Polar OwnIndex is not a reliable indicator of aerobic training status

F Köteles[1], Z Dömötör[2], T Berkes[1], R Szemerszky[1]

[1]Institute of Health Promotion and Sport Sciences, Eötvös Loránd University, Budapest, Hungary
[2]Doctoral School of Psychology, Eötvös Loránd University, Budapest, Hungary

Polar watches with heart rate monitoring function have become popular among recreational and professional athletes. In addition to monitoring functions, they calculate a specific index called OwnIndex which is claimed to measure aerobic training status. The current research attempted to shed light on the factors determining the OwnIndex. In Study 1, OwnIndex calculated by the RS-400 Polar watch was estimated using anthropometric (gender, age, height, weight), cardiovascular (resting HR, RMSSD), and exercise-related (maximal oxygen uptake, self-reported physical activity) data of 45 young adults. In Study 2, the OwnIndex was measured in 21 young adults twice, first with self-reported physical activity set to the lowest, then to the highest value. In the regression analysis (Study 1), the only significant predictor of OwnIndex was self-reported physical activity ($R^2 = 0.883$; $\beta = 0.915$, $p < 0.001$). A significant difference with a large effect size ($t(20) = -16.657$, $p < 0.001$, $d = 3.635$) and no significant correlation ($r = -0.32$; $p = 0.155$) were found between the OwnIndices calculated with different levels of activity in Study 2. As anthropometric and cardiac variables play a practically negligible role in the calculation of the OwnIndex, it cannot be considered an appropriate measure of aerobic fitness.

Keywords: aerobic fitness, assessment, technology, exercise, placebo

Monitoring of heart rate (HR) has become more and more popular among recreational as well as elite athletes in aerobic sports, particularly in cycling and running. Relying on this information, athletes are able to optimize their training load, and avoid cardiac overload. Although even modern mobile phones are able to receive and handle HR-related information, the primary platform for such tasks is a combination of a chest strap that functions as electrodes, a wireless transmitter attached to the strap, and a receiver unit, usually a special watch. The development of these devices started already in the 70s, and today several companies offer products that support the planning and monitoring of workouts. One of the leading companies is Polar Electro; its advanced watches are claimed not only to be able to monitor heart rate during exercise but also to characterize aerobic fitness (i.e., maximal oxygen uptake: VO_2max) by a specific index called OwnIndex. The OwnIndex is calculated using a non-linear method, i.e., an artificial neural network (ANN) approximation from demographic and heart rate related variables. This latter component is not specified in more detail, i.e., the actual variables (e.g. heart rate, certain types of heart rate variability, HRV) used in the approximation are unknown. According to the reported results, the method was able to estimate the VO_2max from a short R-R interval measurement with high correlation (0.96) and accuracy (39–41). In the current implementation of the method, the calculation of

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Corresponding author: Dr. habil. Ferenc Köteles, PhD, associate professor
Institute of Health Promotion and Sport Sciences, Eötvös Loránd University, Budapest, Hungary
Bogdánfy Ö. u. 10, H-1117 Budapest, Hungary
Phone: +36-1-2090619; E-mail: koteles.ferenc@ppk.elte.hu

OwnIndex is based on user-specific data (gender, age, body weight and height, maximal oxygen uptake (if available), minimum (resting) and maximum HR, and average physical activity in the last 6 months) and an approximately 5 minutes long HR measurement (called Polar Fitness Test) in resting state and position (preferably in the morning, under relaxed conditions). Polar Electro claimed that the Polar OwnIndex is "as reliable as any other submaximal fitness test" (30).

According to our current knowledge, a possible (however, not always reliable) cardiac indicator of aerobic training status is resting heart rate (rHR): regular endurance exercise training results in a slight or marked decrease in rHR, depending on the training load (6, 9, 10, 18, 35, 36). Measures of vagal influence on heart rate variability (HRV; in frequency domain: high frequency component of the total variability, HF-HRV, in time domain: root mean square of the successive differences, RMSSD) as possible markers of training status and aerobic fitness have also received special attention. Although promising positive findings were reported (2, 22, 24), the results are not yet conclusive for many reasons. First, vagal-related heart rate variability was found to be higher in moderately trained subjects than in sedentary individuals; however, elite athletes showed no significantly better values than the latter group (9), or were characterized by individual temporal patterns (29). Second, endurance training had no impact on vagal HRV indices in several studies, which might be explained by methodological issues (e.g., duration of recordings, body positioning during recording, characteristics of training load) (6). Third, daily recordings averaged over weeks proved to be better indicators of training status than single measurements that show considerable day-to-day variability (23, 29). In conclusion, measures of heart rate in themselves (and particularly if they are calculated form a single measurement) do not seem to be appropriate indicators of training status in aerobic sports (8, 23, 28).

According to the reported findings (which typically used linear statistical methods), the gap between the accuracy of linear and non-linear approximations of VO_2max from HR-related variables appears to be surprisingly large. In the current study, the accuracy of the OwnIndex as an indicator of VO_2max was investigated. The research comprised two studies designed to investigate the linear contribution of anthropometric, and heart- and exercise-related variables to the Polar OwnIndex. More specifically, it was hypothesized that gender, age, body weight and height, maximal oxygen uptake, resting HR, RMSSD, and average physical activity in the last 6 months would be connected to the Polar OwnIndex, and able to reliably predict it.

Materials and Methods

Participants
The sample of Study 1 consisted of 45 university students (17 males; mean age: 21.24 ± 1.60 yrs; 19–26 yrs) from Eötvös Loránd University, Budapest, Hungary. Their participation was a part of a seminar in exercise physiology. The sample of Study 2 represented a randomly chosen subgroup of the former sample ($N = 21$, 12 males, mean age $= 20.43 \pm 0.99$ yrs; 19–23 yrs). Participants received detailed information before the study, and signed an informed consent form. The study was approved by the institutional ethical board of the faculty.

Measurements
Maximal oxygen uptake (VO_2max) as an indicator of aerobic training status was measured using a Daum Ergo Bike Premium 8i bicycle ergometer (manufactured by Daum Electronic

GmbH, Fürth, Germany) connected to a Fitmate PRO ergospirometer device (Cosmed Srl, Rome, Italy). The built-in automatic graded exercise test with a continuous 85% submaximal protocol was used. A three-minute warm-up of pedaling with 25 W workload was followed by the exercise phase with escalating workload with a duration of 12 minutes. Maximal HR was calculated using the formula of 220 – age. During the escalating phase, pedaling rate was kept at approximately 75 rev * min–1. Gas exchange and ventilator variables were measured by the ergospirometer. These data were recorded every thirty seconds. Heart rate was monitored throughout the test by a HR belt which sent the HR signals to a HR receiver connected to the Fitmate device. The gas sensor of the ergospirometer was calibrated before each test. Tests were stopped by the ergospirometer.

Electrocardiogram (ECG) was recorded using a Nexus-4 device (Mind Media BV, Herten, the Netherlands). ECG data was obtained with a sampling rate of 1024 Hz using the modified lead II electrode placement (distal end of the right collarbone and lower left rib). The rHR and RMSSD indices were calculated using the KubiosHRV software v2.2 (5).

OwnIndex was calculated using the Polar Fitness Test of RS-400 Polar watch and the matching chest strap and transmitter (POLAR WearLink; Polar Electro, Kempele, Finland).

Body weight and *height* were measured by the experimenters before Study 1.

Physical activity level was determined following the instructions of the Polar Fitness Test on a 4-point scale: *low* (no regular aerobic training), *moderate* (0.5–2 hours of aerobic training per week, e.g., 5–10 km running), *high* (2–4 hours of aerobic training/10–40 km running per week), and *top* (heavy physical exercise at least 5 times a week).

Procedure

In Study 1, participants were measured one by one in a separate room. In the first measurement, body weight and height were measured, and then participants completed the 85% submaximal oxygen uptake test. In the second measurement (7–14 days later), participants set their personal data (including the measured VO_2max value) in the Polar watch, then the Polar chest strap with the transmitter and the three electrodes for the ECG measurement were placed on their body. ECG data was recorded simultaneously with the Polar Fitness Test protocol in a lying body position under resting conditions.

In Study 2, participants were asked to enter their personal data (age, gender, height, and weight) in the RS-400 Polar watch. VO_2max, resting and maximum heart rate were left untouched (i.e., the default values of the device were used), activity level was set to the lowest value ("1"), and the OwnIndex test was conducted in a lying position under relaxed conditions (condition 1). After finishing the test, participants set activity level to the highest value ("4"), all other data remained unchanged, and the test was completed again (condition 2).

Statistical analysis

Statistical analysis was carried out using the SPSS v21 software. As variables showed no deviation from normal distribution in either study, parametric methods were used in the statistical analysis. In Study 1, Pearson correlation was used to estimate relationships among continuous variables, and Spearman correlation for binary and ordinal variables. To investigate variables' independent contributions to OwnIndex, a multiple linear regression analysis was conducted. Variables were entered into the equation in two steps (the ENTER method was used): (Step 1) gender (0 = male, 1 = female), age, height, and weight; (Step 2) rHR, RMSSD, VO_2max, and activity. Another regression analysis was run to predict VO_2max.

In this analysis, gender, age, height, and weight were entered in Step 1, and rHR, RMSSD, OwnIndex, and activity were entered in Step 2. In Study 2, the two sets of OwnIndices were compared in two ways: using a paired-samples t-test (group level change) and Pearson correlation (individual level connection).

Results

Descriptive statistics of Study 1 were presented in Table I; results of the correlation analysis are summarized in Table II. The OwnIndex showed significant correlations with VO_2max ($r = 0.33, p = 0.027$) and physical activity ($\rho = 0.91, p < 0.001$), however, it was not connected to age, gender, body weight and height, rHR, and RMSSD. VO_2max correlated with gender ($\rho = -0.34$, $p = 0.021$), body height ($r = 0.49$, $p = 0.001$), and reported physical activity ($r = 0.33, p = 0.025$), but not with rHR and RMSSD.

Table I. Descriptive statistics of the measured variables

	Mean	**Std. Deviation**
Body height (whole sample)	1.73	0.128
Body height (males)	1.84	0.087
Body height (females)	1.66	0.098
Body weight (whole sample)	65.40	11.244
Body weight (males)	77.23	6.584
Body weight (females)	58.22	6.228
VO_2max (whole sample)	40.90	10.128
VO_2max (males)	46.17	12.957
VO_2max (females)	37.70	6.290
Resting HR (1/min)	62.69	8.345
RMSSD (ms)	73.81	35.517
Physical activity	2.84	0.706
OwnIndex	50.18	8.77

Table II. Results of the correlation analysis. Spearman coefficients (ρ) for gender and physical activity, and Pearson coefficients (r) for all other variables

	OwnIndex	**VO_2max**
Age	$r = 0.13, p = 0.401$	$r = 0.24, p = 0.111$
Gender	$\rho = 0.15, p = 0.336$	$\rho = -0.34, p = 0.021$
Body weight	$r = -0.06, p = 0.686$	$r = 0.29, p = 0.054$
Body height	$r = -0.12, p = 0.450$	$r = 0.49, p = 0.001$
rHR	$r = 0.14, p = 0.361$	$r = -0.06, p = 0.673$
RMSSD	$r = -0.10, p = 0.520$	$r = -0.16, p = 0.306$
Physical activity	$\rho = 0.91, p < 0.001$	$r = 0.33, p = 0.025$

The first equation of the regression analysis with OwnIndex as outcome variable was not significant. The second equation explained 88.3% of the total variance ($p < 0.001$), the only significant predictor of OwnIndex was physical activity ($\beta = 0.915$, $p < 0.001$) (see Table III for details).

The first equation of the second regression analysis explained 34.4% of the total variance of VO_2max with the significant contribution of body height ($\beta = 0.504$, $p = 0.009$). The second equation explained 49.1% ($p = 0.001$), however, the only significant contributor remained body height ($\beta = 0.550$, $p = 0.004$). Contribution of OwnIndex was not even close to a significant level ($\beta = 0.370$, $p = 0.287$) (Table IV).

Table III. Results of the multiple linear regression analysis with OwnIndex as dependent variable

	Step 1 $R^2 = 0.042, p = 0.782$		**Step 2** $\Delta R^2 = 0.841, p < 0.001$	
	B ± SE	**β**	**B ± SE**	**β**
Gender	3.994 ± 5.313	.223	1.265 ± 2.070	.071
Age	.792 ± .870	.144	−.386 ± .354	−.070
Height	−4.925 ± 15.162	−.072	1.464 ± 6.519	.021
Weight	.140 ± .225	.179	−.016 ± .088	−.020
rHR			.001 ± .068	.001
RMSSD			−.006 ± .016	−.025
Activity			11.367 ± .826	.915***
VO₂max			.074 ± .068	.085

*** $p < 0.001$

Table IV. Results of the multiple linear regression analysis with maximal oxygen uptake (VO₂max) as dependent variable

	Step 1 $R^2 = 0.344, p = 0.002$		**Step 2** $\Delta R^2 = 0.148, p = 0.052$	
	B ± SE	**β**	**B ± SE**	**β**
Gender	−5.324 ± 5.080	−.258	−6.849 ± 4.881	−.332
Age	1.597 ± .832	.252	1.311 ± .839	.207
Height	39.943 ± 14.496	.504**	43.550 ± 13.941	.550**
Weight	−.225 ± .215	−.249	−.267 ± .206	−.297
rHR			−.007 ± .163	−.006
RMSSD			.020 ± .038	.072
Activity			.381 ± 4.979	.027
OwnIndex			.427 ± .395	.370

** $p < 0.01$

In Study 2, *t*-test showed a significant difference between the two measurements with a large effect size (low activity: M = 32.00, SD = 4.483; high activity: M = 59.38, SD = 4.780; $t(20) = −16.657$, $p < 0.001$, $d = 3.635$). The Pearson correlation between the two data sets was non-significant ($r = −0.32$; $p = 0.155$).

Discussion

According to the results of Study 1, the OwnIndex showed only a medium level correlation with maximal oxygen uptake (explaining approximately 11% of its variance), which disappeared after controlling for anthropometric and cardiac characteristics, and physical activity. Moreover, the OwnIndex was almost completely determined by the reported level of physical activity; more than 83% of its variance was explained by physical activity level in the correlation and regression analyses (after controlling for all other variables).

Study 2 showed that the OwnIndex could easily be manipulated to a great extent by the reported level of physical activity, even in the complete absence of other (i.e., cardiac or anthropometric) changes. In the correlation analysis, the two data sets obtained from the same individuals showed no connection after the change of physical activity. In the group level comparison, change in physical activity substantially changed the OwnIndices; in fact, the calculated OwnIndex was usually evaluated by the software of the watch as *low* or *very low* in condition 1, and typically belonged to the *very good* or *elite* category in condition 2 for the same person.

The results of the reported two studies do not support the claim that the Polar OwnIndex is an appropriate indicator of aerobic fitness and "as reliable as any other submaximal fitness test" (30). First, the connection between OwnIndex and VO_2max was weak. Second, even with the use of linear methods, a great proportion of the variability of OwnIndex was explainable only from reported physical activity. Third, anthropometric and cardiac variables had almost no impact on the OwnIndex; the non-existing correlation between the OwnIndices calculated from two almost identical data sets (the only difference between the two sets was the level of reported physical activity) clearly shows that these variables play an inferior role (if any) in the determination of the OwnIndex.

Polar watches have been accepted as appropriate tools to monitor HR in medicine (1, 20, 27) and also in exercise physiology (4, 16, 21, 38). Recently, their utilization in HRV-based studies (typically, in heart diagnostics) has also been reported (12, 13, 19, 33). According to the results of comparison studies, top-level Polar watches (S810, S810i) can generally be considered as valid as traditional ECG in obtaining data for HR and HRV analysis (14, 15, 25, 26, 31, 32, 42, 45), although limitations were also reported (25, 45). In one study, however, the RS-800 system was found to be inferior compared to the traditional method (44).

According to the present results, these generally positive findings are not generalizable to the OwnIndex, at least not in the case of a medium-level device (Polar RS-400). Limitations of the HR assessment (e.g., a low sampling rate, unsatisfactory identification and removal of non-normal heartbeats) can lead to a considerable decrease of reliability of the measurement (37). These procedures require a considerable calculating capacity, which might not be available in a medium-level Polar device. Even if the formula of calculation takes into consideration anthropometric and cardiac variables, these variables play a practically negligible role in the determination of the OwnIndex compared to the reported level of physical activity. Therefore, in spite of its name and claimed meaning, the OwnIndex does not really encompass, measure, or represent an individual characteristic beyond self-reported physical activity.

Unfortunately, measurement of physical activity seems to be inappropriate, as it is based on self-reported (subjective) average of physical activity over a long period (6 months) which might be heavily biased. Second, only duration of regular physical activity but not its type (e.g., aerobic or anaerobic) is rated, which leads to further inaccuracies. Third, a scale with higher resolution (i.e., a 10-point scale instead of the current 4-point scale) would be desirable

in the case of such an important predictor. As physical activity substantially contributes to the calculation of the OwnIndex, these inaccuracies may cause changes (more precisely: biases and artefacts) in OwnIndex, that might easily be misinterpreted by the users as changes in their aerobic fitness.

According to recent advertisements, top performance in sports does not seem to be achievable without the use of appropriate aids (e.g., magnetic bracelets, kinesiotapes) and monitoring devices. In placebo-controlled studies, these aids and devices usually show no better effectiveness than their respective placebos, and their specific effects are not supported by empirical results (7, 11, 17, 34, 43). This is not to say, however, that placebo interventions are ineffective; it is well known that the placebo effect can play a role in the improvement of sport performance (3). From this point of view, these aids and devices are able to mobilize psychological resources which will result in better performance. In the light of the present results, the Polar OwnIndex can be considered as a "technical placebo": more training leads to the increase of the OwnIndex, this offers a direct and positive feedback for the athlete who tries to train more and more for better OwnIndex values.

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