

A Model of Dickson Index Corrected for Pupils¹

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Abstract

Ruffier – Dickson test is a popular method in school physical education because of a simple procedure and apparatuses, good reliability and validity in evaluation of physical capacity. It is well-known in sports and physical rehabilitation too. The aim of the research is to prepare a model of Dickson index, which should be suitable for school physical education. Two ways to reach this purpose, taking into account a normal heart rate in rest corresponding to pupil's age (70–102 min⁻¹), are proposed. They are a model of correction of Dickson index formula and a model of correction of assessment gradations. A ratio of a normal heart rate in rest of school age pupils and adults should be accepted as a parameter of correction of Dickson index formula. Three measures of heart rate values in Ruffier – Dickson test should be reduced proportionally to this ratio. Application of the corrected formula results in a statistically significant improvement in assessment of young patients' cardiovascular system state ($p < 0.01$). The results of modeling are presented in simple tabular and graphical forms that are suitable for humanists who are unready to use mathematical methods.

Keywords: pupils, cardiovascular system, physical capacity, Dickson index

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Introduction

Ruffier – Dickson test is associated with beginners of sport medicine in the middle of the twenty century (Dickson, 1950; Ruffier, 1951). The test is a popular method in school physical education because of a simple procedure and apparatuses, good reliability and validity in evaluation of physical capacity (Bytniewski & Danielewicz, 2008; Nowak & Pokusa-Zep, 2012). It is well-known in sports (Cisse et al., 2006) and physical rehabilitation (Bruneau et al., 2009) too.

There are two indexes associated with the test. A formula of Dickson index is:

$$I_D = \frac{P_1 - 70 + 2(P_2 - P_0)}{10}, \quad (1)$$

where P_0 is resting heart rate per minute, P_1 is pulse measured during a minute just after the end of the effort (30 squats during 45 s), P_2 is pulse rate measured during a second minute after the end of the effort, $70 \text{ (min}^{-1}\text{)}$ is a normal heart rate in rest.

Seven levels of physical capacity according to the magnitude of Dickson index are introduced. Five of them which are named as ‘very good’, ‘good’, ‘average’, ‘passable’, and ‘bad’ are in the range of index values between zero and ten ($I_D = 0 \div 2 \div 4 \div 6 \div 8 \div 10$). When $I_D < 0$, a physical capacity is evaluated as ‘excellent’ and when $I_D > 10$ – as ‘very bad’.

Basically, Dickson index is rather similar to Ruffier index that is calculated using a formula:

$$I_R = \frac{P_0 + P_1 + P_2 - 200}{10}. \quad (2)$$

However, Ruffier index is more sensitive to variation of a pulse rate than Dickson index (Figure 1).

Several methods of adaptation of Ruffier index for health status assessment of young patients have been proposed (Gerald, 2001; Guseva et al., 2005; Zanevskyy, 2011; Dykhan & Ivanova, 2014). In one of these methods, a value of the Ruffier index was corrected and in another method, a scale of assessment was corrected. A normal value of the heart rate in rest was accepted as a parameter of correction in both models. In general, the proposed model of correction of the test assessment coursed a statistically significant ($p < 0.001$) difference with a corresponding result determined according to the original model (Zanevskyy, 2012).

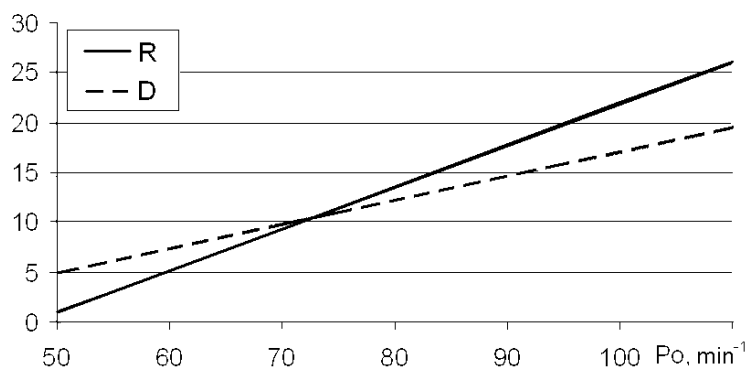


Figure 1. Ruffier (R) and Dickson (D) indexes when $P_1 = 2P_0$, $P_2 = 1.2P_0$.

The aim of this research was to develop a model of Dickson index, which should be suitable for school physical education.

Methods

Pupils' results of the Ruffier – Dickson test were retrieved as internet data in official websites. Mathematical modeling and computer simulation were used in the research. Inter- and extrapolations of the assessment scales based on Dickson index were used. Calculations were done using MS Excel and Statistica computer programs. In the models of pupils' health assessment a normal distribution was employed and Excel functions NORMSDIST and NORMINV were used. Pearson chi-square test was applied and Excel function CHIDIST was used in the analysis of the statistical hypotheses about an existence of a common general totality regarding two samples determined according to the models of pupil's distribution in levels of health and in groups of physical education lessons.

Results

Because a mean value of a normal heart rate in rest for adults equals 70 min^{-1} , theoretically a minimal value of the index is zero when pulse does not increase under the physical effort ($P_1 = P_2 = P_0$). A formula (1) could be rewritten as below:

$$I_D = \frac{S - 70}{10}, \quad (3)$$

where $S = P_1 + 2(P_2 - P_0)$.

When $I_D > 10$ physical capacity is considered as 'very bad', then parameter of heart rate is $S = 170$. Its bottom value equals to a normal heart rate in rest ($S = 70$) theoretically takes place when $I_D > 10$. Therefore, in a common range of heart rates the parameter S is not greater of a normal heart rate in rest more than two and a half times ($170/70 \approx 2.43$).

A normal heart rate of pupils is smaller than heart rate of adults (Fleming et al., 2011). For example, for six years old patients, it is equal to 102 min^{-1} . Theoretically parameter S for this age equals 102, i.e. it is equal to the heart rate at rest. A top magnitude of this parameter when physical capacity could be evaluated as 'bad' equals 248 (102×2.43). Then, corresponding values of Dickson index is situated between 3.2 and 17.8, when the top value is rather greater corresponding to the original scale of the index. Therefore, an age correction parameter of the Dickson formula (1) was derived as followed:

$$k = \frac{P_0^a}{P_0^p}, \quad (4)$$

where P_0^a and P_0^p are normal heart rates at rest for adults (a) and for younger patients (p) respectively (Sanduracci & Bono, 1966).

An analysis of Ruffier index validity regarding the evaluation of physical capacity in children showed that values of two measurements after a physical effort should be reduced k (4) times. Corresponding to this correction, Dickson index formula was derived as follows:

$$I_D^k = \frac{[P_1 + 2(P_2 - P_0)] \frac{P_0^a}{P_0^p} - 70}{10}. \quad (5)$$

Taking into account a normal heart rate value in rest of adults ($P_0^a = 70 \text{ min}^{-1}$), the formula was transformed to the form as below:

$$I_D^k = 7 \left[\frac{P_1 + 2(P_2 - P_0)}{P_0^p} - 1 \right]. \quad (6)$$

In another way, Dickson index formula was derived into the shape:

$$I_D^k = kI_D^a - 7(1-k). \quad (7)$$

Corresponding values of Dickson index vs. test results relatively patient's age are presented as graphs (Figure 2). At the same heart rate, index is smaller when a patient is younger. For example, when $S = 170$, a sixteen years old patient gets $I_D^k = 10$ and a six years old – $I_D^k = 4.7$. When $S = 247$, a sixteen years old patient gets $I_D^k < 10$ that is equal to a passable physical capacity, but a sixteen years old – $I_D^k = 17.7$ – very bad.

With the aim to define borders between levels of physical capacity, equations of the Dickson index (3) were presented in the shape as below correspondingly for adults and younger patients:

$$I_D^a = \frac{S^a - 70}{10}; \quad I_D^p = \frac{S^p - 70}{10}. \quad (8)$$

Taking into account the correlation $\frac{P_0^a}{P_0^p} = \frac{S^a}{S^p}$ (Zanevskyy et al., 2017) and equation (3), a formula for calculation of these borders was derived as:

$$I_D^a = \frac{I_D^p + 7(1-k)}{k}. \quad (9)$$

Corresponding results in a graph form were obtained for the range significant in the practice of physical education (Table 1). For example, when the index equals 9, physical capacity of six years old patient is evaluated as 'good'; seven, eight, and nine years old – as 'average'; ten, eleven, twelve, and thirteen years old – as 'passable'; fourteen, fifteen, and sixteen years old – as 'bad' (Figure 3).

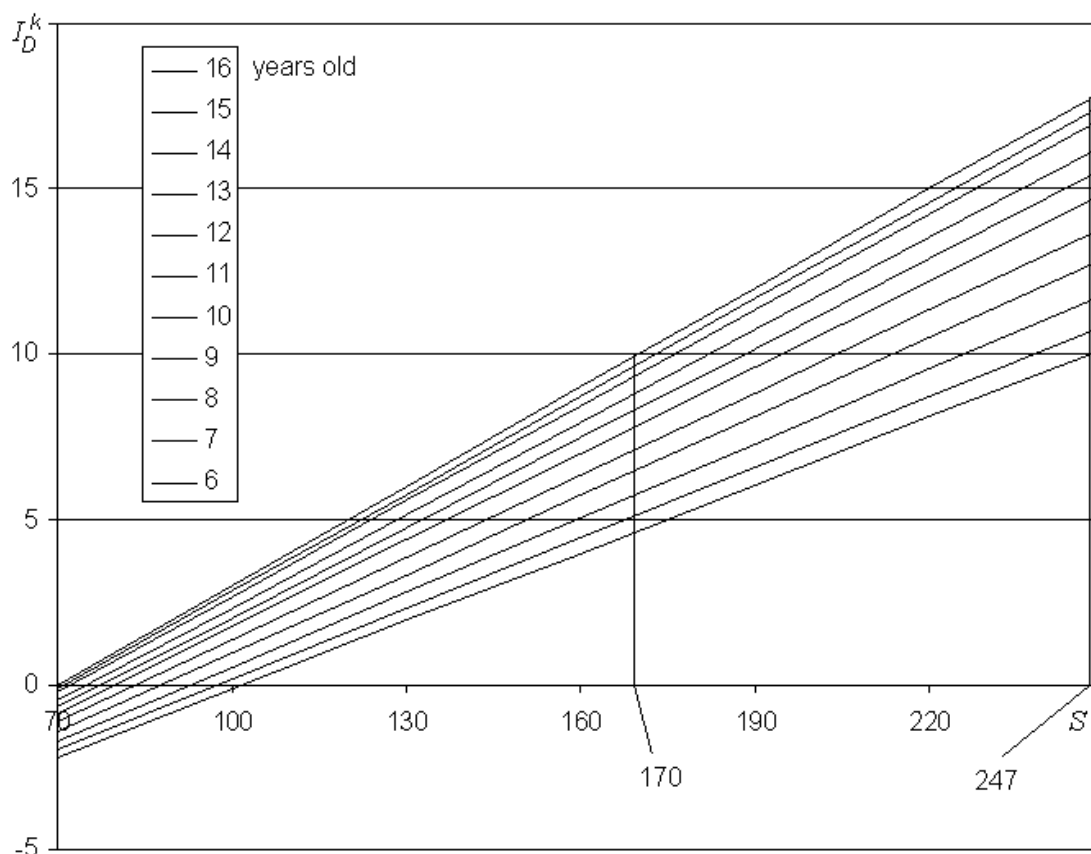


Figure 2. Dickson index vs. test results relatively patient’s age

Table 1. Dickson index values corrected to the age

Years old	I_D^a									
	0	2	4	6	8	10	12	14	16	18
6	-2.2	-0.8	0.5	1.9	3.3	4.7	6.0	7.4	8.8	10.2
7	-2.0	-0.6	0.9	2.3	3.7	5.1	6.6	8.0	9.4	10.9
8	-1.7	-0.2	1.3	2.8	4.3	5.8	7.3	8.8	10.3	11.8
9	-1.4	0.2	1.8	3.3	4.9	6.5	8.1	9.7	11.3	12.9
10	-1.2	0.5	2.2	3.8	5.5	7.2	8.8	10.5	12.2	13.8
11	-0.9	0.9	2.6	4.4	6.1	7.9	9.6	11.4	13.1	14.9
12	-0.7	1.1	2.9	4.7	6.5	8.4	10.2	12.0	13.8	15.6
13	-0.5	1.4	3.3	5.1	7.0	8.9	10.7	12.6	14.5	16.3
14	-0.2	1.7	3.6	5.6	7.5	9.4	11.3	13.3	15.2	17.1
15	-0.1	1.8	3.8	5.8	7.7	9.7	11.7	13.6	15.6	17.6
16	0.0	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0

Discussion

Evaluation of significantly of Dickson index correction was done in two ways: regarding a value of the index and regarding a scale of heart capacity. The first problem was studied using hypothesis regarding normal distribution of index data. It was assumed that index values from the five inner intervals (from second to sixth) are in the interval of “three sigma”: $\mu \pm 3\sigma$. According to this hypothesis, statistical parameters of index distribution for each age group were calculated with the formulas as follow:

$$\sigma_I^k = \frac{I_{6-7}^k - I_{1-2}^k}{6}, \quad (10)$$

where μ_I^k are arithmetic means; σ_I^k – standard deviations.

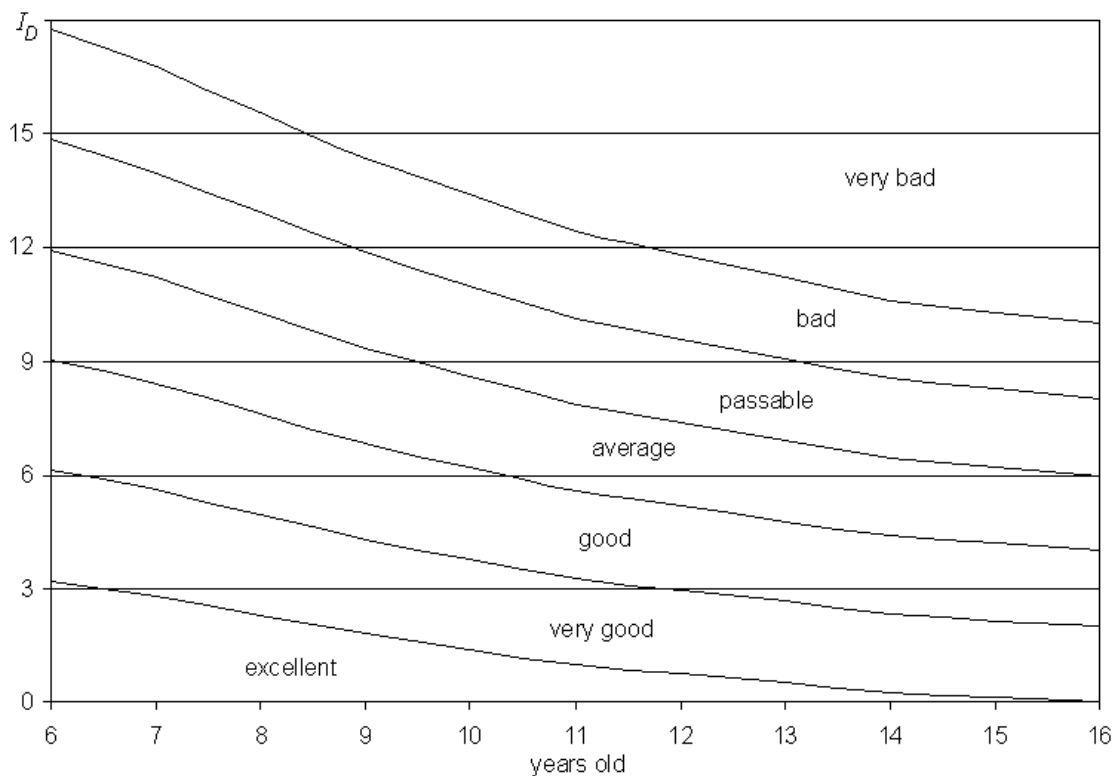


Figure 3. Physical capacity levels relatively Dickson index

Normalized difference between means of the index for adults and young patients was determined by the formula:

$$u_I^k = \frac{|\mu_I^k - 5|}{\sqrt{(\sigma_I^k)^2 + 1.67^2}}, \quad (11)$$

A significant level (p) of the difference was assumed as a quantitative measure of the error determined by the age specificity of cardio-vascular system of children and adolescents when the original formula of Dickson index (1) was used. Corresponding results are presented in Table 2. Zero hypothesis regarding a statistical equal to Dickson index means of seven years old patients was rejected on the significant level $p < 0.05$, and six years old – $p < 0.04$. A normalized distance between top and bottom borders of the index for sixteen years old patients (as well, as for adults when it equals 10) and mean value of the younger age group was determined with the equation:

$$Z_i^k = \frac{10 - \mu_i^k}{\sigma_i^k}. \quad (12)$$

Table 2. Significance of Dickson index correction

Years old	μ_i^k	σ_i^k	u_i^k	p
6	10.49	2.43	1.862	0.031
7	9.80	2.33	1.674	0.047
8	8.94	2.21	1.423	0.077
9	8.09	2.10	1.153	0.125
10	7.40	2.00	0.922	0.178
11	6.71	1.90	0.677	0.249
12	6.29	1.85	0.517	0.303
13	5.86	1.79	0.351	0.363
14	5.43	1.73	0.179	0.429
15	5.21	1.70	0.090	0.464
16	5.00	1.67	0.000	0.500

A part of a total number of patients calculated with the original formula of Dickson index (1), when $I_D \leq 10$ was determined using Laplace function of normal distribution:

$$F^k = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{Z_i^k} e^{-\frac{z^2}{2}} dz. \quad (13)$$

This relative number of patients of any age group was assumed as a quantitative measure of the error of the original Ruffier – Dickson test. A significant level of rejection of a zero hypothesis ($H_0 : F^k = 1$) was determined as chi-square parameter with one degree of freedom:

$$\chi^2 = 2n \frac{1 - F^k}{1 + F^k}, \quad (14)$$

where n is a number of patients. For the common town school in Ukraine, one can assume $n = 40$. Corresponding results are collected in Table 3.

Table 3. Correction of the evaluation scale

Years old	Z_i^k	F^k	χ^2	p
6	-0.20	0.421	32.62	0.000
7	0.09	0.534	24.29	0.000
8	0.48	0.683	15.04	0.000
9	0.91	0.820	7.93	0.005
10	1.30	0.903	4.07	0.044
11	1.73	0.958	1.73	0.189
12	2.01	0.978	0.89	0.345
13	2.32	0.990	0.41	0.523
14	2.65	0.996	0.16	0.687
15	2.82	0.998	0.10	0.757
16	3.00	1.000	0.00	1.000

These results ($F^k = 42.1 \div 99.8\%$) show a significant error in the scale of evaluation for the patients younger than 16 years old. There is statistically significant difference between mean values of index for patients younger than 10 years old ($p < 0.05$), for the patients of 9 years old – $p < 0.005$, and for the younger patients – $p < 0.001$.

A relative part of a total number of patients placed using Dickson index in the i^{th} level of the heart capacity was determined using Laplace function of normal distribution (11):

$$F_i^k = \frac{1}{\sqrt{2\pi}} \int_{(Z_i^k)_B}^{(Z_i^k)_T} e^{-\frac{z^2}{2}} dz, \quad (15)$$

where i is a number of the levels of heart capacity: 1 – excellent, 2 – very good, 3 – good, 4 – average, 5 – passable, 6 – bad, 7 – very bad; $(Z_i^k)_B$ and $(Z_i^k)_T$ are corresponding top and bottom borders of the i^{th} level, which were calculated like equation (10):

$$Z_i^k = \frac{b_i - \mu_I^k}{\sigma_I^k}, \quad (16)$$

where b_i are borders of the levels correspondence to the Dickson index values (for $i=1$ they are $-\infty$ and 0, for $i=2$ – 0 and 2, for $i=3$ – 2 and 4, for $i=4$ – 4 and 6, for $i=5$ – 6 and 8, for $i=6$ – 8 and 10, for $i=7$ – 0 and ∞ ? Results of calculations are collected in Table 4.

Table 4. Parameters of distribution of patients according to Dickson index

Years old	Levels of heart capacity							Total
	1*	2*	3*	4*	5*	6*	7*	
6	0.00	0.02	0.35	2.86	12.07	26.77	57.93	100%
	1				5	34		40
16	0.13	3.46	23.83	45.15	23.83	3.46	0.13	100%
	29				10	1		40
χ^2	26.5				2.4	733.9		762.8

*1 – excellent, 2 – very good, 3 – good, 4 – average, 5 – passable, 6 – bad, 7 – very bad

Because for the supple ($n = 40$) numbers of six years old patients with the first, second, and third (as well, as the seventh) levels of heart capacity are too small (smaller than one), these levels were united with the next levels (corresponding the fourth and sixth).

$$\chi^2 = n \sum_{j=1}^3 \frac{(F_j^{k=6} - F_j^{k=16})^2}{F_j^{k=16}}, \quad (17)$$

where $j = 1, 2, 3$ are numbers of the united groups, and $F_j^{k=16}$ are relative frequencies of six and sixteen years old pupils in the j^{th} interval. With degree of freedom equaled 2, significant level $p < 0.001$ good correlate with results presented in Table 4.

Comparison of original and corrected Dickson index borders was done taking into account a constant distribution of its values. Chi-square parameter was used. The graph evaluation scales of six and sixteen years old patients are presented in Figure 4. A zero statistical hypothesis about distribution of six and sixteen years old pupils regarding the levels of physical capacity was evaluated using Chi-square parameter as following:

$$\chi^2 = n \sum_{j=1}^7 \frac{(F_j^{k=6} - F_j^{k=16})^2}{F_j^{k=16}}, \quad (18)$$

where n is a number of pupils, j are numbers of intervals; $F_j^{k=6}$ and $F_j^{k=16}$ are relative frequencies of six and sixteen years old patients.

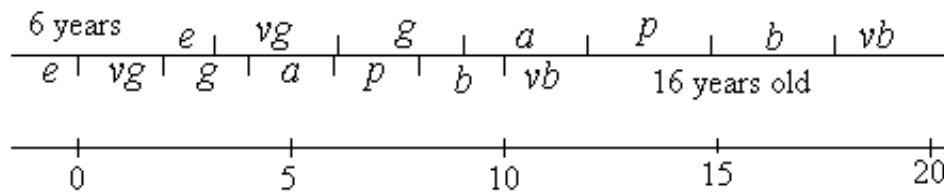


Figure 4. Dickson index values vs. levels of physical capacity: *e* – excellent, *vg* – very good, *g* – good, *a* – average, *p* – passable, *b* – bad, *vb* – very bad.

Regarding a common school, the number of pupils were estimated equal to 40. Application of the corrected formula resulted in a statistically significant improvement in assessment of pupils' cardiovascular system state ($p < 0.01$).

Conclusion

A ratio of a normal heart rate in rest of school-age patients and adults should be accepted as a parameter of correction of Dickson index formula. Three measures of heart rate values in Ruffier-Dickson test should be reduced proportionally to this ratio. It is recommended in the practice of physical education to use the original formula of Dickson index (1) and corrected borders between levels of physical capacity (Table 5).

Table 5. Age correction of Dickson index scale

Years old	Borders of the Dickson index values between the levels of health*					
	1 – 2	2 – 3	3 – 4	4 – 5	5 – 6	6 – 7
6	3.2	6.1	9.0	11.9	14.9	17.8
7	2.8	5.6	8.4	11.2	14.0	16.8
8	2.3	5.0	7.6	10.3	12.9	15.6
9	1.8	4.3	6.8	9.3	11.9	14.4
10	1.4	3.8	6.2	8.6	11.0	13.4
11	1.0	3.3	5.6	7.9	10.1	12.4
12	0.8	3.0	5.2	7.4	9.6	11.8
13	0.5	2.6	4.8	6.9	9.1	11.2
14	0.3	2.3	4.4	6.5	8.5	10.6
15	0.1	2.2	4.2	6.2	8.3	10.3
16	0.0	2.0	4.0	6.0	8.0	10.0

*Physical capacity levels: 1 – excellent, 2 – very good, 3 – good, 4 – average, 5 – passable, 6 – bad, 7 – very bad.

Conflict of Interest

The author has no conflicts of interest.

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