981 to 2014 [7]. For the assessment of younger children we applied the most recent gender- and age-specific standards in European children aged from 6 to 9 [15]. Both major studies applied the Leger et al. equation in order to predict VO<sub>2</sub>max. The software computes the percentile scores for the exact age (years, months) and estimated VO<sub>2</sub>max by linear interpolation.

The following scale was applied to classify children’s performance from the 20mSRT and to observe those with a health risk: very poor ( $X < P10$ ); poor ( $P10 \leq X < P25$ ); medium ( $P25 \leq X < P75$ ); good ( $P75 \leq X < P90$ ); and excellent ( $X \geq P90$ ) [15]. This five-level rating scale is incorporated in the result section of the software, as shown in Figure 2. Moreover, other data, such as children’s height (H), weight (W) and maximum heart rate (HR) can be added and saved with the results.

In addition, the software provides a convenient calculator which can be used separately in order to compute individual VO<sub>2</sub>max (ml/kg/min) and percentile scores after inputting the following variables: gender, age, number of the last stage and shuttle, and the running speed of the final completed stage.

### Statistical Analysis

The statistical analyses were conducted with SPSS Statistics 19, using descriptive statistics, independent-samples t-test and Pearson correlation. Statistically significant differences between the average values were evaluated at  $p < 0.05$ , and all data in the text are presented as mean  $\pm$  SD.

### Results

Estimated maximal oxygen uptake (VO<sub>2</sub>max, ml/kg/min) and percentile scores of all participants are shown in Table 1. Whilst boys performed significantly better than girls in VO<sub>2</sub>max ( $47.7 \pm 3.1$  vs  $45.9 \pm 2.2$

ml/kg/min respectively,  $p < 0.05$ ), the percentile scores were, however, similar ( $53.2 \pm 23.6$  and  $53.9 \pm 22.1$  respectively).

**Table 1.** Estimated maximal oxygen uptake ( $\text{VO}_{2\text{max}}$ , ml/kg/min), percentile scores and age (mean  $\pm$  SD)

	Girls (n=31)	Boys (n=32)	Significance
Age (y)	$9.01 \pm 0.48$	$8.62 \pm 0.72$	$p < 0.05$
Weight (kg)	$37.22 \pm 9.73$	$34.50 \pm 7.51$	
Height (cm)	$139.67 \pm 8.63$	$135.56 \pm 7.60$	$p < 0.05$
BMI ( $\text{kg/m}^2$ )	$18.88 \pm 3.63$	$18.63 \pm 3.06$	
BMI (Z-score)	$0.91 \pm 1.22$	$1.14 \pm 1.29$	
$\text{VO}_{2\text{max}}$ (ml/kg/min)	$45.85 \pm 2.17$	$47.71 \pm 3.13$	$p < 0.01$
$\text{VO}_{2\text{max}}$ (percentile score)	$53.90 \pm 22.14$	$53.17 \pm 23.64$	

A significant, negative correlation between the BMI Z-scores and  $\text{VO}_{2\text{max}}$  in girls and boys ( $-0.54$ ,  $p = 0.002$  and  $-0.44$  respectively,  $p = 0.011$ ) was observed.

The administration of the 20mSRT by BeepShuttle Junior is highly convenient and comprehensive, with a good audio-visual animation. The individual results and assessments exactly matched the interpolated normative data tables.

## Discussion

There are different prediction equations for children and adolescents which differ in validity and can result in substantially different estimates of  $\text{VO}_{2\text{max}}$  from their performance in the 20mSRT [7]. However, normative studies which have provided the most recent international and European reference standards applied the Léger et al [20] prediction equation [7, 15]. Another significant issue is that there are often several different cassettes or CDs used for the same protocol when administrating the 20mSRT, and methodological variations on these cassettes (e.g. calling the stage number at the start as opposed to the finish of each stage, and using only full minutes rather than both full minutes and half minutes to indicate completed stages) which might lead to identical performances reported in different ways [5]. Moreover, it is difficult to follow the shuttles and the speed for each individual properly when using cassettes or CDs. Furthermore, field-based test batteries, such as Alpha-fit and ASSO-FTB, do not refer to  $\text{VO}_{2\text{max}}$ , but only to levels (stages) from the 20mSRT, which is not always an effective means of assessment. In addition, these reference standards have gaps in their values for younger children, which makes it more difficult to assess school children of all ages because of the need to further apply either country-specific or internationally available reference standards.

Our software, BeepShuttle Junior, however, has the following advantages: it provides immediate assessment of cardiorespiratory fitness by using audio and visual signals, and calculates and assesses results (such as  $\text{VO}_{2\text{max}}$  and percentile scores) of children and adolescents in accordance with comprehensive international norms. In addition, the software exports its results in files, which are compatible with Excel for further analyses.

## Conclusion

BeepShuttle Junior is highly convenient and comprehensive, with a good audio-visual animation, and it is appropriate for administrating the 20mSRT, in addition to calculating and assessing the results of individuals between the ages of 6 and 17, in accordance with comprehensive and up-to-date sets of gender- and age-specific international norms. The individual results and assessments exactly matched the interpolated

normative data tables. This software can also be applied for health and fitness screening, profiling, monitoring and surveillance in schools and sports clubs.

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## چکیده فارسی

## نرم افزار اجرای آزمون شاتل ران در کودکان و نوجوانان: BeepShuttle Junior

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آزمون شاتل ران ۲۰ متر (20mSRT) برای ارزیابی آمادگی قلبی-عروقی و دستگاه تنفس مورد استفاده قرار می‌گیرد و در بسیاری از آزمونهای آمادگی جسمانی مانند آزمونهای Eurofit، Alpha-fit، FitnessGram و غیره استفاده می‌شود. هدف این مطالعه، اعتبارسنجی نرم افزار طراحی شده توسط نویسندگان مقاله (BeepShuttle Junior) است که اجرا و ارزیابی نتایج این آزمون را مدیریت می‌کند. این نرم‌افزار حداکثر اکسیژن مصرفی (VO2max) را در کودکان و نوجوانان ۶ تا ۱۷ سال محاسبه می‌کند و آنها را مطابق با نورم جامعه بین المللی در جنس و سن مذکور مقایسه می‌کند. این نرم افزار با امکانات انیمیشن مناسب و سیگنال های صوتی آزمون را اجرا و مدیریت می‌کند. در این نرم‌افزار، جدیدترین استانداردهای مرجع VO2max برای ارزیابی آمادگی قلبی-تنفسی ارزیابی شد. نتایج را می‌توان در یک فایل CSV سازگار با میکروسافت اکسل برای تحلیل آماری بیشتر ذخیره کرد. در مجموع ۶۳ کودک ۶ تا ۹ ساله (۳۱ دختر و ۳۲ پسر) از لندن، با نرم افزار BeepShuttle Junior، که VO2max و نمره صدک (پرسنتایل) برای هر کودک محاسبه شد، مورد آزمایش قرار گرفتند. از نظر آمادگی قلبی-تنفسی، پسران به طور معنی داری بهتر از دختران بودند ( $47.7 \pm 3.1$  در برابر  $45.9 \pm 2.2$  میلی لیتر به ازای هر کیلوگرم وزن در دقیقه،  $p < 0.05$ ) اما میانگین نمره صدک در پسران و دختران یکسان بود ( $53.2 \pm 23.6$  و  $53.9 \pm 22.1$ ). این نرم افزار نمره صدک برای سن دقیق (بر حسب سال و ماه) و برآورد دقیق VO2max هر یک از شرکت کنندگان را با در نظر گرفتن روش درونیابی خطی محاسبه می‌کند. نتایج و ارزیابی های فردی به طور کامل با جداول داده های درونیابی خطی انطباق دارد.

**واژه‌های کلیدی:** آزمون شاتل ران، آمادگی قلبی ریوی، حداکثر جذب اکسیژن، کودکان و نوجوانان، آزمون بیپ.

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