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A SWIM-TEST AND ECHOCARDIOGRAPHIC RESULTS ON MALE JUNIOR WATER POLO PLAYERS

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Abstract. *The purpose of this study was to evaluate the results of a swim-test which we repeatedly used for the assessment of the fitness level in Hungarian male junior water-polo players by relating the results to the players' echocardiographic parameters. It could be a point of interest if a relationship between the results of the swim-test and cardiac function were established.*
26 male junior elite and 11 Olympic champion water-polo players participated in the swim-tests and the echocardiographic measurements. 25 healthy men served as a non-athletic comparison group. The swim test included the time result of a 30 m maximal intensity swim (Tmax), the mean time of a 6×30 m interval swim (Tmean), the number of heart beats during the 4 minutes of recovery (P4) and the difference between the heart beats during the first and the second half min. of recovery (Delta). Morphological and functional parameters of the heart were measured by echocardiography. The observed variables were related to body size by indices in which the exponents of the numerator and the denominator were matched. The echocardiographic measurements showed clear signs of left ventricular hypertrophy in the water-polo players compared to the non-athletic group. Between the swim-test and the echocardiographic measurements no close correlations were found, though when we correlated the cardiac parameters with swimming velocity (instead of the time results of the swim-test) some correlations became stronger. The results suggest that there was no linear relationship between the swim-test and the cardiac parameters; however, a parallel adaptive improvement of the junior players to non-athletes could be noticed in both measurements as a result of regular training. It appears justifiable that associations should be sought above all in the pace of

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the respective improvements on a proportional basis. The current swim-test seems to be not precise enough to evaluate the cardiac function of the athletes. The methodological conception in relating a resting parameter (echocardiographic measurements) to maximal dynamic ones (swim-test) needs further investigation.

Key words: *water-polo, swim-test, athlete's heart, echocardiography, cardiac adaptation.*

1. Introduction

Water-polo has a long history in competitive sports as it was the first ball game ever introduced to the Olympic program (Findling, 1996). Through the evolution of the game rules water-polo has become faster and more dynamic, requiring better physiological adaptation. Similarly to other ball games, it is considered being a sport of intermittent effort and requiring a particular mixture of all factors of physical conditioning as well as numerous technical and tactical abilities. However, the special environment makes physiological adaptation to training and competition demands more difficult (Klissouras, 1997).

To assess the physiological demands of the water polo game is technically difficult. Aerobic endurance adaptation was measured by various ways. Pinnington et al. (1986) used heart rate measurements to estimate the metabolic demands of the game; Cazorla et al. (1998) measured metabolic and cardiopulmonary responses during maximal free-style swimming. Hohmann et al. (1992), Rodriquez et al. (1994), Avlonitou et al. (1991) used repeated swims of increasing velocity with continuous heart rate monitoring and lactate level measurements after the swim. The above measurements provide us with valuable information on the aerobic capacity of the water-polo players, but the use of these data for the study of the physiological demands of the game is limited. Due to the unfamiliar environment and the specificity of the game the attempts to measure the aerobic power of the water-polo players with ergometric tests (Dlin et al. 1984, cycle ergometer; Stromme et al. 1977 and Pavlik et al. 2001, treadmill running) were found to be unsuitable for validating the results in respect of individual game performance.

Since 1983 the fitness level of the Hungarian elite water-polo players has been estimated by a simple swim-test (Pavlik et al., 1991, 2001), designed to mimic a characteristic part of the game. Since the first measurement numerous tests have been performed (n=642), that allow comparisons between the various measurements.

In the literature we did not find any study in which a swimming or any other physical test had been related to the athletes' cardiac parameters. If such a relationship existed, we could use cardiac parameters in the selection of the athletes or make predictions for swimming performance. The main purpose of this study was to evaluate the swim-test repeatedly used for the assessment of the fitness level in the Hungarian elite water-polo players by relating its results to the players' echocardiographic parameters. Theoretically a better cardiac adaptation would become manifest in better swimming performance.

2. Methods

Subjects

Swim-test results and echocardiographic measurements of 26 male water-polo players of 17-18 years were collected and analyzed. All the subjects were elite water-polo players, members either of the Hungarian national team or of teams of the first division. The subjects attended a minimum of 12-14 h of training sessions weekly and had been training intensely for at least 6 years. 25 healthy men of the same age served as a non-athletic comparison group in the echocardiographic studies. To better evaluate the results of the junior water-polo players we compared the swim-test results and the echocardiographic measurements to the results and measurements of the 11 Olympic champions water-polo field players in the 2000 Sydney Olympic games. Table 1 shows the general data of the examined subjects.

Table 1. General data of the subjects

		Age (year)	Height (cm)	Weight (kg)	BSA (m²)
WPL	Mean	17.62	189.62	82.20	2.10
(n=26)	s.d.	0.49	6.31	10.05	0.14
NA	Mean	17.60	175.58	72.70	1.88
(n=25)	s.d.	0.50	6.13	10.72	0.14
OC	Mean	22.00	191.90	92.40	2.22
(n=11)	s.d.	1.67	5.99	6.87	0.10

Abbreviations:
BSA: Body Surface Area (Du Bois and Du Bois, 1915)
WPL: water-polo players, NA: non-athletic subjects, OC: Olympic champions in the Sydney 2000 Olympic games.

The swim-test

The swim-test consisted of two parts. First for the assessment of the individual swimming speed we measured the time results of a 30 m maximal intensity swim (Tmax). The distance corresponds exactly to the length of a water-polo court. Then, after a full recovery from the sprint swim, speed endurance was measured by calculating the mean time of a 6×30 m interval swim (Tmean), with a 15 s rest time between the bouts. Following the interval swim the total number of heart beats was recorded using 5 s intervals for four minutes (P_4). From the heart beat counts we also calculated the difference between the beats during the first and the second half-minutes of the recovery period (Delta).

The swim-test mainly represents two abilities: maximal speed as measured by the 30 m sprint swim and speed endurance as measured by the 6×30 m interval swim. The latter has been acknowledged as being the most dominant swimming element of the game (Rodriguez et al., 1994; Thoden et al., 1985). The total of heart beats during the four minutes of recovery shows the basic endurance adaptation and regulation of the athletes, the four-minute recovery period conforms to the total duration of the interval swims (3-3.5 min.). Lower values indicate better endurance ability. The difference of the beat counts between the first and the second half-minutes of the recovery is also an indicator of endurance capacity. After the interval swim heart rate decreases rapidly, however, the pace of this decrease is a key-element in the game. Quick recovery ability will mean a better adaptation and thus a better physical condition for a good game performance (Pavlik et al., 2001).

Echocardiography

Cardiac dimensions were measured in recumbent position always during the morning hours by a two dimensionally guided M-mode and Doppler Dornier AI 4800 echocardiograph, with a 2.5 MHz transducer. The measurements were carried out in accordance with the recommendations of the American Society of Echocardiography (Sahn et al.

1978). In all subjects we measured three to five cardiac cycles and then we calculated the means for the further analysis. All echocardiographic measurements were performed by the same observer.

Based on reports by several authors and on our own observations (George et al. 1999; Pavlik et al. 1996 and 2001) body size related indices were calculated by indices in which the exponents of the numerator and the denominator were matched. As linear measures wall thickness and internal diameter were therefore related to the square root of body surface area (BSA), while left ventricular muscle mass and volumes were related to the cube of the square root of BSA. Transmitral flow velocity was estimated by pulse wave Doppler measurements in the four chamber apical view. The measured variables and their calculation were as follows:

Morphological parameters

$LVWTd/BSA^{1/2}$ = body size related left ventricular wall thickness at end diastole (LVWTd = IVSTd + LVPWTd, where IVSTd = interventricular septum thickness at end diastole and LVPWTd = left ventricular posterior wall thickness at end diastole); $LVIDd/BSA^{1/2}$= body size related left ventricular internal diameter at end diastole; $LVMM/BSA^{3/2}$= body size related left ventricular muscle mass [LVMM = ($TEDD^3$-EDV)·1.053 where: TEDD = left ventricular diameter at end diastole (LVWTd+LVIDd), EDV = left ventricular volume at end diastole ($LVIDd^3$), 1.053 = density of the cardiac wall]; MQ = muscular quotient (LVWTd/LVIDd).

Functional and regulatory parameters

$SV/BSA^{3/2}$ = body size related stroke volume (SV = $LVIDd^3$-$LVIDs^3$); E/A = ratio of early to late diastolic filling; HR = heart rate; LVET/QT = ratio of the LV ejection time to the electric systole.

Statistical analysis

Results are shown as means and standard deviations. *t*-tests for independent data were used to establish the differences between the athletic, non-athletic groups and the Olympic champions. To establish the relationship between the swim-test results and the echocardiographic parameters we used Pearson's product-moment correlation. Differences and correlations at $p<0.05$ were regarded as significant.

3. RESULTS

Swim-test comparisons for all four components of the swim-test (Tmax, Tmean, P4, Delta) showed a strongly significant difference between the examined junior water-polo players and the Olympic champions. Swim-test results are shown in Table 2.

Signs of left ventricular hypertrophy were manifest in our study. Compared to the non-athletic group junior water-polo players had a significantly larger $LVWTd/BSA^{1/2}$ ($p<.001$), $LVIDd/BSA^{1/2}$ ($p<.01$) and $LVMM/BSA^{3/2}$ ($p<.05$). There was no difference in MQ. On the other hand compared to the Olympic champions junior water-polo players had significantly lower values in body size related LVWTd/BSA$^{1/2}$ (p<.001), LVMM/BSA$^{3/2}$ (p<.001) and MQ (p<.001). Morphologic data of the junior water-polo players, non-athletes and the water-polo Olympic champions are shown in Table 3.

Table 2. The swim-test results of the junior water-polo players and of the Olympic champions

		Tmax (sec)	Tmean (sec)	P4 (heart beats)	Delta (heart beats)
WPL	Mean	16.98***	19.18***	510***	10.50***
(n=26)	s.d.	0.76	0.95	47.22	4.99
OC	Mean	15.77	17.54	453	16.63
(n=11)	s.d.	0.53	0.41	20.67	3.26

Abbreviations
WPL: junior water-polo players, OC: Olympic champions in the Sydney 2000 Olympic games.
Tmax: time result of a 30 m maximal intensity swim, Tmean: mean time result of the 6x30 m swim, P4: total number of heart beats during the 4 min recovery, Delta: difference between heart beat counts during the first and second half-minutes of recovery.
*: p<0.05, **: p<0.01, ***: p<0.001significant difference in favour of the Olympic champions.

Table 3. Body size related echocardiographic morphology of the subjects

		LVWTd/BSA$^{1/2}$ (mm/m)	LVIDd/BSA$^{1/2}$ (mm/m)	LVMM/BSA$^{3/2}$ (g/m^3)	MQ (%)
WPL	Mean	14.31***	36.99**	89.56***	38.80
(N=26)	s.d.	1.49	2.36	16.42	4.49
NA	Mean	12.78	34.99	70.13	36.64
(N=25)	s.d.	1.03	2.12	10.83	3.62
OC	Mean	16.79###	37.87	116.00###	44.47###
(N=11)	s.d.	1.49	2.83	22.83	4.30

LVWTd/BSA$^{1/2}$: body size related left ventricular wall thickness, LVIDd/BSA$^{1/2}$: body size related left ventricular internal diameter at diastole, LVMM/BSA$^{3/2}$: body size related left ventricular muscle mass.
WPL: junior water-polo players, NA: non-athletic subjects, OC: Olympic champions in the Sydney 2000 Olympic games.
*: p<0.05, **: p<0.01, ***: p<0.001significant difference compared to the non-athletic group.
#: p<0.05, ##: p<0.01, ###: p<0.001significant difference compared to the junior water-polo players.

Training induced bradycardia was found in junior water-polo players, a significantly lower resting heart rate was measured compared to the non-athletes (HR: WPL vs. NA, p<.001). Contractility of the heart was measured by two parameters, namely the stroke volume and the ratio of LVET/QT. In both indices the values of the junior water-polo players differed significantly from those of the non-athletes indicating a better systolic function (SV/BSA$^{3/2}$; p<.001 and LVET/QT; p<.01). Between the junior athletes and the Olympic champions there were no differences. Functional and regulatory data are presented in Table 4.

From the echocardiographic parameters only LVIDd/BSA$^{1/2}$ and SV/BSA$^{3/2}$ showed sign reversed significant correlation with the Tmean of the swim-test (LVIDd/BSA$^{1/2}$; r=0.4, p<.05 and SV/BSA$^{3/2}$; r=0.47, p<.05) and with the calculated average swimming velocity (Vmean: LVIDd/BSA$^{1/2}$; r=-0.39, p<.05 and SV/BSA$^{3/2}$; r=-0.45, p<.05). This correlation suggests that larger body size related LVIDd and SV are associated with higher Tmean or lower Vmean; that is with a poorer swimming performance. An expected correlation would suggest that larger body size related LVIDd or SV is associated with a lower Tmean or a higher Vmean, which means a better swimming performance. However, the latter was not supported by our findings in this study. The correlation results between the swim-test results and the echocardiographic measurements of the junior water-polo players are shown in Table 5.

Table 4. Body size related echocardiographic functional data of the subjects

		HR (beats×min^{-1})	SV/BSA$^{3/2}$ (ml/m^3)	E/A	LVET/QT
WPL (N=26)	Mean	56.71***	37.34***	2.06	0.71**
	s.d.	7.60	16.42	0.41	0.06
NA (N=25)	Mean	71.23	31.02	1.93	0.81
	s.d.	14.04	5.66	0.36	0.09
OC (N=11)	Mean	55.09	40.60	2.32	0.73
	s.d.	9.71	9.94	0.62	0.05

HR: heart rate, SV/BSA$^{3/2}$: body size related stroke volume, E/A: ratio of the early and late diastolic filling peak velocity, LVET/QT: ratio of the LV ejection time to electric systole
WPL: junior water-polo players, NA: non-athletic subjects, OC: Olympic champions in the Sydney 2000 Olympic games.
*: p<0.05, **: p<0.01, ***: p<0.001 significant difference compared to the non-athletic group

Table 5. The correlation results of the swim-test and the echocardiographic measurements of the junior water-polo players

	Tmax (sec)	Vmax (m/s)	Tmean (sec)	Vmean (m/s)	P4 (heart beats)	Delta (heart beats)
LVWTd/BSA$^{1/2}$ (mm/m)	r = -0.04 p = 0.84	r = 0.03 p = 0.85	r = -0.09 p = 0.63	r = 0.08 p = 0.67	r = -0.24 p = 0.23	r = -0.08 p = 0.69
LVIDd/BSA$^{1/2}$ (mm/m)	r = 0.17 p = 0.39	r = 0.16 p = 0.43	*r = 0.40* *p = 0.03*	*r = -0.39* *p = 0.04*	r = 0.10 p = 0.6	r = -0.02 p = 0.90
LVMM/BSA$^{3/2}$ (g/m^3)	r = 0.06 p = 0.74	r = -0.06 p = 0.76	r = 0.15 p = 0.43	r = 0.29 p = 0.14	r = -0.10 p = 0.61	r = -0.08 p = 0.69
MQ (%)	r = -0.11 p = 0.57	r = 0.10 p = 0.60	r = -0.30 p = 0.13	r = -0.16 p = 0.43	r = -0.27 p = 0.16	r = -0.05 p = 0.78
HR (beats×min^{-1})	r = -0.04 p = 0.84	*r = 0.39* *p = 0.04*	r = -0.09 p = 0.63	*r = 0.36* *p = 0.06*	r = -0.24 p = 0.23	r = -0.08 p = 0.69
SV/BSA$^{3/2}$ (ml/m^3)	r = 0.25 p = 0.21	r = -0.23 p = 0.24	*r = 0.47* *p = 0.01*	*r = -0.45* *p = 0.01*	r = 0.12 p = 0.53	r = -0.07 p = 0.70
E/A	r = -0.15 p = 0.50	r = 0.13 p = 0.55	r = -0.05 p = 0.79	r = 0.03 p = 0.88	r = 0.05 p = 0.81	r = -0.18 p = 0.41
LVET/QT	r = -0.18 p = 0.43	r = 0.18 p = 0.43	r = -0.007 p = 0.97	r = 0.01 p = 0.95	*r = 0.45* *p = 0.03*	r = 0.39 p = 0.07

Abbreviations
LVWTd/BSA$^{1/2}$: body size related left ventricular wall thickness, LVIDd/BSA$^{1/2}$: body size related left ventricular internal diameter at diastole, LVMM/BSA$^{3/2}$: body size related left ventricular muscle mass, HR: heart rate, SV/BSA$^{3/2}$: body size related stroke volume, E/A: ratio of the early and late diastolic filling peak velocity, LVET/QT: ratio of the LV ejection time to electric systole, Tmax: time result of a 30 m maximal intensity swim, Tmean: mean time result of the 6x30 m swim, P4: total number of heart beats during the 4 min recovery, Delta: difference between heart beat counts during the first and second half-minutes of recovery, Vmax: maximal velocity of the 30 m swim, Vmean: mean velocity of the 6×30 m swim.
Italics: *: p<0.05

4. DISCUSSION

In the present study we measured the results of a swim-test used for the assessment of the physical condition of the Hungarian water-polo players and we correlated the results to the athletes' echocardiographic parameters. Both measurements were conducted close to each other in time, the average period between the two series of measurements was two weeks.

An analysis of the water-polo game showed that it contains swims of high intensity up to 15 s and also intervals of lower intensity lasting up to 20 s (Smith, 1998); the average intensity of the game is maintained approximately at the 80% level of maximum (Geladas et al., 2000). Both aerobic and anaerobic metabolisms therefore appear important for the game, sprint swims and rapid movements of maximal intensity, but of short duration.

From the swimming components of the test we can evaluate the efficiency of both the anaerobic and aerobic energy systems. From the heart rate measurements after the swim we can evaluate aerobic metabolic adaptation. Cardiac function is known to be dominant in the endurance type (aerobic) events; therefore relation between the two measurements is more likely to appear in the elements of the swim-test which represent endurance ability. However, cardiac adaptation to long term training can occur also in speed and strength events (Fleck, 1988); this also suggests that a relationship between the anaerobic type elements (Tmax) of the swim-test and the cardiac function may exist. In such a kind of correlation we also have to take into consideration the fact that a better cardiac function, as a result of the cardiac adaptation process, is only one component of the swimming performance, hence performance can also increase without a significant improvement in cardiac function. Of course, better cardiac function gives a good base and background for later performance improvement; indeed, most probably without the significant contribution of the cardiac function the development of the swimming performance is limited. The question arising from this approach is whether the improvement of swimming performance as a result of an appropriate and adequate training, and cardiac adaptation as a physiological response of the body to long-term regular physical activity can depend, and to what degree, on each other or else they are two separate parallel processes: the respective results and products of physical activity.

The echocardiographic measurements showed clear evidence of the cardiac adaptation to physical activity. Numerous studies have showed that cardiac morphology and functionality of the heart adapt to long-term physically activity and a left ventricular hypertrophy occurs in athletic groups (Morgan et al., 1991; Maron et al., 1986; Huston et al., 1985; Shapiro et al., 1984; Blomquist et al., 1983). In our study clear signs of LV hypertrophy were found in the water-polo players, in accordance with other authors (Pio Caso et al., 2000; Hollmann et al., 1986; Hayashi et al., 1987; Medved, 1986) and showing training induced changes in the morphology and functionality of the left ventricle. Herein, body size related LV wall thickness and LV internal diameter were significantly larger; however, the hypertrophy was better demonstrated by the body size related LVMM. The 21% larger muscle mass in the junior athletic group was strongly significant.

The well-known training induced bradycardia was also manifest in our study. Water-polo players had a 21.12% lower resting HR than the non-athletic group. A better systolic function was also noticeable by the significant differences in body size related SV and the LVET/QT rate. Increased SV can be associated with the LV chamber size. An enlargement of the LV chamber will increase LV preload (Pio Caso et al. 2000) that in turn, will result in a better diastolic stretching of the myocardium, so according to the Frank-Starling mechanism (Patterson, 1914) would lead to a better systolic function, that is, to an increased SV (Scharhang et al., 2002).

In order to evaluate the swim-test and the echocardiographic results of the junior water-polo players we compared their results to those of the Olympic champion national team (Table 2). In the swim-test junior players had significantly poorer values than the Olympic champion players, which is normal as they still have some years to reach their peak performance. Junior players, except body size related LVID, in all measured morphologic indices had significantly poorer values than the Olympic champions (Table 3). It seems that a morphologically less developed left ventricle was accompanied by poorer swim-test results although no direct evidence establishes this connection.

The correlation measurements failed to show any linear relationship between the two kinds of measurements (Table 5). The significant correlations of the Tmean and of the Vmean with the $LVIDd/BSA^{1/2}$ and the $SV/BSA^{3/2}$ show a reverse (unexpected) correlation for which no valid explanation could be given. It seems that there might be a parallel improvement in both factors, without a direct dependent connection. Perhaps, there is a minimal level of cardiac adaptation needed for high level swimming performance, but above that level cardiac function does not significantly increase performance. In the relationship of the cardiac parameters with the swimming velocity of the swim-test (instead of the time results) correlations in some cases became stronger. In relating the swim-test to maximal oxygen uptake (VO_2max), in previous studies (Pavlik et al., 2001) we found that VO_2max correlated significantly with Tmean, confirming the association of aerobic power (endurance level predictor) with the swim-test. However, when we related VO_2max to the echocardiographic parameters (Petridis et al., 2002) we only found significant correlation with LV muscle mass.

5. CONCLUSION

1. Existing data for the establishment of the relationship between the swim-test and the echocardiographic parameters showed some slight association, however, they were not enough to draw important conclusions. The methodological conception in relating a resting parameter (echocardiographic measurements) to maximal dynamic ones (swim-test) is still open to debate and needs further investigation.
2. A parallel adaptation of the junior players in both measurements (swim-test and echocardiography) can be noticed suggesting however, that the relationship may not be directly causal.

In the future, a revision of the swim-test is recommended in order to better separate the different abilities. Future studies should contain a separation of the swim-test components to exactly measure each component separately and then by longitudinal studies to precisely monitor the changes of each component in various stages of the training program. A possible isolation of the studied cardiac functions in the swim-test with the evaluation of the parallel improvement in both measurements on a proportional basis would also help to understand how cardiac adaptation can influence the swimming performance.

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TEST PLIVANJA I EHOKARDIOGRAFSKI REZULTATI KOD JUNIORA - IGRAČA VATERPOLA

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Svrha ove studije je da proceni rezultate testova plivanja koji su korišćeni za procenu fitnes-nivoa kod Mađarskih juniora - vaterpolo igrača i odnosi se na ehokardiografske parametre igrača. Osnovni cilj je da se utvrdi da li može postojati veza između rezultata testa plivanja i srčane funkcije 26 elitnih juniora i 11 olimpijskih vaterpolo šampiona koji su učestvovali u testu plivanja i ehokardiografskim merenjima. 25 zdravih muškaraca nesportista služili su kao grupa za upoređivanje. Test plivanja uključuje vremenske rezultate: 30 m plivanja maksimalnim intenzitetom (T max), srednje vreme 6×30 m intervalnog plivanja (T mean), broj srčanih otkucaja tokom četiri minuta oporavka (P4) i razliku između srčanih otkucaja tokom prve i druge polovine min oporavka (Delta). Morfologija i funkcionalni parametri srca su mereni ehokardiografijom. Ehokardiografska merenja pokazala su jasne znake leve ventrikularne hipertrofije kod vaterpolo igrača u poređenju sa nesportistima. Između testa plivanja i ehokardiografskih merenja neka bliža korelacija nije pronađena. Rezultati su sugerisali da između testa plivanja i srčanih parametara ne postoji linearna veza. Ipak, zapaženo je adaptivno poboljšanje na oba merenja kod juniora igrača kao rezultat regularnog treniranja. Trenutni test plivanja izgleda da nije dovoljno precizan da proceni srčanu funkciju sportista. Metodološka koncepcija koja se odnosi na parametre odmaranja (ehokardiografska merenja) i maksimalne dinamičke parametre zahteva dalja istraživanja.

Ključne reči: *vaterpolo, test plivanja, srce sportiste, ehokardiografija, srčana adaptacija*.