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A Maximal Multistage 20-m Shuttle Run Test to Predict $\dot{V}O_2$ max*

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Summary. In order to validate a maximal multistage 20-m shuttle run test for the prediction of $\dot{V}O_2$ max, 91 adults (32 females and 59 males, aged 27.3 ± 9.2 and 24.8 ± 5.5 year respectively and with mean $\dot{V}O_2$ max (± SD) of 39.3 ± 8.3 and 51.6 ± 7.8 ml · kg^{-1} · min^{-1} respectively) performed the test and had $\dot{V}O_2$ max estimated by the retroextrapolation method (extrapolation to time zero of recovery of the exponential least squares regression of the first four 20-s recovery $\dot{V}O_2$ values). Starting at 8 km · h^{-1} and increasing by 0.5 km · h^{-1} every 2 min, the 20-m shuttle run test enabled prediction of the $\dot{V}O_2$ max (y, ml · kg^{-1} · min^{-1}) from the maximal speed (x, km · h^{-1}) by means of the following regression equation: y = 5.857x − 19.458; r = 0.84 and SEE = 5.4. Later, the multistage protocol was slightly modified to its final version, in which the test started at stage 7 Met and continued with a 1 Met (3.5 ml O_2 · kg^{-1} · min^{-1}) increment every 2 min. Twenty-five of the 91 subjects performed the 20-m shuttle test twice, once on a hard, low-friction surface (vinyl-asbestos tiles) and another time on a rubber floor, as well as a walking maximal multistage test on an inclined treadmill. There was no difference between the means of these tests or between the slopes of the $\dot{V}O_2$max − maximal speed regressions for the two types of surfaces. The 20-m shuttle run test and another maximal multistage field test involving continuous track running gave comparable results (r = 0.92, SEE = 2.6 ml O_2 · kg^{-1} · min^{-1}, n = 70). Finally, test and retest of the 20-m shuttle run test also yielded comparable results (r = 0.975, SEE = 2.0 ml O_2 · kg^{-1} · min^{-1}, n = 50). It is concluded that the 20-m shuttle run test is a valid and reliable test for the prediction of the $\dot{V}O_2$ max of male and female adults, individually or in groups, on most gymnasium surfaces.

Key words: $\dot{V}O_2$ max − Retroextrapolation method − Validity − Reproducibility − Field test

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Introduction

In order to assess the maximal aerobic power of large groups of subjects, one has to rely on valid, reliable, safe and inexpensive tests. Prediction of $\dot{V}O_2$ max from the submaximal heart rate response has been repeatedly criticized for its lack of accuracy, particularly on an individual basis (Davies 1968; Rowell et al. 1964; Taylor et al. 1963; Wyndham 1967). One of the most often used tests is the 12-min run (Cooper 1968). This test is, however, maximal from the beginning to the end of the 12-min period, which is contrary to the current tendency to use multistage exercise tests with adults (ACSM 1975). The 12-min run test also depends on the anaerobic capacity, the motivation and the ability to run at an even pace throughout the test. A maximal mulistage running track test (Léger and Boucher 1980) for group testing was found to be as valid and reliable as individual indirect maximal multistage treadmill tests, but could not be performed inside gymnasia because of the high speeds achieved in the final stages of the test. The present study reports a maximal multistage 20-m shuttle run test that was found to be valid and reliable for testing groups of adults on two types of surfaces covering a wide range of hardness and friction.

Methods

Experimental Protocol of the 20-m Shuttle Run Test

A pilot study on five young adults running back and forth on a 20-m course for 5 min at various speeds from 7–14 km · h^{-1} revealed that the energy cost increased by 1 Met (3.5 ml · kg^{-1} · min^{-1}) for each 0.5 km · h^{-1}. Thus the experimental protocol for the validation studies started at 8 km · h^{-1} and increased by 0.5 km · h^{-1} every 2 min. Once the validation studies were completed, the experimental protocol was slightly modified in order to have a stage increment of 1 Met, to yield the final version of the test which starts at 7.5 km · h^{-1} (Table 2). The final version was used for the reproducibility study. The pace was set with audio signals emitted at specific frequencies using a precorded tape. Subjects were instructed to complete as many stages as possible. Time was announced every $^1/_2$-min of the 2-min stage to help the subject to decide whether or not he should attempt to complete it. The test stopped when the subject was unable to follow the pace (i.e., 3 m behind the 20-m line at the audio signal) or felt that he could not complete the stage.

Oxygen Uptake Measurement

Maximal oxygen uptake was assessed by establishing the O_2 recovery curve following the maximal multistage test. The Douglas bag method was used for the collection of four consecutive 20-s samples of expired air immediately at the end of the test. A single exponential regression curve was fitted to the four points with the least-squares regression technique, and $\dot{V}O_2$ at time zero of recovery ($\dot{V}O_2$ max in this case) was obtained by retroextrapolating the O_2 recovery curve. The retroextrapolation method has previously been found valid ($r = 0.92$) and accurate (SEE = 3.21 ml O_2 · kg^{-1} · min^{-1}) for the determination of $\dot{V}O_2$ max after maximal multistage test (Léger et al. 1980). O_2 and CO_2 were analyzed with Beckman OM-11 and LB-1 analysers previously calibrated with gases of known concentrations (micro-Scholander technique). Attention was paid to starting and ending the 20-s collection period at the same phase of the respiratory cycle and to timing this period exactly.

Table 1. Physical characteristics of the subjects

Group	*n*	Sex	Age (years)[a]	Weight (kg)[a]	$\dot{V}O_2$ max (ml · kg^{-1} · min^{-1})[a]
I	25	m + f	23.8 ± 6.0	67.2 ± 11.2	44.4 ± 10.6
II	91	(32) f	27.3 ± 9.2	56.8 ± 9.4	39.3 ± 8.3
		(59) m	24.8 ± 5.5	71.1 ± 9.6	51.6 ± 7.8
III	70	(35) f	22.7 ± 5.4	58.7 ± 8.9	42.9 ± 9.5
		(35) m	25.5 ± 6.6	74.6 ± 9.5	50.0 ± 11.5
IV	50	(23) f	24.0 ± 6.5	57.8 ± 7.2	44.4 ± 7.9
		(27) m	25.6 ± 8.7	74.3 ± 10.6	53.8 ± 10.9

[a] Mean ± SD

Three values for $\dot{V}O_2$ max are considered in this paper: the directly measured $\dot{V}O_2$ max, the retroextrapolated $\dot{V}O_2$ max and the $\dot{V}O_2$ max predicted from the maximal speed achieved during the multistage test using the appropriate regression equation. Since the exercise and retroextrapolated $\dot{V}O_2$ max are almost the same and since both values are based on the direct measurement of $\dot{V}O_2$, both methods will be classified as direct methods and compared to the predicted or indirect estimate for discussion purposes.

Validity Studies

In the first series of experiments, 13 males and 12 females (Table 1, Group I) randomly performed three maximal multistage tests: (1) an inclined walking treadmill test, (2) and (3) the experimental 20-m shuttle run test on rubber floor (Mondo Rubber or Sportflex type) and on vinyl-asbestos tiles (hard and low friction type of surface). The treadmill test was an adaptation of the Balke protocol (Pollock et al. 1976). Starting at 4.8 km · h^{-1} (3 mph) and 0% slope, the slope increased 2.5% every 2 min up to 20%; thereafter, the speed was increased by 0.4 km · h^{-1} (0.25 mph) every 2 min. In each of these tests, $\dot{V}O_2$ max was assessed by the retroextrapolation method. In addition, for the treadmill protocol $\dot{V}O_2$ max was also assessed during the last minute of exercise.

In the second series of experiments, 66 additional subjects performed the experimental 20-m shuttle run test once, mostly on vinyl-asbestos tiles, with $\dot{V}O_2$ max determination by the retroextrapolation method. These data were combined with the average value obtained by the 25 subjects of the first series of experiments while performing on both types of surfaces. The total sample was thus 91 subjects, 32 females and 59 males, whose physical characteristics are given in Table 1 (Group II).

In the third series of experiments, 35 males and 35 females (Table 1, Group III) performed the final version of the 20-m shuttle run test (Table 2) and a maximal multistage running track test (Léger and Boucher 1980). Only the predicted $\dot{V}O_2$ max scores were compared. Tests were performed in groups of 10–25 subjects at a time on a rubber floor.

Reproducibility Study

In the fourth series of experiments, 27 males and 23 females (Table 1, Group IV) twice performed the final version of the 20-m shuttle run test (Table 2) 1 week apart in groups of 10–25 subjects at a time on a rubber floor.

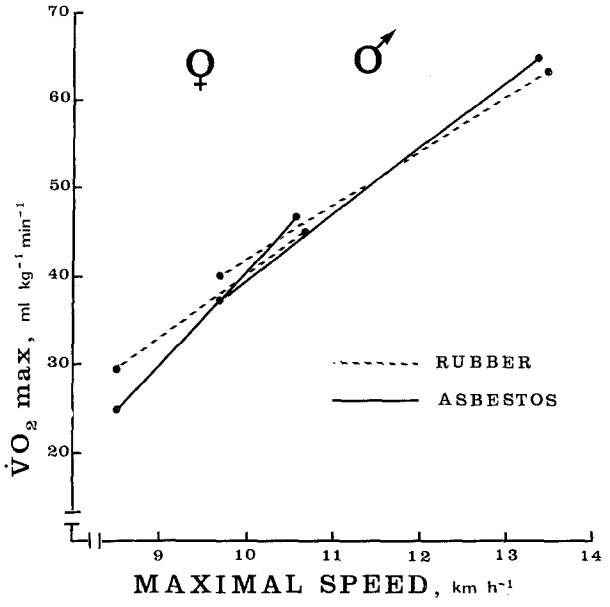

Fig. 1. $\dot{V}O_2$ max as a function of the maximal speed achieved in the 20-m shuttle run test. Comparison of the regression curves obtained on males (n = 13) and females (n = 12) while performing on two different surfaces: rubber or hard vinyl-asbestos tiles

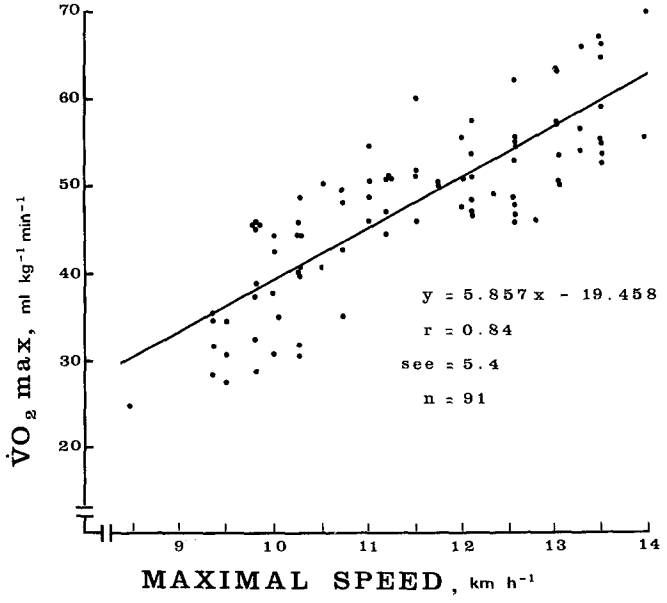

Fig. 2. $\dot{V}O_2$ max as a function of the maximal speed achieved in the 20-m shuttle run test for a total sample of 91 adult subjects. Each point in this figure represents maximal effort

Table 2. The maximal multistage 20-m shuttle run test for the prediction of the maximal aerobic power[a]

Stage Met	$\dot{V}O_2$ max ($ml \cdot kg \cdot min^{-1}$)	Time (min)	Speed ($km \cdot h^{-1}$)	Split time (s/20 m)[b]
7	24.5	2	7.51	9.693
9	31.5	4	8.70	8.276
10	35.0	6	9.30	7.744
11	38.5	8	9.90	7.276
12	42.0	10	10.49	6.862
13	45.5	12	11.09	6.492
14	49.0	14	11.69	6.160
15	52.5	16	12.29	5.860
16	56.0	18	12.88	5.589
17	59.5	20	13.48	5.341
18	63.0	22	14.08	5.114
19	66.5	24	14.68	4.906
20	70.0	26	15.27	4.714
21	73.5	28	15.87	4.537
22	77.0	30	16.47	4.372
23	80.5	32	17.07	4.219

[a] The protocol is based on the relation between the $\dot{V}O_2$ max (y, $ml \cdot kg^{-1} \cdot min^{-1}$) and the maximal speed achieved in the multistage 20-m run (x, $km \cdot h^{-1}$): $y = 5.857x - 19.458$, SEE = 5.4, $r = 0.84$, $n = 91$ adults

[b] Split times used to record audio signals on a magnetic tape. A precision of 0.01 s is necessary to discriminate consistently stage increments. The speed of the playback system is also crucial. It is suggested that a standard 60 s calibration period is recorded and checked before running the test: a ± 1 s error over 60 s corresponds to an average error of ± 2.5% in the $\dot{V}O_2$ max prediction, that is a half stage at high fitness level (20 Met)

Results

Retroextrapolated and Exercise $\dot{V}O_2$ max

Data on the 25 subjects who performed the modified Balke protocol indicated similar results ($r = 0.975$ and SEE = 3.3 ml $O_2 \cdot kg^{-1} \cdot min^{-1}$) for the retroextrapolated (42.78 ± 10.76) and the last minute of exercise $\dot{V}O_2$ max (42.65 ± 10.03).

Sex and Surface

Data from the first series of experiments revealed neither sex nor surface difference in the regression lines for $\dot{V}O_2$ max on the maximal speed achieved during the 20-m shuttle run test (Fig. 1). Combining males and females together ($n = 25$) revealed that the retroextrapolated $\dot{V}O_2$ max and the maximal speed (indirect score) achieved were similar on a rubber floor (45.0 ± 9.5 $ml \cdot kg^{-1} \cdot min^{-1}$ and 10.6 ± 1.1 $km \cdot h^{-1}$) and vinyl-asbestos floor (43.8 ± 9.4

$ml \cdot kg^{-1} \cdot min^{-1}$ and 10.6 ± 1.1 $km \cdot h^{-1}$) and resulted in correlation coefficients of 0.93 and 0.92.

Validity of the 20-m Shuttle Run Test for the Assessment of $\dot{V}O_2$ max

The second series of experiments on 91 subjects yielded the following regression equation for $\dot{V}O_2$ max (y, in $ml \cdot kg^{-1} \cdot min^{-1}$) on the maximal speed (x, in $km \cdot h^{-1}$) achieved during the 20-m shuttle run test:

$$y = 5.857x - 19.458 \quad (1)$$

with a correlation coefficient of 0.84 and a standard error of the estimate of 5.4 $ml \cdot kg^{-1} \cdot min^{-1}$ (Fig. 2). Equation (1) was later used to construct the final version of the 20-m protocol where the stages are increasing by one Met (resting metabolism = 3.5 $ml \cdot kg^{-1} \cdot min^{-1}$) at a time (Table 2).

The 20-m Shuttle Run Test Versus the Inclined Walking Treadmill Test

$\dot{V}O_2$ max measured directly during the last stage of the modified Balke protocol (42.65 ± 10.03) was similar ($r = 0.914$ and SEE = 4.16) to that measured by the retroextrapolation method at the end of the 20-m shuttle run test (43.9 ± 9.18). This is illustrated by the dotted line in Fig. 3. Similar results were obtained for the predicted or indirect values (full line in Fig. 3). Values predicted from the treadmill data (43.4 ± 8.22), using the ACSM standards (ACSM 1975) were similar ($r = 0.890$ and SEE = 3.83 ml $O_2 \cdot kg^{-1} \cdot min^{-1}$) to those predicted by equation (1) from the data of the 20-m shuttle run test (42.3 ± 5.84). The means of the two tests (direct or indirect) were not statistically different (paired *t*-test, $p > 0.05$) but the slopes of the regression curves (Fig. 3) indicate slightly lower results for the 20-m shuttle run test above the average and higher results below it.

The 20-m Shuttle Run Test Versus the Maximal Multistage Running Track Test

As compared to a maximal multistage running track test (Léger and Boucher 1980), the 20-m shuttle run test yielded significantly lower values ($\Delta = 2.8 \pm 2.9$ ml $O_2 \cdot kg^{-1} \cdot min^{-1}$, $p < 0.01$ for a paired *t*-test). The correlation was 0.923 and the standard error of the estimate, 2.63 ml $O_2 \cdot kg^{-1} \cdot min^{-1}$ (Fig. 4).

Reproducibility of the 20-m Shuttle Run Test

Test and retest one week apart (Fig. 5) indicated that the 20-m shuttle run test was highly reproducible ($r = 0.975$ and SEE = 2.00 ml $O_2 \cdot kg^{-1} \cdot min^{-1}$). However,

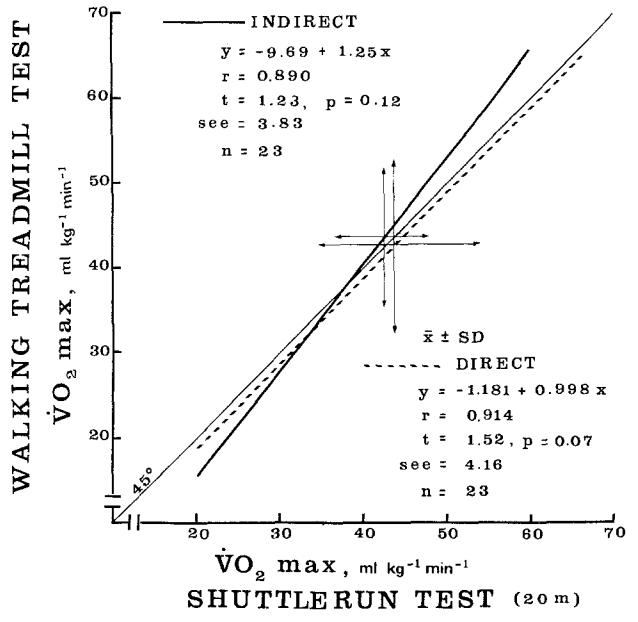

Fig. 3. $\dot{V}O_2$ max in the maximal multistage inclined treadmill test (modified Balke protocol) as a function of the $\dot{V}O_2$ max in the 20-m shuttle run test. The direct (exercise or retroextrapolated $\dot{V}O_2$ max) and indirect values (prediction from pre-established O_2 efficiency regression curves using the ACSM data (ACSM, 1975) and Eq. (1) for each test) are plotted

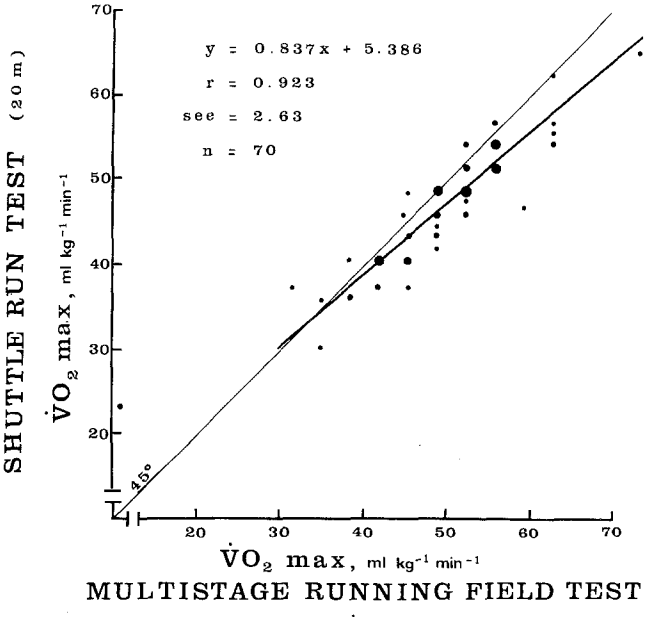

Fig. 4. Indirect $\dot{V}O_2$ max in the 20-m shuttle run test as a function of $\dot{V}O_2$ max estimated indirectly in the maximal multistage running track test (Léger and Boucher 1980). Means and standard deviations were respectively 47.4 ± 6.8 and 50.1 ± 7.5 ($p < 0.001$, $n = 70$). The size of data points indicates the number of subjects ($n = 1-6$) having the same coordinates

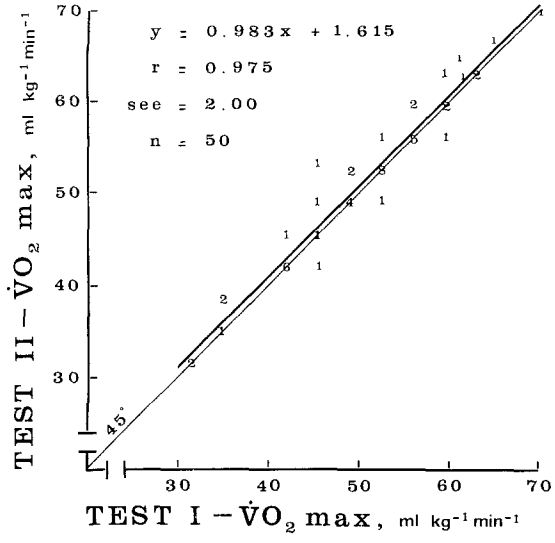

Fig. 5. Reproducibility of the 20-m shuttle run test. Means and standard deviations were 50.30 ± 8.93 and 51.05 ± 9.00 for the first and second trials ($p < 0.005$, $n = 60$). Numbers used as coordinates indicate the number of subjects having the same coordinates

the second trial yielded slightly but significantly higher values ($p < 0.05$) by 0.75 ml $O_2 \cdot kg^{-1} \cdot min^{-1}$ (1.5%).

Discussion

The Extrapolation Method

The fact that the retroextrapolated $\dot{V}O_2$ max was essentially the same as the exercise $\dot{V}O_2$ max for the 25 subjects who did the inclined walking treadmill test confirms the validity of the method, as previously reported by Léger et al. (1980), and justifies its use to validate the 20-m shuttle run test.

Sex and Surface Effects

Since there were no sex and surface differences (Fig. 1), a single protocol is appropriate for the 20-m shuttle run test. This is particularly useful in view of the various types of gymnasium surfaces. The studied surfaces were quite different and covered a wide range of hardness and friction. It may be useful to know that wooden floors have almost the same characteristics as vinyl-asbestos tiles. Thus the type of surface of most gymnasiums should not affect the results of this test. The absence of surface effect could be explained by the highest speeds achieved in the test. At 70 ml $O_2 \cdot kg^{-1} \cdot min^{-1}$, an adult individual is running the 20-m shuttle test at 15 km $\cdot$ h^{-1} (Table 2). This is not very fast if one is comparing it to the fast stop and go that prevails in a basketball game. In fact most adult subjects will not run much faster than 12 km $\cdot$ h^{-1} (i.e., $\dot{V}O_2$ max = 52 ml $\cdot kg^{-1} \cdot min^{-1}$) in this test.

Table 3. Validity of various maximal indirect tests to predict $\dot{V}O_2$ max

Test	Sex	Age	n	$\dot{V}O_2$ max ($ml \cdot kg^{-1} \cdot min^{-1}$)	Standard error of the estimate[b]		r[b]	References
					($ml \cdot kg^{-1} \cdot min^{-1}$)	(%)		
Individual treadmill tests								
Balke protocol	M	40.5	51	39.4	–	–	0.92	Pollock et al. 1976
	M+F	25	28	62.0	3.64	5.9	0.89	Léger and Boucher 1980
	M	20–53	708	37.1	4.41	11.9	0.69	Froelicher and Lancaster 1974
Bruce protocol	M+F	Adult	295	32.7[a]	3.45	10.5	0.91	Bruce et al. 1973
	M	40.5	51	40.0	–	–	0.88	Pollock et al. 1976
Ellestad protocol	M	40.5	51	40.7	–	–	0.90	Pollock et al. 1976
Group field tests								
Cooper 12-min run	M	22	115	38.1[a]	3.57[a]	9.4	0.90	Cooper 1968
	M	17–54	25	45	3.10	6.9	0.94	Wyndham et al. 1971
	M	12–16	9	–	–	–	0.90	Doolittle and Bigbee 1968
	M	16	40	50.3	3.87[a]	7.7	0.80	Massicotte 1972
	M	63	26	30	3.01	10.0	0.83	Sidney and Shephard 1977
	F	63	29	26	4.37	17.0	0.51	Sidney and Shephard 1977
	F	12–16	30	–	–	–	0.63	Martin 1971
UM-track test	M	24.4	25	61.5	2.81	4.6	0.96	Léger and Boucher 1980
20-m shuttle run	M+F	27.3	91	47.3	5.40	11.4	0.84	Present study

[a] Calculated from reported data

[b] Even though the validity indices are comparable, the regression coefficient might be quite different from one population to another. This is particularly true for subjects of various age performing the Cooper test

Validity of the 20-m Shuttle Run Test

The fact that there was no sex or surface difference explains why the data of the first series of experiments ($n = 25$) were combined with those of the second one to yield a total sample of 91 subjects in order to achieve a better accuracy in the regression curve. It was found that the maximal speed of the multistage 20-m shuttle run test could predict the maximal aerobic power with an r of 0.84 and a standard error of the estimate of 5.4 ml · kg^{-1} · min^{-1}, which is equal to 11.4% of the mean (Fig. 1). An analysis of the literature (Table 3) for maximal indirect tests indicates comparable results for individual treadmill tests and for group field tests such as the 12-min run test. Thus the main advantage of the 20-m shuttle run test is not so much its validity but the fact that it is a progressive multistage test that can be performed in groups. The user should know however that the individual error of these tests is quite large (10%) and researchers still have to improve their accuracy or design new, more accurate, ones. More specifically, the present study revealed that the 20-m shuttle run test yielded results similar to a conventional inclined treadmill test, whether direct or indirect $\dot{V}O_2$ max values were considered (Fig. 3). Comparing indirect values is important because this is the way the tests are usually performed (except for research). On the other hand, direct measurements show the $\dot{V}O_2$ max specificity: could the same $\dot{V}O_2$ max be achieved in running back and forth and in walking on an inclined treadmill? The present study does not indicate much difference between the two forms of activity. The 20-m shuttle run test offers the advantages of both requiring no sophisticated equipment and enabling the testing of many individuals at the same time.

As compared to a continuous running multistage track test ($r = 0.96$ and SEE = 2.8, Léger and Boucher 1980), the 20-m shuttle run test is slightly less valid ($r = 0.84$ and SEE = 5.4, Fig. 2). This might be explained by a larger interindividual variation in the mechanical efficiency of running back and forth. Although preferable, the track test requires better sporting facilities (an inside track with inclined turns or an outside track with a good sound system). While the present study indicated a high correlation between the shuttle test and the track test ($r = 0.92$ and SEE = 2.63, Fig. 4), there was a slight but significant difference in favor of the track test. This might be a real difference due to the more natural activity of track running or it might be a validity bias due to different samples of subjects. In any event, the difference (2.8 ± 2.9 ml · kg^{-1} · min^{-1}) is not physiologically very significant.

Reproducibility of the 20-m Shuttle Run Test

The present study revealed that the 20-m shuttle run test is very reproducible ($r = 0.975$ and SEE = 2.00 ml O_2 · kg^{-1} · min^{-1}, Fig. 5). There were however slightly higher results on the second trial. The difference (0.75 ml O_2 · kg^{-1} · min^{-1}) seems unimportant and might reflect a learning effect. This phenomenon was more obvious for the females ($p = 0.008$, $n = 23$) than for the males ($p = 0.115$, $n = 27$). In order to minimize the anaerobic contribution to

the test performance, only the completed stages are recorded, which explains why many subjects had the same coordinates for both trials (Fig. 5). In fact 68% of the subjects completed the same number of stages, 34% did one more and 6% one less. The reliability of the 20-m shuttle run test ($r = 0.975$) is at least equal to or even better than that of other field tests, with r values ranging from 0.72 to 0.97 (Doolittle and Bigbee 1968; Léger and Boucher 1980; Martin 1971; Massicotte 1972), or of direct multistage treadmill tests with r equal 0.99 (Bruce et al. 1963). For indirect multistage treadmill tests, Froelicher et al. (1974) reported a slight improvement from test to retest but gave no correlation coefficient between those.

It is concluded that a maximal multistage 20-m shuttle run test as described, with stages increasing by 1 Met every 2 min, appears valid and reliable in predicting the maximal aerobic power of both male and female adults, alone or in groups, on most types of gymnasium surfaces.

Addendum

A recent study has shown that the same multistage shuttle run test could be performed with 1-min stages instead of 2-min stages which save considerable administrative time and make it easier to motivate the subjects, particularly with children in schools. The correlation between the 1-min and 2-min protocols for 142 adults (72 women) aged 20–45 years old was 0.97 and regression between the two tests was $T_{1\text{-min}} = 0.4 + 1.2\ T_{2\text{-min}}$, T indicating the number of stages in each test. Reliability of the 1-min protocol was verified on 81 subjects (22 women): a correlation of 0.95 with less than 0.5 stage in favor of the retest.

A French report of this research is available from the Ministère du Loisir, de la Chasse et de la Pêche du Québec. Preliminary reports of this study were presented at the Canadian Association for Sports Sciences, Toronto, Oct. 1980 and at the Satellite Symposium of the International Congress of Physiology, Praha, July 1980.

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