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HISTORICAL PERSPECTIVE

A brief history of exercise clearance and prescription: 1.The era of heart rate recovery curves.

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Abstract

Objective: The aim of this 2-part article is to provide a brief chronicle of the development of exercise clearance and prescription procedures over the past century, with particular reference to Canadian innovations. Part 1 considers the era when any advice was based upon pulse rate recovery curves, with examples of specific approaches from Canada, the United States, Britain and France. Recent laboratory data are presented for one such test (that of Ruffier and Dickson), and these findings are compared with the response to a more modern field test of endurance performance, the 20-m shuttle run test. *Methods:* Volunteers for the empirical recovery tests were 12 moderately active male students recruited from the University of Amiens Faculty of Sports Sciences. Each subject performed a Ruffier-Dickson test on 2 days, followed on the second day by a 20-meter shuttle run (20-MSR). Parameters measured for the 20-MSR were the resting heart rate, the heart rate at the immediate end of the test, and the heart rate after 1 minute of recovery, with evaluation of the predicted maximal aerobic power ($\dot{V}O_{2max}$), the predicted maximal aerobic velocity (MAV) and recuperation indices based on application of the Ruffier-Dickson formulae. *Results:* The 20-MSR prediction of ($\dot{V}O_{2max}$ was much as in average young adults, with a value (mean ± SD) of 46.8 ± 3.5 $mL\cdot kg^{-1}\cdot min^{-1}$. Indices calculated for the two Ruffier tests showed day-to-day stability (Ir1 10.9 ± 2.5, Ir2 = 10.2 ± 3.3). However, based on published norms, the average scores suggested a relatively low level of physical fitness. A much higher recuperation index (IrN = 23.8 ± 4.1) was calculated for the shuttle run data than for the Ruffier tests. Corresponding indices obtained by applying the Ruffier-Dickson formulae were 11.1 ± 3.3, 11.7 ± 3.3 and 29.4 ± 4.1. The scores obtained in the duplicate Ruffier tests were fairly closely correlated with each other, with similar mean scores and no significant change in the ranking of subjects. Application of the Ruffier-Dickson formula also gave comparable scores on the two occasions. There were moderate correlations between the standard Ruffier test indices and 20-MSR shuttle run Ruffier indices (r = 0.63-0.65). However, the ranking of participants based on Ruffier test scores bore little relationship to a classification of aerobic fitness based upon 20-MSR predictions of $\dot{V}O_{2max}$. *Conclusions:* Although the heart rate recovery tests undertaken in the first half of the 20th century gave consistent day-to-day scores within a given laboratory, the values obtained depended heavily on test details such as posture when measuring heart rates and the timing and duration of pulse counts. Moreover, in the selected example (the Ruffier-Dickson test) the ranking of individuals bore little or no relationship to more modern measures of endurance fitness such as $\dot{V}O_{2max}$, or maximal aerobic velocity. Recovery test scores had an uncertain physiological basis; most indices probably reflected a combination of the immediate cardiac response to moderate exercise, achieved mainly by an increase of stroke volume in a fit individual, but by an increase of heart rate in those who are unfit, and the rate of recovery from this stress. However, the information was of limited help in terms of exercise clearance and the prescription of appropriate physical activity, pointing the need to develop reliable, objective and evidence-based procedures for this purpose. **Health & Fitness Journal of Canada 2014;7(1):26-35.**

Keywords: Exercise testing; Lactate; Oxygen debt; Recuperation; Ruffier test; Ruffier-Dickson test, 20-metre shuttle-run

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Introduction

The aim of this 2-part article is to provide a brief chronicle of the development of procedures for exercise clearance and prescription over the past century, with particular reference to Canadian contributions. Part 1 considers the era when simple fitness classifications were based upon heart rate recovery curve techniques, looking at early medical attitudes, the restricted role of physical educators and kinesiologists, and examples of test procedures from Canada, the United States, Britain and France. Recent laboratory data are provided for one such test (that of Ruffier and Dickson), and empirical findings using this test are compared with the response of a small group of subjects to a more modern field test of endurance performance, the 20-m shuttle run test. Part 2 of this article will trace the emergence of more modern, objective and evidence-based approaches, focussing specifically upon the PAR-Q clearance procedure and the Canadian Test of aerobic fitness (CAFT).

Early Medical Attitudes

During the first half of the 20th century, many Canadian physicians, like their European counterparts, remained strongly influenced by the thinking of John Hilton (1805-1879 CE). Hilton was an anatomist and surgeon at Guy's Hospital in London, and author of the text "Rest and Pain" (Hilton and Jacobson 1879). Based upon his teaching, prolonged bed rest was regarded as the panacae for most medical problems. If healthy individuals asked their physician about the wisdom of exercising, they were usually met by a cursory clinical examination, and the advice "don't overdo it." However, there were some exceptions to this negative attitude. We may note particularly the celebrated Canadian-born physician William Osler (1814-1919 CE), who became one of the founding professors at Johns Hopkins Hospital in Baltimore. He urged the "*quadrangle of health*:" rest, food, fresh air, and exercise. Moreover, he underlined the pedagogic and preventive values of moderate physical activity (Osler 1904):

"Within the past quarter of a century, the value of exercise in the education of the young has become recognized."

"the prophylactic value of exercise, taken in moderation by people of middle age, is very great"

Early Role of Physical Educators and Kinesiologists

The primary responsibility of many early North American physical educators was the success of their university football and hockey teams. When evaluating fitness they placed a heavy emphasis upon strength. Thus, the test proposed by Dudley Sargent (1849-1924 CE), 4-time president of the *American Physical Education Association,* was an index of explosive muscle force, based on the product of the individual's body mass and the height jumped when standing erect (Sargent 1921). If aerobic fitness was examined, the usual recourse was to test the recovery of pulse rate following a period of moderate sub-maximal exercise. The risks of exercise had yet to be clearly defined, and many physicians insisted that vigorous physical activity should not be undertaken unless they were present in the test facility. The logistics and expense of such a requirement precluded vigorous aerobic testing for many departments of physical education.

There was also difficulty in obtaining a stable ECG record during exercise. Moreover, physicians were reluctant to allow physical educators or kinesiologists access to any laboratory instrumentation such as an ECG that had diagnostic potential. The alternative was a pulse count, obtained by palpation of the wrist or the neck, something that was difficult to accomplish during exercise. Attention was thus focussed on pulse rate recovery curves following a period of moderate (and often quite brief) physical activity.

Interest in Heart Rate Recovery Curves

The speed of recovery of the pulse rate following a bout of exercise was soon accepted as an indicator of a person's cardio-respiratory fitness. Indeed, based on the observations of Hunt and Pembrey (1921), the British Medical Research Council concluded that the pulse recovery curve gave the best simple index of a person's general physical condition (Medical Research Council 1922). It was established that values measured during and 10-15 seconds immediately following exercise showed good agreement with each other (Cotton and Dill 1935), although if pulse counting was delayed for 30-60 seconds, a third of the information concerning the cardio-respiratory response to exercise response was lost (Ryhming 1954; Shephard 1967; Millahn and Helke 1968; McArdle et al. 1969). Nanas et al., (2001) argued further that the recovery of oxygen consumption following sub-maximal exercise was closely correlated with peak oxygen intake, thus allowing practitioners to use early recovery measurements in determining the suitability of patients for sports participation, in following the response to training and in monitoring over-training.

Interest in recovery curves as a method of aerobic fitness followed differing paths in Canada, the U.S., Britain and France.

Canada. Lucien Brouha (1899-1968 CE), a Belgian rowing star, became interested in work physiology after completing his medical training. He emigrated to North America, and became the first Director of the Montreal Fitness Research Unit when this was established in 1965. Depending upon the subject's age and body size, Brouha's fitness assessment required test candidates to engage in 4 or 5 minutes of climbing on a 16, 18 or 20 inch (0.406, 0.457 m or 0.508 m) platform, with counting of the heart rate 1.0-1.5, 2.0-2.5 and 3.0-3.5 minutes into the recovery period (Brouha, 1943; Gallagher and Brouha, 1943; Johnson et al., 1943). Fitness indices were calculated as (50 x test duration in seconds, divided by the sum of the 3 half-minute pulse counts), with scores ranging from <50 (very poor) to >90 (superb).

United States. In the U.S., one approach to fitness assessment was the Foster test. This required subjects to run on the spot for 15 seconds at a pace of 180 steps/min (Foster 1914). The procedure was used extensively in school health examinations, but the exercise was probably too short to provide useful data on a pupil's cardiac health. One trial noted a correlation as low as -0.14 between a cardiac efficiency score derived from this test and the classroom teacher's rating of the pupil's physical efficiency (Bliss 1926). Other investigators used rather longer periods of stepping exercise, with bench heights varying from 0.33 m (Tuttle 1931) to 0.507 m (Brouha 1943). Tuttle and associates (Schroeder and Tuttle, 1931;

Tuttle, 1931) based their assessments on the ratio of the pulse rate observed following 2 minutes of exercise to resting values.

Another method of cardiac evaluation that became popular in the United States was devised by Master (1968, 1969). In the Master test, subjects climbed up and down a double flight of 0.23 m steps for 90 seconds (a "single" test) or for 3 minutes (a "double" test) at a rate adjusted somewhat for age and body mass. Typically, the subject reached a heart rate of about 120 beats·min^{-1} at the conclusion of the test. Physical fitness was originally judged from the heart rate recovery curve, but more recently, the focus shifted to vulnerability to a future heart attack, as inferred from changes in the ECG waveform seen during the recovery period.

Great Britain. Marcus Pembrey (1868-1934) conducted much of his research at Guy's Hospital, in central London, but it was while with the British army that he became interested in the measurement of physical fitness by step testing (Hunt and Pembrey, 1921). He, also, interpreted physical fitness in terms of a a pulse ratio; this was calculated from the pulse rate during the first 2 minutes following a step test, divided by the resting pulse rate recorded over one minute.

France. In France, the "cardiac resistance" test of Ruffier enjoyed a long period of popularity among both kinesiologists and sports physicians. The test was originally developed by Jean-Edouard Ruffier (1874-1964 CE), but the method of scoring was modified slightly by J. Dickson (1950). Ruffier indices were sometimes based upon pulse counts following a step or cycle ergometer test (Brauer, 1981), but more commonly measurements were made immediately following 30 full knee-bends completed in 45 s, and after one minute of supine recovery. Dickson (1950) considered the procedure an ideal test for the sports physician. He claimed that it was simple to perform, and if it was undertaken with rigorous attention to detail it gave very reproducible results. More recently, use of the test has continued with authors such as Levavasseur (2000), Rodriguez Mendez and Molina (2001), Monod and Flandrois (2007), and Bacquaert (2010).

Empirical Evaluation of the Ruffier Test

To gain insight into the meaning of these early screening tests, the scores obtained by the Ruffier formula were compared with the results obtained by a more current field assessment of aerobic fitness, the 20 m shuttle run prediction of maximal aerobic power ($\dot{V}O_{2max}$; Léger et al., 1988; Cazorla, 1992) in a small sample of healthy young men.

Participants. Twelve male volunteers were recruited from the Faculty of Sports Sciences at the University of Picardie-Jules Verne in Amiens, in accordance with a protocol approved by the human experimentation committee at that university. Subjects were informed of the date, place and conduct of the protocol before giving their written agreement to the performance of a 20-meter shuttle run and two Ruffier tests. They were aged (mean ± SD) 21.5 ± 1.9 yr, with an average height of 1.84 ± 0.08 m and a body mass of 74.3 ± 11.6 kg. Their average $\dot{V}O_{2max}$ as predicted from the shuttle run data, was 46.8 ± 3.5 mL·kg^{-1}·min^{-1}, and their predicted maximal aerobic velocity was 12.4 ± 0.6 km·hr^{-1}.

All tests were performed in the gymnasium, under comparable environmental conditions. The subjects wore shorts or a tracksuit and tennis shoes, and exercised on a floor with a smooth surface. At the first laboratory visit, anthropometric data were obtained, and the first Ruffier test was performed. At the second visit, a day later, a second Ruffier test and a 20-m shuttle run were completed. Heart rates were monitored throughout using the *XTrainer Polar Plus* (Polar Electro France, Bassussary, France).

20-m Shuttle Run. The seated heart rate was first recorded after 3 minutes of rest. The subjects then ran between 2 lines set 20 m apart, paced by an audible signal (Léger and Boucher, 1980). The initial pace of 8.5 $km \cdot hr^{-1}$ was increased each minute by 0.5 $km \cdot hr^{-1}$ until participants fell 3 m short of covering the 20 m distance in the allotted time (Léger et al., 1984). The heart rate at this point was used in the calculation of the Ruffier recovery indices for the shuttle run.

The maximum aerobic velocity (MAV) was determined as proposed by Kuipers et al. (1985):

$$\text{MAV } (km \cdot hr^{-1}) = 0.5\ V + (n/60)$$

where V is the velocity reached during the final test stage, 0.5 is the increase in speed per stage (in $km \cdot hr^{-1}$), and n is the number of seconds during which the final velocity was maintained.

The maximal aerobic power was estimated using the equation of Léger et al. (1988):

$$\dot{V}O_{2max}\ (mL \cdot kg^{-1} \cdot min^{-1}) = 6\ \text{MAV} - 27.4$$

Ruffier Test. The Ruffier test was conducted as described by Monod et al. (2007). Subjects completed 30 full knee-bend curls over 45 seconds, paced by a beeper, with the feet placed flat on the floor and the trunk held erect. Instantaneous heart rates were recorded by Polar monitor after 3 minutes of seated rest (P_0), standing at the immediate end of the test (P_1) and after one minute of seated recovery (P_2. The Ruffier index was calculated as:

$$\text{Index} = [(P_0 + P_1 + P_2) - 200]/10$$

The number 200 was introduced into the formula as representing approximately three times the resting heart rate. Thus, the difference $(P_0 + P_1 + P_2) - 200$ corresponded roughly to the sum of pulse rates above the resting level during the first two minutes of recovery. Potential scores on the Ruffier test have been reported as ranging from 0 or less in a well-trained athlete through 5-10 (an average performance) to 15 or more (in an individual requiring further medical examination) (Table 1). Some people using the test have also drawn an adverse inference about an individual's fitness if P_1 was more than twice P_0 or if P_2 differed from P_0 by more than 10 $beats \cdot min^{-1}$.

The Ruffier-Dickson Index, intended to minimize the effects of emotional reactions at rest, was calculated as:

$$\text{Index} = [(P_1 - 70 + 2\ (P_2 - P_0])/10$$

with expected scores ranging from 0 or less in very fit individuals to >10 in those who were unfit.

Statistical Analyses

All of the empirical data were analyzed using Excel software, with statistical significance set at $p< 0.05$ throughout. Data were expressed as means ± standard deviations. Recovery indices for the 2 Ruffier tests (Ir1, and Ir2) and the 20-m shuttle run (IrN) were compared using repeated measures ANOVA, and a partial correlation matrix examined relationships between the 3 indices.

Results. The Ruffier test scores seemed stable in our group of subjects, with no significant difference between mean values derived from the first (Ir1) and second (Ir2) tests. Both values indicated a fairly low level of fitness relative to published norms, with respective means of 10.9 ± 2.5 and 10.2 ± 3.3 ($p = 0.31$). The rankings of individual subjects did not differ significantly between the two tests (Ir1 vs. Ir2, $p = 0.341$).

Likewise, there was no significant difference between the two Ruffier-Dickson indices (IRD1, IRD2); both tests again indicated that our group of subjects had only moderate fitness, with respective mean scores of 11.2 ± 3.3 and 11.8 ± 3.3 ($p = 0.32$). Subject rankings again did not differ between the 2 Ruffier-Dickson tests (Ird1 vs. Ird2, $p = 0.344$).

The shuttle run brought subjects to maximal effort, with no significant difference between heart rate readings at the end of the shuttle run (196 ± 3.9 beats.min^{-1}) and the individuals' theoretical maximal heart rates (198 ± 1.9 beats·min^{-1}) calculated according to the formula [220 - age (yr)] (Åstrand et al., 2003). Ruffier indices (23.8 ± 4.0) and Ruffier-Dickson indices (29.4 ± 4.1) derived from the shuttle run data were much larger than values for either the standard Ruffier or the standard Ruffier-Dickson tests ($p <0.0001$).

Scores for the two Ruffier tests were fairly closely correlated with each other (Ir1 and Ir2, $y = 1.05 x – 1.24$; $r = 0.789$). However, the coefficient of correlation between either Ir1 or Ir2 and IrN was more modest ($y = 0.70x - 6.51$, $r = 0.65$; $y = 0.51x -1.37$, $r = 0.63$). Moreover, when subjects were ranked in terms of their predicted $\dot{V}O_{2max}$, these rankings bore little relationship to the scores yielded by the Ruffier and Ruffier-Dickson formulae (Table 2).

Table 1: Potential scores on the Ruffier and Ruffier-Dickson indices, if values P_0 and P_2 are obtained with the subject lying recumbent.

Classification	Ruffier Index	Ruffier-Dickson Index
Endurance athletes	< 0	<0
Excellent or Good Aerobic fitness	0.1 to 5	0.1 to 4.0
Average fitness	5.1 to 10	4.1-6.0
Poor fitness	10.1 to 15	6 to 8
Very poor or medical issues	15.1 to 20	> 8

Discussion

The main finding from the empirical data was that the information obtained from a manipulation of recovery pulse rates bear little relationship to the scores obtained from a current and well-accepted method of screening for aerobic fitness, the $\dot{V}O_{2max}$, as predicted from a 20-m shuttle-run. Physiological factors influencing the form of the heart rate recovery curve are unclear; however, the data probably reflect a variety of processes, including feed-forward

Table 2: Ranking of subjects in terms of predicted maximal aerobic power (mL·kg^{-1}·min^{-1}). Note that none of the Ruffier indices conformed to the ranking of aerobic fitness obtained from the shuttle-run data.

Predicted Maximal Aerobic Power	Ir1	Ird1	IrN	IrdN
42.3	11.1	10.9	26.9	33.2
42.3	11.7	13	20.3	25.5
43.1	9.3	11.9	21.5	29.3
43.1	6.7	10.5	20.7	26.5
44.6	9.7	11.2	24.5	31.4
46.8	10.5	5.4	25.2	30.1
49.1	10.2	11.9	25.8	30.2
49.1	11.3	14.4	23.3	22.6
49.1	6.0	6.7	22.7	26.5
50.6	5.0	7.4	20.9	26.8
50.6	13.9	16.6	22.9	33.5
51.3	16.7	13.6	30.7	37.1

stimulation of the heart from the cortex, reflex stimulation from presso-receptors and chemoreceptors, a removal of lactate from the working muscles, the replenishment of local phosphagen stores, and more long-term effects from an increase of body temperature and the release of catecholamines (Shephard, 1967; 1982). The relative magnitude of these influences depends on the intensity and duration of the preceding bout of physical activity relative to the individual's physical fitness. Both the intensity and duration of effort were plainly greater in the 20-m shuttle run than in the Ruffier test, and it is thus not surprising that recovery indices calculated for 20-MSR were substantially greater than those seen with the standard Ruffier and Ruffier-Dickson tests. Although the rate of energy expenditure in a standard Ruffier test is sometimes fairly high, the duration of effort is sufficiently short that there is little call upon anaerobic metabolism. The score for a standard Ruffier test probably reflects largely recovery from the increase of cardiac output at the onset of the test exercise. In the fit athlete, the cardiac output is increased mainly by a greater stroke volume, giving a low Ruffier index; on the other hand, in an unfit individual, most of the increase in blood flow is brought about by an increase of heart rate (thus giving a larger index). However, interpretation of the recovery index remains far from clear; if the Ruffier score depends mainly upon the stroke volume reached during exercise, one might have anticipated a close inverse relationship between this score and the individual's $\dot{V}O_{2max}$ intake, which is also strongly dependent upon peak stroke volume. Possibly, the relationship with maximal stroke volume that should have been apparent in the immédiate post-exercise data was obscured by inter-subject differences in the rate of recovery as reflected in the P2 score for the Ruffier test.

The shuttle run is a very demanding test, providing estimates of $\dot{V}O_{2max}$ that are closely correlated with the individual's performance in 1500 and

3000 m runs (r = 0.90), and with direct laboratory estimates of $\dot{V}O_{2max}$ (r = 0.87 and 0.57 in 2 reports; Ahmaidi et al., 1999; Lacour et al., 1989). The ability to recover following a shuttle-run test is not usually evaluated by the Ruffier formulae; however, this may offer a simple method of examining responses otherwise explored by looking at lactate recovery curves (Ahmaidi et al., 1996; Freund et al., 1990, 1992; Oyono-Enguelle et al., 1993), as when evaluating cardiac function following cardiac transplantation (Lampert et al., 1996). The potential of interpreting 20-MSR data in this way merits future exploration.

The other feature of the pulse rate recovery curve highlighted by our empirical data is the importance of details of technique to the score obtained. The figures that we observed on the Ruffier test would have been regarded as disappointing in terms of athletic selection (Table 1). Two possible factors increasing Ruffier scores for pour subjects were that P_0 and P_2 were measured in the seated rather than in the supine position (the latter being adopted by many users of the Ruffier test), and in our empirical study instantaneous heart rate counting by pulse monitor began immediately after exercise. These issues emphasize the difficulties in comparing recovery scores from one laboratory to another. A third possibility is that the subjects that we studied were not, in fact, very fit. The average $\dot{V}O_{2max}$ of our subjects as predicted by the shuttle run data (46.8 ± 3.5 $mL \cdot kg^{-1} \cdot min^{-1}$) was typical of moderately well-conditioned young adults in the general population, but would be considered low for a group of endurance athletes. Measurements were made on first year students who had only recently enrolled in university, and they had not yet undertaken any serious training. In Toronto, our average figure for non-smoking male physical education students was of a similar order, averaging 49.0 $mL \cdot kg^{-1} \cdot min^{-1}$ (Shephard and Pimm, 1975). Presumably, the fairly low numbers reflect university training schedules that are only moderately rigorous, and the absence of that genetic selection one would expect in in top athletes.

Conclusions

During the first half of the 20th century, physicians made little attempt to encourage physical activity in the general population, and reliable objective procedures for screening and exercise prescription were lacking. Any testing of aerobic fitness was undertaken by physical educators, and was based largely upon various methods of analyzing pulse-rate recovery curves. Our empirical data for one recovery procedure (the Ruffier test) show that the scores obtained by a given observer were consistent from day-to-day, but (probably because of inter-laboratory differences in technique) average values for a group of healthy subjects could deviate quite widely from anticipated norms. Moreover, in our study, the ranking of aerobic fitness obtained from pulse recovery data bore little relationship to that provided by a more modern field test of aerobic fitness (the 20-m shuttle-run). The physiological basis of the heart rate recovery curve following a bout of physical activity is complex, and the practical significance of recovery curves in terms of exercise screening and prescription is unclear. Physical educators and kinesiologists thus entered the second half of the 20th century using fallible tools, and badly in need of a reliable, objective and evidence-based screening procedure that would enable them to recommend safe, appropriate and effective doses of physical activity for a population that was rapidly becoming more sedentary.

Authors' Qualifications

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