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Anne R. Crecelius
University of Dayton, acrecelius1@udayton.edu

Paul M. Vanderburgh
University of Dayton, pvanderburgh1@udayton.edu

Lloyd L. Laubach
University of Dayton, llaubach1@udayton.edu

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Contributions of Body Fat and Effort in the 5K Run Age and Body Weight Handicap

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Anne R. Crecelius, Paul M. Vanderburgh, EdD*, Lloyd L. Laubach, PhD

*Corresponding Author

Department of Health and Sport Science

300 College Park

University of Dayton

Dayton, OH, 45469-1210

TEL: 937.229.4213

FAX: 937.229.4244

vanderburgh@udayton.edu

Running Head: Body Fat and Effort in the 5K Handicap

ABSTRACT

The 5K Handicap (5KH), designed to eliminate the body weight (BW) and age biases inherent in the 5K run time (RT), yields an adjusted run time (RTadj) that can be compared between runners of different BW and age. As hypothesized in a validation study, however, not all BW bias may be removed due to the influences of body fatness (BF) and effort (RPE). This study's purpose was to determine the effects of BF and RPE on BW bias in the 5KH. For 99 male runners in a regional 5K race (age = 43.9 ± 12.1 yr; BW = 83.4 ± 12.9 kg), BF was determined via sum-of three-skinfolds just prior to the race. RPE, on the 20 pt Borg scale, was used to assess overall race effort upon race completion. Multiple regression analysis was used to develop a new adjusted run time (NRTadj, the RTadj corrected for BF and RPE) which was computed for each runner then correlated with BW to determine bias. Indicative of slight bias, BW was correlated with RTadj (r = 0.220, p = 0.029). Both BF (p = 0.00002) and RPE (p = 0.0005) were significant independent predictors of RTadj. NRTadj was not significantly correlated with BW (r = 0.051, p = 0.61), but BF explained 90% and RPE only 6% of the remaining BW bias evidenced in the 5KH. The previous finding that the 5KH does not remove all BW bias is apparently accounted for by BF and not RPE. Since no handicap should be awarded for higher BF, this finding suggests that the 5KH, for men, appropriately adjusts for the age and BW vs. RT biases previously noted.

INTRODUCTION

To account for the inevitable age and body weight (BW) related declines in distance running

potential, the 5K handicap (5KH) was developed (14) and validated (16). Based on the scientific

literature, it adjusted one's actual 5K run time (RT) by the documented independent effects of

age and BW. The resulting adjusted run time (RTadj) could be used to compare 5K performance

between runners of different age and BW within the same gender. Despite the fact that the 5KH

could eliminate the use of age and weight categories common in 5K races, it has been used in

selected regional Midwestern U.S. races as a supplement to existing awards categories.

The age adjustment was derived from the empirically documented effects of both age on

maximal oxygen uptake (VO_{2max}, in $ml^{.}kg^{-1.}min^{-1}$) and VO_{2max} on 5K run time. Specifically, in

large subject samples, Jackson and colleagues (9,10), determined that VO_{2max} declined by 0.25

and 0.26 ml O_2 per kg of BW per year in women and men, respectively, *independent* of body

fatness (BF) and self-reported physical activity. This could be thought of as the inevitable

decline in aerobic function due to age. Nevill et al. (13), from a sample of 320 runners,

developed an equation that predicted run speed (essentially the inverse of RT) from BW and

VO_{2max}:

$$RS = 84.3VO_{2max}^{1.01}BW^{-1.03} \tag{1}$$

Combining the documented slope of age vs. VO_{2max} with Eq.1, the associated RT, adjusted for

age (RTage), could then be calculated.

The adjustment in the 5KH for BW was based on theoretical and empirical evidence associated with laws of geometric similarity and aerobic energy expenditure. Astrand & Rodahl (2) theorized that VO_{2max}, expressed in $L^.min^{-1}$, was directly proportional to $BW^{2/3}$ because O_2 consumption was proportional to BW and time (min^{-1}) was proportional to $BW^{1/3}$. This relationship has been validated empirically (6,13). Combining this with Nevill's assertion from Eq. 1 that RS was essentially proportional to relative VO_{2max} (ml $O_2^.min^{-1}kg^{-1}$), Vanderburgh derived that RT must be proportional to $BW^{1/3}$ (14), a relationship that has also been validated empirically (17). From this, and a minimum weight standard, below which distance running performance likely declines, the RT adjusted for BW, RTbw, can be calculated. Height was not considered in the 5KH because BW had been previously shown to be a more potent predictor of RT than height and because no theory existed to explain height's role beyond that of BW (14). Though the details of the 5KH derivation are explained elsewhere, the combination of RTage and RTbw are used to determine RTadj, the RT adjusted for the independent effects of age and BW. Of key importance, however, is the fact that the 5KH adjustment for BW is based on a "scale model" approach. That is, the algorithm statistically makes the runner not only lighter (to the minimum weight standard) but a perfect scale model smaller (e.g., lighter and shorter), and computes the RTadj based on that new body size. Therefore, a runner is not made disproportionally thinner – a problematic scenario especially for one who is tall and thin to begin with.

The impact of the BW bias inherent in distance running has been quantified. Vanderburgh & Crowder (15) calculated that the penalty against heavier (not fatter) men and women was 15-26% on the distance run portion of the Army, Air Force and Navy physical fitness tests. This

penalty was defined as the test score difference between lighter runners (45 kg for women, 60 kg for men) who earned the highest possible score and heavier runners (75 kg for women, 90 kg for men) who ran physiologically equivalent performances. Because promotions have been based, in part, on physical fitness scores, the current tests unduly penalize larger service men and women. Furthermore, because the lack of occupational relevance for the distance run tests has been linked to the BW bias, the case has been made that elimination of BW bias may lead to not only a fairer test, but one that is more indicative of military task performance (15).

Beyond the influence of BW, distance run time performance has also been explained by the independent contribution of some measure of BF (7,8), largely due to its affect on increasing variability in the amount of metabolically inactive tissue that runners of the same BW must carry. This would likely confound analysis of BW bias. Nevill et al. (12) suggested that BW and BF in combination, as opposed to FFM, a fixed linear function of the two, allows for a more flexible predictive function. This suggests that the addition of BF as a predictor, improves the prediction of the BW vs. RT model.

In a recent validation study of the 5KH (16) with 275 male runners, the correlation between BW and RTadj was small but significant ($r = 0.134$, $p = 0.0263$), indicating that the 5KH did not remove all BW bias. Researchers hypothesized that, compared to faster runners, slower runners ran at a smaller percentage of maximum capability and had more BF. Both might have confounded bias analysis since the 5KH model assumes maximum effort and an algorithm independent of the effects of BF. Since neither BF nor some index of effort were measured, sampling of faster runners served as a surrogate. A repeat of the bias analysis among the new

sample yielded near-zero correlations between BW and RTadj, suggesting that the 5KH eliminated BW bias to some degree. This conclusion, however, was based on the assumption that slower runners tended to be fatter and exhibited less relative effort. Clearly, direct assessment of the effects of BF and effort on BW bias in the 5KH was warranted and was, therefore, the purpose of this study.

METHODS

Approach to the Problem

The presence of BW bias in the 5KH was first ascertained in the sample. To test the hypothesis that BF and/or RPE explained some or most of this bias, a new adjusted run time (NRTadj), the RTadj adjusted for BF and RPE, was calculated. No BW bias in the NRTadj would support the hypothesis. Repeating the NRTadj analysis for BF and RPE separately would yield the independent contributions of each in explaining remaining BW bias.

Subjects

Subjects were 99 male runners in a regional 5K race held in Dayton, OH. For bias analysis, the goal was to have a sufficient sample size for which 5% of explained variance would be statistically significant. Power analysis revealed that the minimum sample size to accomplish this was N=80. Women were not recruited based on findings of a previous validation study using the same race in which women were generally hesitant to be weighed (16). Subjects were recruited both at pre-race registration and on race day via a t-shirt incentive. Written, informed consent was obtained from each participant prior to their participation in data collection and the study was approved by the University of Dayton's Institutional Review Board and Committee

for the Protection of Human Subjects. Subjects were identified by race number only to ensure confidentiality. Only subjects with complete data were used in the data analysis.

Procedures

Pre-race data were collected either at a pre-race registration event two days before the race or on race morning, just prior to the race. The same procedure was followed regardless of day. Subjects self-reported age as well as running and road racing experience (as explained in Table 1). Each subject's height was measured using a validated wall scale and BW with a calibrated digital scale. BF was estimated using the sum of three skinfold sites: chest, triceps, subscapular (11). All skinfolds were measured by the same experienced technician who had over 20 years body composition assessment experience. American College of Sports Medicine Guidelines for Exercise Testing were followed for all anthropometric measurements (1).

Race day start time conditions were widely scattered clouds, 23ºC temperature, 17 ºC dewpoint, and 2.4 m·sec^{-1} wind speed. Race data were RT and RPE. Each subject's RT was measured electronically and uploaded into a database via an electronic shoe-worn chip supplied to each runner by race officials. The race software included the 5KH algorithm which allowed for real time calculation of each subject's 5KH run time, the RTadj (14). The RPE was assessed via the 20-pt Borg scale (3) within one minute after race completion for each subject. The phrase, "According to this scale, how hard did you feel you ran overall during this race?" was read to each subject prior to self-reporting his score. Though the use of this scale to quantify overall effort is somewhat uncommon, Foster et al., (5) validated the *session* RPE as a "valid method of quantitating exercise training during a wide variety of types of exercise." Furthermore,

Dishman, in his comprehensive RPE review (4), explained research literature supporting the contention that RPE is more accurate at higher relative intensities. Therefore, the case could be made that the Borg 6-20 RPE scale was a valid measure of overall effort during the 5K race.

Statistical Analyses

To ascertain BW bias in RT scores, BW vs. RT was plotted for all subjects and the corresponding Pearson product moment correlation was calculated. To determine remaining BW bias in the 5KH, BW vs. RTadj was similarly analyzed. Finally, the effects of RPE and BF on this remaining bias were assessed by computing a new adjusted run time (NRTadj), the RTadj adjusted for the independent effects of RPE and BF, and determining its correlation with BW. The NRTadj was calculated in two steps. First, multiple regression analysis, using RTadj as the dependent variable and RPE and BF as independent variables, yielded the following prediction equation with coefficients each for RPE and BF:

$$\text{RTadj (predicted)} = a\text{RPE} + b\text{BF} + c \qquad (2)$$

Second, each individual's NRTadj score was computed by "correcting" for the influences of RPE and BF using the following equation:

$$\text{NRTadj} = \text{RTadj} - a\text{RPE} - b\text{BF} \qquad (3)$$

.

This convention, similar to that used to compute RTage (14), based on the age-related decline in VO_{2max}, is actually a form of analysis of covariance applied to each individual score. Since the

RTadj is already adjusted for BW and age, then Eq. 2 determines the additional influences of

RPE and BF on RTadj. By reversing the signs of the coefficients ($-a$RPE $+ -b$BF) and adding

them to the RTadj, the resulting individual score is corrected for their influences. If the

correlation between RTadj and BW was non-zero and the corresponding correlation between

NRTadj and BW was near zero, this would suggest that what BW bias remained in the 5KH

model, could be explained by RPE and/or BF. Given the distinct possibility that both RPE and

BF could be independent predictors but not necessarily contributors to the remaining BW bias,

the regression analyses above were done with RPE and BF separately to ascertain the

independent contribution of each. The criterion for presence of bias was set at $p < 0.05$.

RESULTS

Descriptive data for subjects' pre-race and race data, shown in Table 1, suggested that runners

were heterogeneous in BW, BF, and RT. The scatterplot of BW vs. RT (Fig. 1) indicated, as

expected, a BW bias such that heavier runners exhibited slower RT values. This bias, $r = 0.357$

($p = 0.0003$), was similar to that indicated in the 5KH validation study (16), in which bias was r

$= 0.424$ ($p < 0.0001$) for the sample of 275 men. Furthermore, allometric scaling analysis

indicated that the body mass exponent for this sample was 0.410 ± 0.108, similar to that reported

(17) for young men (0.40 ± 0.86). In both cases, the 95% confidence interval included 0.33, the

value supported by theory (14). As shown in Fig. 2, a small but significant BW bias (BW vs.

RTadj) still remained when the 5KH model was applied ($r = 0.220$, $p = 0.029$). This was

somewhat congruent with the remaining bias ($r = 0.134$, $p = 0.026$) noted previously (16). In

other words, the 5KH, with its BW (and age) handicap did not eliminate all BW bias. Multiple

regression analysis revealed that both BF (p = 0.00002) and RPE (p = 0.0005) were significant independent predictors of RTadj and the resulting equation for NRTadj was:

$$NRTadj = 24.22(RPE) - 10.92(BF) + RTadj \qquad (4)$$

This equation was used to correct each RTadj score for the independent effects of RPE and BF. Plotting the resulting NRTadj vs. BW scores, yielded Fig. 3, which showed no BW bias (r = 0.051, p = 0.61). Stated differently, the 4.8% variance (r^2) in RTadj explained by BW was reduced to 0.3% when the effects of RPE and BF were considered.

Independent contributions of the effects of RPE and BF were similarly analyzed by repeating the regression analyses above but with only one variable. RPE, which was moderately correlated (Table 2) with RTadj but not significantly with BW, showed a very slight effect of reducing bias: from 4.8% to 4.5%, a 6% reduction. This finding did not support our hypothesis that heavier runners did not exert as much relative effort as lighter runners. The potency of RPE in the multiple regression model (Eq. 3) was almost entirely based, then, on its correlation with RTadj (r = -0.40). The same analysis for BF, however, revealed that the BW bias inherent in the 5KH was reduced from 4.8% to 0.5%, a 90% reduction. The underlying mechanisms were its modest correlations with both RTadj (r = 0.46) and BW (r = 0.63). In short, BF explained 90% and RPE only 6% of the remaining bias in the 5KH.

DISCUSSION

The previous finding (16) that the 5KH does not remove all BW bias is apparently accounted for

by the influence of BF and not RPE. While the remaining BW bias, which translated to

explaining 4.8% of the variance in RTadj, may seem practically insignificant, the best-fit

regression equation from Fig. 2 (RTadj = 2.86BW + 979) indicated that for every one kg

increase in BW, RTadj would slow by nearly 3 sec. This translated, for example, to a 29 sec

"penalty" for a 10 kg heavier person, arguably not an insignificant amount.

These findings were not unexpected for BF but were for RPE. Because the 5KH derivation was

based, in part, on Nevill's (13) equation (Eq. 1) which included VO_{2max}, a key assumption for its

validity was that subjects gave a maximal effort. If not, VO_{2max} would be underestimated and the

resulting run speed (RS, in Eq.1) and, therefore, RTadj, would be overestimated. The link to

explaining BW bias, however, would depend on the relationship between RPE and BW. As the

data suggest, although RPE was correlated with RTadj, it was not correlated with BW (Table 2).

The latter finding was apparently due to the fact that heavier runners, though slower, did not tend

to run at different relative intensities. Subsequent analyses, however, indicated that correlations

between BW and running experience (Table 1) expressed in miles run per week and road races

completed in the past year, were -0.257 and -0.283 (both $p < 0.05$), respectively. This left open

the possibility that heavier runners, perhaps due to less running experience, may have

overestimated relative effort but this assertion could not be tested in the present data. These

findings do challenge the assumption described previously in the 5KH validation study (16), that

heavier runners gave less effort. Their finding that sub-sampling faster runners removed

remaining BW bias may have been due not to RPE but to the association between BF and RT (in

the present data, that correlation was r = 0.61). In other words, this sampling method likely

removed fatter runners, thereby reducing the influence of BF on remaining BW bias. Their

study, however, did not include assessment of BF so this could not be verified.

The present finding that BF explained most of the remaining BW bias can be explained by its

correlation with both BW and RTadj. Furthermore, the law of biological similarity, the

foundation upon which the $BW^{1/3}$ scaling is based, applies most ideally to lean body mass, not

BW. Therefore, excess body fat, a component of BW, but not of lean body mass, should have

been a primary contributor to the remaining BW bias in the RTadj scores. To test congruence

with the previously cited rationale for the 5KH not adjusting for height along with BW (14), the

Pearson product moment correlation between height and RT was computed to be 0.07 (p>0.05),

much lower than the significant correlation of BW vs. RT (r=0.36, p<0.05, Table 2). This

supports the assertion that BW is a much more potent predictor of RT than height.

The implications of these findings are important from a health-related fitness perspective. To

those unfamiliar with the basis of the 5KH, awarding a handicap for BW may appear to reinforce

undesirable health behaviors (e.g., gaining weight). Vanderburgh & Laubach previously

demonstrated, however, that gaining fat weight would lead to a slower RTadj, despite the

handicap, because the change in RT caused by the fat weight is more unfavorable than the credit

for having the extra weight is positive (14). Here, they used the example of a man, 45 yrs, 85 kg,

a 5K RT = 1500 sec, and the resulting 1227 sec RTadj. If he gained 3 kg of body fat (assuming

no change in functional capacity), his new RT would change to 1556 sec (from Eq.1) and his

RTadj would be 1253 sec – a new 26 sec slower RTadj from gaining the fat weight. This case,

however, was based on modeling and was never tested empirically. The present data provide empirical evidence that the 5KH does not reward BF, but in a different way. Here, the data suggest that the portion of BW bias not factored out in the 5KH algorithm can be explained largely by BF. Clearly, however, the "go-forward" strategy should not be one of accounting for BF. One can say, however, that the remaining BW bias in the 5KH is due to one factor for which runners should not get credit (i.e., being fatter).

How well these findings can be replicated with other populations requires further investigation. For women, though previous validation of the 5KH suggests that the model exhibits similar BW bias trends regarding faster runners, the present methods should be applied to a sufficiently large sample of women before assuming that gender is not a factor in modeling BF and RPE effects on the 5KH. Of particular importance is the voluntary participation of women, who appear to be more hesitant than men to be weighed (16). For younger and more competitive runners, often more homogeneous in weight and performance, the present results may not be as applicable for two reasons. First, these are the very runners for whom the 5KH would not be as beneficial due to the small difference between RT and RTadj values. Second, such a population is more apt to give closer to maximal effort and be of low BF. Explaining variance, then, based on BF and RPE would be statistically difficult to justify. Optimally, these findings should be applicable to recreational runners whose anthropometric and performance data fall between the means $\pm$ 2SD shown in Table 1.

In summary, the remaining BW bias of the 5KH is largely accounted for by the influences of BF and not RPE. Since no handicap should be offered for excess BF, these findings suggest that in

men, the 5KH appropriately adjusts for the age and BW vs. RT biases in men. Further studies

are needed to evaluate a similar approach for women runners.

PRACTICAL APPLICATIONS

The 5K Handicap, which adjusts one's 5K run time by age and body weight, allows for

comparisons of running performance between individuals of different size and/or age within the

same gender. Since the handicap is based on the scientific evidence of the independent

influences of increasing age and body weight on 5K run time, one would expect that the

handicap would not eliminate all body weight influences because of other factors like effort or

body fatness. In this study with 99 recreational male runners, heavier runners still tended to have

slower run times, even when adjusted for age and BW. When the effects of effort and body fat

were factored in, however, this body weight "bias" disappeared. Further analysis indicated that

this disappearance was nearly all due to body fat, suggesting that the 5K Handicap factors out

body weight appropriately since no extra "credit" should be given for excess body fat.

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Table 1. Subject (N=99) descriptive statistics.

Variable	Mean ± SD	Range (Min/Max)
Age (yr)	43.9 ± 12.1	18/76
Height (cm)	178.6 ± 7.4	158.8/199.4
Body mass (kg)	83.4 ± 12.9	53.1/119.3
Percent body fat	17.6 ± 6.0	5/32
Rating of perceived exertion (20 pt Borg)	16.1 ± 2.2	11/20
5K run time, RT (sec)	1475.8 ± 262.7	937/2086
5K adjusted run time, RTadj (sec)	1216.8 ± 167.1	890/1600
Miles run per week category*	2.4 ± 1.1	1/4
Road races completed in the past year category**	2.5 ± 1.2	1/4

*Miles run per week category, self-reported according to the following:

1 = 0-10 miles, 2 = 11-20 miles, 3 = 21-30 miles, 4 = 30+ miles

**Road races completed in the past year category, self-reported according to the following:

1 = 0-2, 2 = 3-5, 3 = 5-7, 4 = 7+

Table 2. Correlation Matrix of Key Variables

	BW	BF	RPE	RT
BW	_			
BF	0.626**	_		
RPE	-0.062	-0.212*	_	
RT	0.357*	0.614**	-0.452**	_
RTadj	0.220*	0.455**	-0.395**	0.899**

$*p < 0.05$

$**p < 0.01$

BW = body weight

BF = percent body fat

RPE = rating of perceived effort overall

RT = 5K run time

RTadj = 5K Handicap adjusted run time

FIGURE CAPTIONS

Fig.1. BW vs. 5K run time. The correlation, r = 0.357, is statistically significant (p = 0.0003), suggesting BW bias.

Fig. 2. BW vs. adjusted run time (RTadj), the actual run time adjusted by one's BW and age. The correlation r = 0.220 is statistically significant (p = 0.029) and indicates remaining BW bias.

Fig.3. BW vs. the new adjusted run time (NRTadj), the 5K Handicap further adjusted for effort (RPE) and body fat (BF). The correlation coefficient, r = 0.051, is not statistically significant (p = 0.51), suggesting that the remaining BW bias was removed with the BF and RPE

Fig. 1

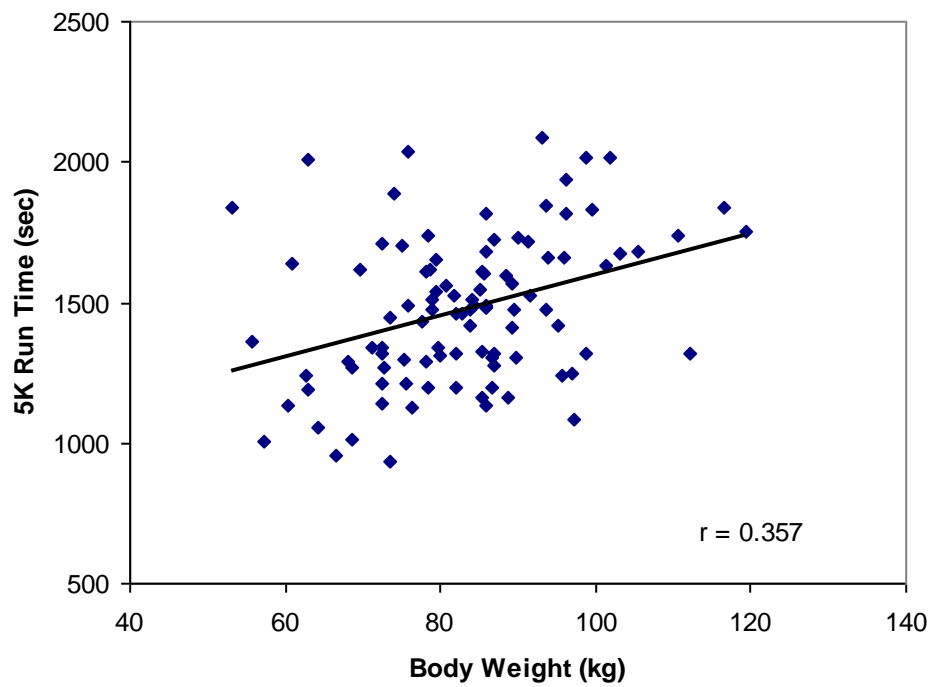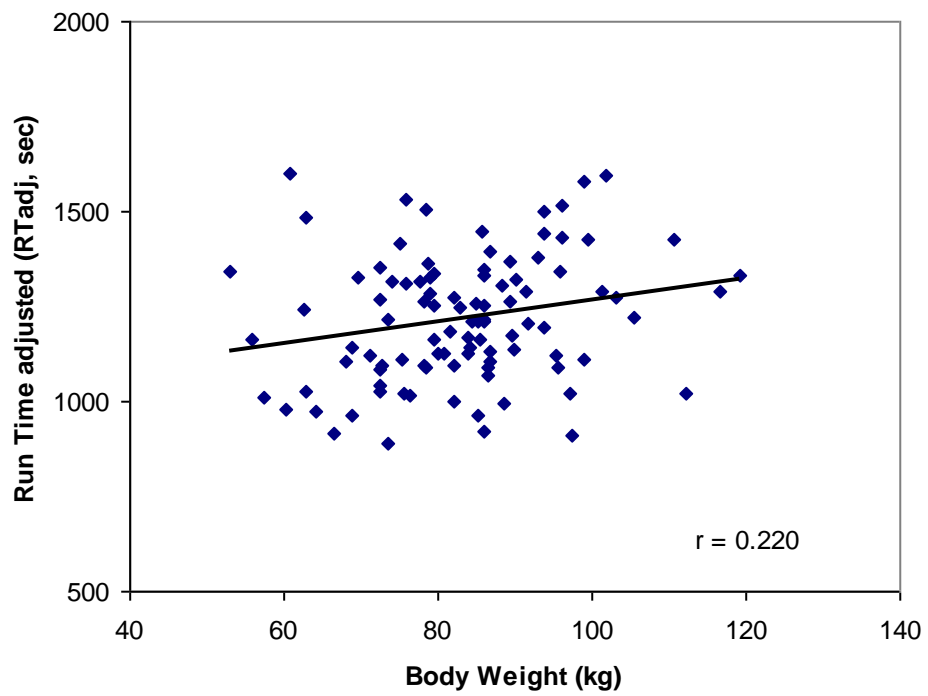Fig.2

Figure showing a scatter plot of Run Time adjusted (RTadj, sec) versus Body Weight (kg) with a fitted regression line and r = 0.220.

Fig.3