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DERIVATION OF AN AGE AND WEIGHT HANDICAP FOR THE 5K RUN

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Abstract

The adverse effect of increasing age and/or body weight on distance run performance has been well documented. Accordingly, nearly all five kilometer (5K) road races employ age categories and, sometimes, a heavier body weight classification. Problems with such conventions include small numbers of runners within older age categories and the advantage given to the lightest runners within each weight category. We developed a 5K Handicap (5KH), a model that calculates an adjusted run time based on the inputs of actual 5K run time, age, and body weight for men and women. This adjusted time, then, can be compared between runners of different ages and body weights. The purpose of this paper was to explain, in detail, the derivation of the 5KH formula using published theoretical and empirical findings on age, body weight and distance run time relationships. To our knowledge, the 5KH is the first such model and overcomes the problems associated with being heavier within one weight class and having too few runners in certain age categories. We are currently undertaking large-scale validation studies and evaluation of its race day implementation.

Key Words: allometry, age handicap, weight handicap, running

Participation in distance running road races suggests their increasing popularity. According to the Running USA's Road Running Information Center (www.runningusa.org), 2004 U.S. road race participation grew by an average of 4% from the previous year, with increases evidenced at every standard race distance, and nearly eight million finishers. Furthermore, recent research advances offer new ways to evaluate race performance that may enhance such participation especially for older and heavier runners.

While many factors contribute to distance run performance, the notion that runners of advanced age and body weight (BW) post slower times is widely accepted. Accordingly, nearly all races have age categories and, in some cases, body weight divisions. The primary limitation of the age categories is that there are often very few competitors in the older categories, sometimes fewer runners than awards. When BW divisions are used, typically only two heavier weight divisions are added such that runners above the minimum weight can compete against each other for the additional awards beyond those of the open division. The divisions, named "Clydesdale" for men and "Fillies" or "Athena" for women, have different BW cut-offs depending on the choice of organization affiliation (www.clydesdale.org or www.usa-clydesdale.com). The minimum BW established for these divisions is arbitrarily assigned and the use of such a category gives competitors close to the minimum weight an advantage over heavier ones (based on physiological laws of similarity discussed in the Methods section below). These limitations could be mitigated by using an age and BW handicapping system that more precisely handicaps age and weight as continuous variables. More importantly, the modeling of distance run performance has more recently included both theoretical and physiological evidence defending various handicap systems.

The World Association of Veteran Athletes (WAVA) has popularized an age handicap model for many different track and field events including distance runs up to the marathon. Though never published, and because the organization no longer exists, the WAVA age handicap model appears to be available only on an independent website (http://www.howardgrubb.co.uk/athletics/wavalookup.html, Nov 2005) which also includes links to the development of its algorithms. According to this source, the WAVA model is based on world best performances which determine the slopes of the age vs. run time curves. Comparisons of distance run times between individuals of different age, then, are based on distance from the curve. This can be problematic because the slope of any such curve is very sensitive to data at the limits of age. The fewer elderly competitors at the world class level would likely contribute to world bests not being age-comparable to those of younger runners. This, in turn, would lead to larger than appropriate age handicaps for older runners.

To our knowledge, however, there exists no published, physiologically defensible model that adjusts distance run time by age and BW. Recently, however, research has been published examining the relationship between body size and age on various indices of physical performance, including distance running (Nevill, Ramsbottom, & Williams, 1992; Vanderburgh & Mahar, 1995). These data and the application of related theoretical models of allometry, also receiving attention in recent literature, can be used in combination to better quantify the contributions of age or BW on distance run times.

The first step in developing an age and BW handicap model for distance runs is to quantify the physiological effect of age on distance run performance. The pathway of assimilating empirical findings is based on two key relationships: age vs. maximal oxygen uptake (VO_{2max}) and VO_{2max} vs. distance run time. The former has been well documented for men (Jackson et al., 1995) and women (Jackson et al., 1996). In these large scale studies, Jackson and colleagues assessed VO_{2max}, percent body fat, and self-reported physical activity levels for 1499 men (ages 20-75) and 409 women (ages 20-64). Using cross-sectional and longitudinal analyses, they determined that, for both genders, 50% of the age-associated decline in VO_{2max} was due to the influence of percent body fat and self-reported physical activity. Furthermore, they quantified the change in VO_{2max} with age independent of these two factors as 0.26 and 0.25 $ml \cdot kg^{-1} \cdot min^{-1} \cdot year^{-1}$ for men and women, respectively. These slopes are key in the consideration of an age handicap model for distance runs because they represent how functional capacity, a key determinant of distance run speed, should change due to age, independent of body fatness and activity level.

The link between VO_{2max} and distance run speed has been well-established for the 5K distance. Nevill and colleagues assessed the relationship between 5K run speed and VO_{2max} and BW for 308 recreationally active men and women (Nevill et al., 1992) and developed the following equation:

$$\text{5K Run Speed} = 84.3(VO_{2max})^{1.01}(BW)^{-1.03} \quad (1)$$

where run speed, VO_{2max} and BW are expressed in $m \cdot sec^{-1}$, $l \cdot min^{-1}$ and kg, respectively. This equation can then be used in combination with the findings of Jackson and colleagues (1995, 1996) to quantify the independent effect of age on run speed and, in turn, develop the resulting precise age handicap.

The second step in developing a physiologically appropriate run handicap model is to quantify the independent contribution of body size to distance run time. We chose BW as the single body size variable and did not include height for two reasons. First, scaling laws dictate that the height should be approximately proportional to $BW^{1/3}$ (Astrand & Rodahl, 1986, pp. 399-405). In essence, accounting for BW also accounts for height, albeit, perhaps moderately at best. Second, and more importantly, BW is a more potent predictor of running economy than height (Bourdin, Pastene, Germain, & Lacour, 1993; Walker, Murray, Jackson, Morrow, & Michaud, 1999).

A suitable starting point is, once again, Nevill's work referenced above (1992). They concluded empirically that 5K run speed was directly proportional to the simple ratio of VO_{2max} ($l \cdot min^{-1}$) and Body Weight (BW):

$$\text{Run Speed } \alpha \ VO_{2max} \cdot BW^{-1}. \qquad (2)$$

In turn, the following relationship has been documented theoretically (Astrand & Rodahl, 1986, pp. 399-405, 1986) and empirically (Nevill et al., 1992):

$$VO_{2max} \ \alpha \ BW^{2/3}. \qquad (3)$$

Substituting the right side of the relationship from Equation 2 into the VO_{2max} term in Equation 1 yields:

$$\text{Run Speed } \alpha \ BW^{-1/3}. \qquad (4)$$

Because run speed is inversely proportional to run time (RT), then:

$$RT \ \alpha \ BW^{1/3}. \qquad (5)$$

This relationship has empirical support. Crowder and Yunker (1996), in a sample of 238 fit service academy males, reported a BW exponent of 0.26 $\pm$ 0.06 for the two-mile run. Similarly, Vanderburgh and Mahar (1995), with a sample of 59 male cadets from the same service academy, found the BW exponent to be 0.40 $\pm$ 0.09. Because these were active, fit, lean, and young cadets, the effect of BW on these run times can be considered somewhat independent of body fatness and physical activity level.

The purpose of this paper, then, was to use published theoretical and empirical evidence to develop an age and BW handicap system for the 5K distance run that could be used to evaluate run performance in a novel way.

METHODS

The basis of our methodology was to use these theoretically based and empirically supported findings to develop the 5K Handicap (5KH), an age and BW handicap model for male and female 5K runners. The model calculates an adjusted run time, RT_{adj}, the score that can be used to compare against those of other runners of different BW or age, within each gender. We modeled our approach after that of the Wilks Formula of the International Powerlifting Federation (http://www.powerlifting-ipf.com, Nov 2005), validated by Vanderburgh and Batterham (1999). This formula computes a correction factor, F, for BW which is multiplied by the total weight lifted to yield an adjusted score that determines the overall best lifter among all BW categories. For the 5KH, however, two correction factors are needed, F_{age} and F_{BW}, such that:

$$RT_{adj} = F_{BW} \cdot F_{age} \cdot RT \qquad (6)$$

But each F is equal to the ratio of the adjusted run time for that variable (RT_{BW} and RT_{age}) to the actual run time. Therefore:

$$RT_{adj} = RT \cdot (RT_{BW} \cdot RT^{-1}) \cdot (RT_{age} \cdot RT^{-1})$$

or

$$RT_{adj} = RT_{age} \cdot RT_{BW} \cdot RT^{-1} \quad (7)$$

Obtaining one's RT_{adj}, then, requires the calculation of RT_{age} and RT_{BW}. These can be thought of as the RT the runner would obtain if he/she were a "scale model" of him/herself but younger and lighter, at a standard age and BW for all runners. In other words, the 5KH statistically makes each runner the same age and BW and computes the resulting performance.

Distance run time, widely acknowledged to increase with increasing age and BW, presents an interesting modeling dilemma. One could mathematically infer that lower BW and age result in improved run performance. Clearly, though, as age and BW approach zero, run performance cannot possibly improve. To account for this, we established limits for both age and BW, below which RT would not be adjusted. These limits could be thought of as the "optimal" distance running age and BW for each gender. We chose 25 years, 50 kg for women, and 65 kg for men as these lower limits. The age value of 25 was based on the mean age 25 (male) and 26 (female) for the top 20 5K male and female runners in the world, according to the International Association of Athletics Federations (IAAF) rankings as of November, 2005 (www.iaaf.org, Nov 2005). The BWs of 50 kg for women and 65 kg for men were selected based on the mean BWs of samples of national-class female (Morikawa et al., 2001, $N = 26$, mean BW = 51.8 kg) and male (Saunders et al., 2004, $N = 81$, mean BW = 66.6 kg) middle-distance runners.

Using these elite lower limit values is actually more advantageous to novice runners than using those of the reference man and woman because this affords everyone above 50 kg (women), 65 kg (men), and/or 25 years of age a handicap.

Fundamentally, RT_{age} is the equivalent RT if the runner were "made younger" to the age of 25 years. This entails computing the change in VO_{2max} with the age change via Jackson's slope values (1995, 1996) as well as the resulting RT using Equation 1. Though the equation becomes a bit lengthy, it can be broken down into several steps. First, the equivalent VO_{2max} is computed at the specified RT and BW with Nevill's Equation 1 (1992). This involves both the conversion of run speed to run time and absolute ($l \cdot min^{-1}$) to relative VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$), both simple arithmetic operations. Second, the resultant relative VO_{2max} is increased by adding actual minus target age (25 years) and multiplying that number by the slopes of Jackson's (1995,1996) age vs. VO_{2max} slopes, 0.25 and 0.26 $ml \cdot kg^{-1} \cdot min^{-1} \cdot year^{-1}$ for women and men, respectively. Third, this adjusted VO_{2max} is then used to recompute the RT_{age} using Equation 1.

RT_{BW}, the adjusted RT due to BW alone, is computed by applying Equation 5: $RT \alpha BW^{1/3}$. Similar to RT_{age}, RT_{BW} is the functional equivalent of creating a scale model of the runner at the standard weight of 50 and 65 kg, for women and men, respectively and recomputing the resulting RT. If Equation 5 dictates that a change in $BW^{1/3}$ is directly proportional to RT, then:

$$RT_{BW} = RT \cdot (X \cdot BW^{-1})^{1/3} \qquad (8)$$

where X = 50 and 65 kg, for women and men, respectively. Substituting into Equation 7, this yields the final basic formula to compute RT_{adj}:

$$RT_{adj} = RT_{age} \cdot (X \cdot BW^{-1})^{1/3} \qquad (9)$$

Armed with RT_{age} and RT_{BW}, and, of course, the actual RT, one can now apply Equation 7 to compute the final RT_{adj}, which is that adjusted for BW and age. Age and BW below the standard values should be entered as the standard values (e.g., “25” would be entered for an age of 18 and “65” would be entered for a male BW of 59 kg) because of the unknown nature of the physiological and allometric modeling for run times with children and young adults. Furthermore, the 5KH is designed to overcome the unavoidable RT increase due to age and BW, which primarily occurs only in adulthood. The formula is not designed to handicap young, pre-pubertal runners for being below the age and BW standards.

RESULTS

Table 1 shows four hypothetical examples of male and female runners and the adjusted run times associated with age alone, RT_{age}. Runner A receives minor credit for age because he is close to the age standard of 25 years. The 9 s of handicap he receives is due to the three extra years above 25 that would reduce his VO_{2max}. Note that runners B and D, who are 18 and 14 years, respectively, away from the standard of 25 years, receive the most handicap for age which shows up in the RT minus RT_{age}.

Table 1 also shows RT_{BW} for the same four runners. Runners B and D receive a larger handicap for BW than age because, physiologically, each experiences a greater handicap for being heavier compared to being older. Incidentally, Nevill’s Equation 1 (1992) could have been used to compute the RT_{BW}, yielding approximately a 1% difference from the RT_{adj} obtained using Equation 8. This is because the 5KH model was predicated on Equation 4 which is slightly different from that derived from Equation 1 where the ratio of the VO_{2max} and BW exponents was not exactly 1.0. Our decision to use Equation 4 rather than Equation 1 for BW adjustment was based on our preference to defer to that which is theoretically more defensible rather than empirical. Nevertheless, either approach yields very similar results.

Finally, Table 1 shows the RT_{adj} column. Runners B and D, who run considerably slower than their counterparts of the same gender, actually score lower RT_{adj} values because they are older and heavier. Furthermore, for each runner, the handicap due to age (RT minus RT_{age}) plus that due to BW (RT minus RT_{BW}) is greater than the the total handicap (RT minus RT_{adj}) because of Equation 7. In other words Equation 7 shows that the individual handicaps are not additive. The resulting equations, in the form that can be quickly adapted to a common spreadsheet software program, for BW (kg), AGE (years), and RT (sec), are:

Women's RT_{adj} = (59.31*BW^1.03/((((((59.31*BW^1.03/RT)^(1/1.01))*1000/BW+(AGE- 25)*0.25))*BW)/1000)^1.01)*(50/BW)^(1/3) (10)

Men's RT_{adj} = (59.31*BW^1.03/((((((59.31*BW^1.03/RT)^(1/1.01))*1000/BW+(AGE-25)*0.26))*BW)/1000)^1.01)*(65/BW)^(1/3) (11)

DISCUSSION

To our knowledge, the 5KH is the first age and BW distance run handicap model developed using documented relationships between age and BW on distance run time. The formula is based on the scale model approach that essentially recalculates a runner's time if he/she were 25 years of age and 50 or 65 kg BW, for women and men, respectively. This adjusted time, RT_{adj}, can be used to compare against any other runner of the same gender but of different BW and age. Figure 1 shows four hypothetical men and women of varying ages and BW and the effect of the overall handicap. Clearly, an older, heavier and slower runner can "compete" with younger, lighter and faster runners.

One might posit that the 5KH rewards excess body fat. Detailed analysis of some "what-if" scenarios suggests otherwise. Consider a man, 45 years, 85 kg, 15% body fat, who runs a 1500 s (25:00) 5K. His RT_{adj} would be 1227 s (20:27). If, however, he gained 3 kg of fat weight with no change in functional capacity, then his RT, according to Equation 1, would change to 1556 s (25:56), 56 s slower. His new RT_{adj} would be 1253 s (20:53), for a net slower RT_{adj} of 26 sec. Conversely, if he gained 3 kg of only muscle mass, assuming that functional capacity remained proportionally the same with respect to lean body mass, he would show a net improvement of 13 s in RT_{adj}. Finally, if the 3 kg gain in weight maintained the same percent body fat with similar functional capacity assumptions, the calculations reveal that his RT_{adj} would remain unchanged. This is expected because he would essentially be a larger scale model of himself. In short, excess fat weight is disadvantageous for the 5KH.

Validation of the 5KH is an important objective associated with any such model, but should be done only after careful consideration of the model's characteristics. From a simplistic perspective, a valid model means that the bias against heavier and older runners is eliminated. Statistically, this could be ascertained by correlating age and BW each with RT_{adj}; both correlations should be near zero. For a large sample of 5K runners, however, this is not likely even with a valid model. For example, few runners will give maximum effort. This will lead to slower RT performance and RT_{adj} scores not commensurate with age or BW, yielding a spurious effect on the correlation. Furthermore, as mentioned previously, runners who are heavier due to excess body fat, will have slower than expected RT_{adj} scores. The 5KH's advantage, however, is that while effort and percent body fat are not directly measured, the model does penalize runners who give less than a maximum effort and/or carry excess body fat, a desirable outcome from a health perspective. When attempting to validate the 5KH, therefore, researchers need to control for the effects of effort and body fatness or at least consider them in the interpretation of the validation data. Additional information regarding the practice application of the 5KH will be available upon completion of our ongoing validation and implementation studies.

We compared the 5KH standards to those of the aforementioned WAVA (http://www.howardgrubb.co.uk/athletics/wavalookup.html, Nov 2005), and their age-only grading formula for the 5K. Because their data include the world best performance for different age categories, and the older categories have fewer competitors, we expected the WAVA model to provide a larger handicap for increasing age. Indeed, as shown in Figure 2, for an average RT, male and female, the WAVA standards show a steeper slope than the 5KH for either gender, indicating a larger handicap for older runners than physiological modeling supports. Furthermore, they more closely coincide with those of the 5KH at the lighter weights, which is to be expected because world bests across all age groups are most likely from light runners. Finally, the WAVA model, for heavier, younger runners, yields a significantly smaller handicap than the 5KH because the WAVA model makes no adjustment for body weight.

In conclusion, we have detailed the derivation of the 5KH, an age and BW handicap model for 5K runners, which yields an adjusted race time, RT_{adj}, based on the contribution of these two factors. This contribution has a theoretical and physiological basis that appears defensible. We recommend rigorous large scale validation studies of this model, which we are currently conducting; however, careful interpretation of results will be important given the likelihood that the handicap is not likely to eliminate all effects of age and BW due to the influences of effort and/or body fatness.

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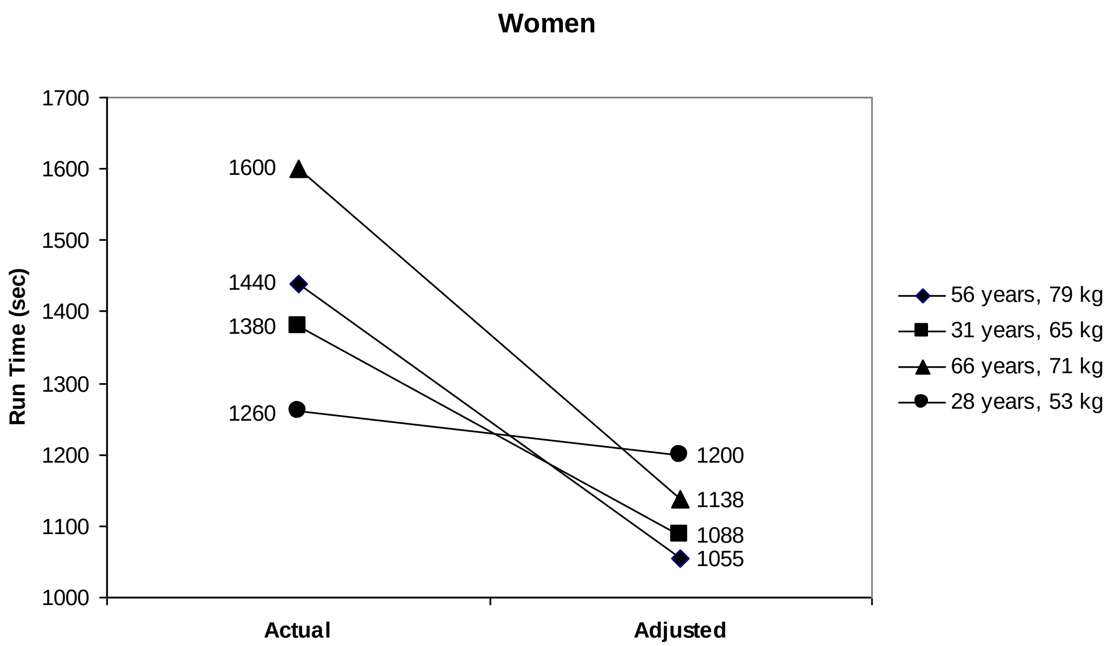
Table 1. Four Hypothetical Examples of Runners with Handicaps for Age, BW, or Both

Subject	**Gender**	**RT (s)**	**Age (years)**	**BW (kg)**	**RT_{age} (s)**	**RT_{BW} (s)**	**RT_{adj} (s)**
A	M	1080	27	68	1071	1064	1055
B	M	1212	43	89	1128	1091	1005
C	F	1104	28	55	1090	1069	1056
D	F	1315	39	79	1229	1129	1055

RT (s) = actual run time
BW (kg) = body weight
RT_{age} = RT adjusted by Age only
RT_{BW} = RT adjusted by BW only
RT_{adj} = Run Time (RT) adjusted by Age and BW

Figure Caption

Figure 1. The 5K Handicap (5KH) for four hypothetical women and men of varying age and body weight. Run time values are shown adjacent to each data point.


Women
1700
1600
1500
1400
1300
1200
1100
1000
Run Time (sec)
1600
1440
1380
1260
1200
1138
1088
1055
Actual
Adjusted
56 years, 79 kg
31 years, 65 kg
66 years, 71 kg
28 years, 53 kg

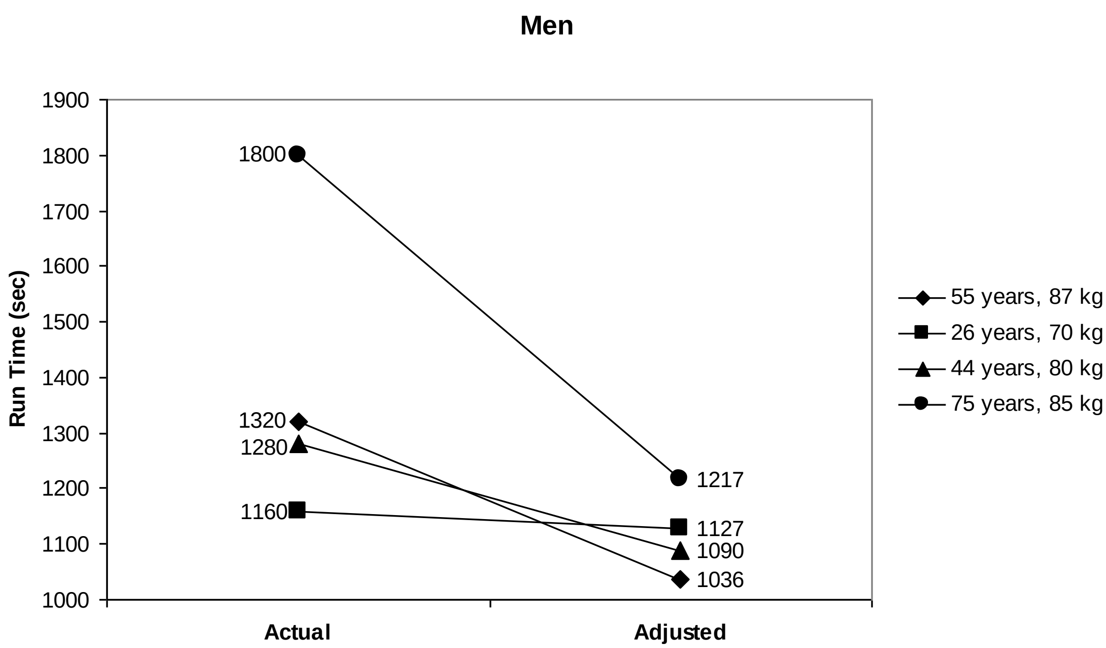
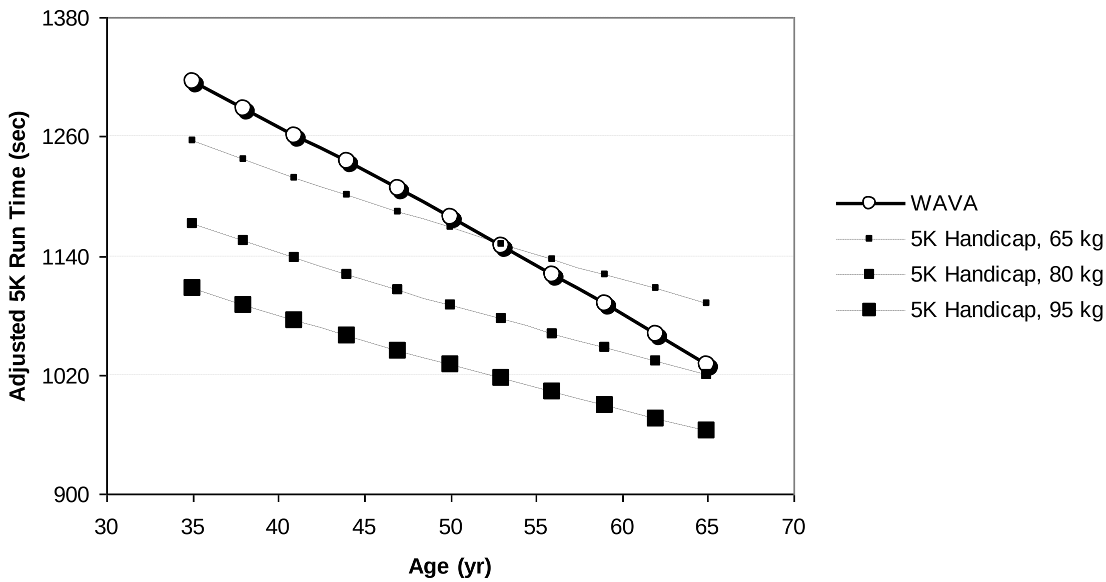

Men
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
Run Time (sec)
1800
1320
1280
1160
1217
1127
1090
1036
Actual
Adjusted
55 years, 87 kg
26 years, 70 kg
44 years, 80 kg
75 years, 85 kg

Figure Caption

Figure 2. Comparison of World Association of Veteran Athletes (WAVA) age handicap standards with those of the 5K Handicap which handicaps both age and weight.

Men with a 22:00 (1320 sec) 5K Actual Run Time



Women with a 25:00 (1500 sec) 5K Actual Run Time