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A SIMPLE INDEX TO ADJUST MAXIMAL STRENGTH MEASURES BY BODY MASS

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ABSTRACT

A SIMPLE INDEX TO ADJUST MAXIMAL STRENGTH MEASURES BY BODY MASS.

PAUL M. VANDERBURGH. ***JEP*ONLINE, 1999, 2(4):7-12.** Numerous recent studies have suggested that maximal strength lifts (S) can be adjusted by body mass (M) using the following expression based on allometric scaling (AS): $S \cdot M^{-2/3}$, thus facilitating appropriate comparisons of strength between individuals of different size. However, use of this convention has not been readily embraced, probably because of the cumbersome nature of calculating with exponents and the strange units or "currency" that results. To provide a more "user friendly" method of adjusting maximal lifts by M, a mathematical transformation of the function associated with the $S \cdot M^{-2/3}$ index was used to create a simple table for each gender that easily facilitates comparisons. For example, two men, A and B, with S values of 75 and 65 kg, respectively, and M values of 67 and 52 kg, respectively, can be compared to each other by multiplying the index, I, based on M (0.9083 for A and 1.0755 for B) by S. The resulting scores, S_{adj}, 79.41 kg for A and 81.50 kg for B, are body-mass adjusted indices of S. Therefore, Man B is considered to have a larger body-mass-adjusted S. This index has two advantages over traditional AS methods. First, no exponents are used, thus facilitating easier calculations. Second, the resulting units of S_{adj}, "kg," are still the same as were those of S, contributing to a more meaningful interpretation. We recommend the use of such a table when individual comparisons of body-mass adjusted strength for men or women is warranted.

Key Words: muscle strength, allometric scaling, power function

INTRODUCTION

Little doubt exists about the positive relationship between muscular strength (S) and body mass (M). Discussion continues, however, over how to best express strength as a function of body mass for the specific purposes of individual or group comparisons. This stems from the theoretical and empirical support for S being related directly to $M^{2/3}$ and not M. The M-adjusted expression of strength would be $S \cdot M^{-2/3}$ and can be used for either group or individual comparisons. The theoretical basis centers on the principle of "geometric similarity" which suggests that S, a two-dimensional factor, and M, a three-dimensional factor, conforms to the following relationship: $S \propto M^{2/3}$ (1). Thus, S could be expressed as $S \cdot M^{-2/3}$ to adjust for the effect of M. Empirical support for the validity of the $S \cdot M^{-2/3}$ expression as applied to isometric (grip strength) or variable resistance strength measures for different populations can be found elsewhere (2,3,4,5,6).

Stature, or height (H), could also be used to adjust maximal strength scores. Because it is essentially an index of length, a one-dimensional factor, then H^2 should be proportional to S. No empirical evidence, however, is available to substantiate this for strength. Furthermore, no theoretical support exists for how H and M could be used in a multivariate fashion to scale S scores, due primarily to their colinearity. Finally, body mass is clearly the most widely used scaling variable for strength. In fact, no evidence of H-adjustment could be found for any measures of strength, and consequently, H is not considered in the present data.

Evidence does exist to refute the contention that the optimal M exponent for strength is 2/3. Batterham and George (7), found that the universal M exponent of 2/3 does not eliminate bias among elite Olympic-style weightlifters, a finding replicated with elite powerlifters (5). In this latter study, however, Vanderburgh and Dooman contend that the reason the 2/3 exponent approach tends to "bias" those in the extreme weight classes is because far more competitors are found in middle weight classes (not surprising as M tends to be normally distributed in the population). As these lifters have more competition, one should not be surprised when middle weight class lifters tend to receive the highest $S \cdot M^{-2/3}$ scores. Furthermore, when Batterham and George (7) eliminated the heaviest lifters (those who have no upper limit of M) from their analysis, the resulting exponent for M was 0.68, nearly identical to 2/3. Others have reported the 95% confidence intervals for M exponents not containing the 2/3 value for elite lifters (8), schoolboys (9), and adult women (10). Explanations for this are offered as failure to account for the undue influence of body fat, training status, and pubertal status (6,7). When these confounding factors are considered, the evidence to support the use of the $S \cdot M^{-2/3}$ convention seems somewhat substantiated.

To compare two individuals of different size on some index of S, one could divide the weight lifted (S) by $M^{2/3}$ for each and compare the resulting values. The largest values correspond to the individual with the higher M-adjusted S. Similarly, this index can be computed for an entire sample of subjects and tests for group difference can be applied to these values. Generally this process is somewhat analogous to analysis of covariance (with M as the covariate) but usually entails the simpler t-test. One limitation of this group difference approach is that the 2/3 M exponent is not as statistically appropriate as computing the actual sample specific exponent, the latter of which maximizes control for the independent effect of body mass. An argument can be made, then, that individual comparisons of strength can be done conveniently and appropriately using the 2/3 M exponent while group comparisons, which will require some type of inferential statistical analysis, are better done by computing the sample specific exponent.

Nevertheless, the convention of expressing S in terms of M as $S \cdot M^{-2/3}$ has clearly not been embraced by exercise physiologists or fitness experts as a feasible way to compute M-adjusted strength. The reasons are probably many and varied but likely include the problematic "currency" of the index itself, with units of $kg_{lifted} \cdot kg^{-2/3}$. Fitness experts and exercise physiologists are probably familiar with the use of a simple S/M ratio and associated values considered "above average" or "poor." For example, a bench press lift of greater than one's body weight, or S/M > 1, is often considered exceptional for a woman. Therefore, a woman with S = 70 kg and M = 70 kg would receive a score of 1.0 $kg_{lifted} \cdot kg^{-1}$. Using the $S \cdot M^{-2/3}$ convention, however, the same woman would receive a score equal to $70 \cdot 70^{-2/3}$ $kg_{lifted} \cdot kg^{-2/3}$, or 4.12 $kg_{lifted} \cdot kg^{-2/3}$. The units of the latter are different and, as such, cannot be compared with standard ratios. Furthermore, the score of 4.12 $kg_{lifted} \cdot kg^{-2/3}$ must be evaluated against a new "currency" which suggests that exceptional scores for the bench press are now above 4.12. The second problem with the $S \cdot M^{-2/3}$ index is that it is difficult, if not impossible, to compute by hand, something that fitness testing personnel and even individuals might find troublesome, particularly in the field testing setting. One simple index used and developed by the International Powerlifting Federation (IPF), the Wilks index, is presently used for IPF competitions to determine the "Champion of Champions," or the lifter who achieved the heaviest lifts when taking body size differences into account. The index is simply a dimensionless number from a published table (11) based on a competitor's body mass to the nearest 1/10 kg, which is multiplied by the total weight lifted. The resulting adjusted score is that which is compared between lifters to determine the "Champion of Champions." Use of this index has recently been validated for use with elite men and women powerlifters (6) for the total lift (bench press + squat + deadlift) and the bench press alone.

To make M-adjusted comparisons of S between non-elite individuals, one could simply apply the Wilks index. This may, however, be problematic for several reasons. First, this index is based on real data from elite-level powerlifts (bench press, deadlift, and squat), not on data from non-elite subjects using other strength measures. In other words, it is valid for use in one specific setting with elite subjects. Second, it is based on a polynomial transformation of real data from elite powerlifters. Such a transformation forces the curve to fit the data, and this may tend to penalize the lifters in the middle weight classes (those from whom one would expect superior performance as more competitors are found in these weight classes – as discussed previously). This transformation allows the curve (the function that "levels the playing field") to "bend at both ends" so that the "Champion of Champions" winner is not always a middle weight class lifter. As mentioned previously, this "spurious" effect has been observed and contested by others (5,6).

Another concern related to the polynomial nature of the Wilks index is that it has no theoretical basis because such a transformation forces the best-fit curve to fit existing real data, unlike the theoretically more supportable allometric model (e.g., $S \cdot M^{-2/3}$). More discussion of the issue of model fit versus theoretical appropriateness as applied to strength measures can be found elsewhere (5,6,7). Given that the allometric model has both theoretical and empirical support for a variety of subjects in a variety of strength measures, the argument against using the Wilks index for non-elite subjects in such settings seems appropriate.

In short, the computation of $S \cdot M^{-2/3}$ is theoretically and empirically defensible for measures of strength among non-elite subjects but is rather cumbersome to apply to practical situations. The Wilks index has a much more practical utility but exhibits questionable generalizability characteristics to non-elite subjects with little theoretical basis. Therefore, a need for a simple Wilks-like index based on the allometric approach seemed apparent. The purpose of this paper, then, is to compute and present such an index, I, in the form of a table, based on M, which is multiplied by S to yield a new adjusted S, or S_{adj}. S_{adj} would retain the same units of S, can be easily computed by hand, and is based on a mathematical transformation of the allometric $S \cdot M^{-2/3}$ index. It would, therefore, be considered an appropriate expression of M-adjusted S.

METHODS

As the objective was to produce a simple multiplicative index similar in utility to that of the Wilks index, one assumption and selection of one reference point had to be made. First, that the appropriate adjustment of S by M should be $S \cdot M^{-2/3}$ was assumed. As stated previously, this point has received considerable empirical and theoretical support particularly for expressions of strength for men and women. Second, reference weights of 73.0 kg for men and 60.0 kg for women were selected as those which would receive the index of "1.00." These choices, though completely arbitrary, serve as a reference point from which all other indices could be calculated. Any weight combination could be chosen and the resulting convention would be mathematically equivalent to any other choice. In fact, the same holds true for one index for men and women. The choice for gender-specific reference values, however, allows minimal deviation from the actual score for values somewhat close to the estimated mean body mass values for men and women. For example, M values for men above and below 73.0 kg will have index values less than and greater than 1.0, respectively. When S scores are

Table 1. Men's Index based on body mass. Left column indicates mass in units of 10 kg and numbers in 1st row indicate units in 1 kg. For example, a subject of 64 kg body mass would have an index of 1.0917.

	0	1	2	3	4	5	6	7	8	9
40	1.4934	1.4690	1.4456	1.4231	1.4015	1.3806	1.3605	1.3412	1.3225	1.3044
50	1.2870	1.2701	1.2538	1.2379	1.2226	1.2077	1.1933	1.1793	1.1657	1.1525
60	1.1397	1.1272	1.1150	1.1032	1.0917	1.0805	1.0695	1.0588	1.0484	1.0383
70	1.0284	1.0187	1.0092	1.0000	0.9910	0.9821	0.9735	0.9651	0.9568	0.9487
80	0.9408	0.9330	0.9254	0.9180	0.9107	0.9035	0.8965	0.8896	0.8829	0.8762
90	0.8697	0.8634	0.8571	0.8509	0.8449	0.8389	0.8331	0.8274	0.8217	0.8162
100	0.8107	0.8054	0.8001	0.7949	0.7898	0.7848	0.7799	0.7750	0.7702	0.7655
110	0.7608	0.7563	0.7517	0.7473	0.7429	0.7386	0.7344	0.7302	0.7260	0.7220
120	0.7180	0.7140	0.7101	0.7062	0.7024	0.6987	0.6950	0.6913	0.6877	0.6842
130	0.6806	0.6772	0.6738	0.6704	0.6670	0.6637	0.6605	0.6573	0.6541	0.6509
140	0.6478	0.6448	0.6417	0.6387	0.6358	0.6329	0.6300	0.6271	0.6243	0.6215
150	0.6187	0.6160	0.6133	0.6106	0.6080	0.6053	0.6027	0.6002	0.5976	0.5951

multiplied by these indices, the adjusted score is minimally affected when M is close the mean. On the other hand, to set the reference weight at a large value such as 100 kg (where the index value is set at 1.0), will yield very large deviations between S_{adj} and S.

The transformation intent was to create the index by which S could be multiplied so that men heavier than 73.0 kg would receive a "decrement" index (less than 1.0) and those lighter than 73.0 kg would receive an "increment" index (greater than 1.0). The index, I, must adjust an allometric score, $S \cdot M^{-2/3}$ as follows. The index at certain M and identical S values for men must conform to the following relationship (the same applies to women but with a reference weight of 60.0 instead of 73.0):

$$S \cdot M^{-2/3} = (S \cdot 73^{-2/3})I \qquad (1)$$

Equation 1 illustrates that, for the same weight lifted, S, a subject of weight M, would have his score (the theoretically and empirically correct allometric score of $S \cdot M^{-2/3}$) adjusted by I. Rearranging the equation and solving for I yields:

$$I = 73^{2/3} \cdot M^{-2/3} \qquad (2)$$

RESULTS

For all weight values between 40 and 150 kg, in increments of 1.0 kg, indices were computed and indicated in tabular form using the Microsoft Excel (Microsoft, Seattle, WA) software program (Tables 1 and 2). This range is intended only for adults as maturational changes would tend to confound the S to M relationship in children.

For example, two men, A and B, with S values of 75 and 65 kg, respectively, and M values of 65 and 55 kg, respectively, could be compared in absolute terms (S only), as a simple ratio ($S \cdot M^{-1}$), or as a scaled term (S_{adj}, where S_{adj} = S x I, where I is from the table, based on M). Table 3 illustrates the effects of such comparisons to include percent differences (values indicate how much stronger, as a percentage, the larger score is). Clearly, the method used has a significant impact on the comparison of S between subjects.

DISCUSSION

The tables of indices are actually nothing more than an application of the body-mass adjusted expressions for strength, $S \cdot M^{-2/3}$. As discussed previously, the original units and "currency" are maintained in the S_{adj} score, something not possible with the $S \cdot M^{-2/3}$ convention for individual comparisons. As such, differences between individuals on S_{adj} or $S \cdot M^{-2/3}$ would be identical in percent difference.

A more important limitation of using this index, I, is a lack of appreciation for how exponents might vary in populations. Recent literature is replete with examples of allometric modeling applied to various measures of strength or power. Determination of a

Table 2. Women's Index based on body mass. Left column indicates mass in units of 10 kg and numbers in 1st row indicate units in 1 kg. For example, a subject of 64 kg body mass would have an index of 0.9579.

	0	1	2	3	4	5	6	7	8	9
40	1.3104	1.2890	1.2684	1.2487	1.2297	1.2114	1.1938	1.1768	1.1604	1.1446
50	1.1292	1.1144	1.1001	1.0862	1.0728	1.0597	1.0471	1.0348	1.0229	1.0113
60	1.0000	0.9890	0.9784	0.9680	0.9579	0.9480	0.9384	0.9291	0.9199	0.9110
70	0.9023	0.8938	0.8855	0.8774	0.8695	0.8618	0.8542	0.8468	0.8395	0.8324
80	0.8255	0.8187	0.8120	0.8055	0.7991	0.7928	0.7866	0.7806	0.7747	0.7688
90	0.7631	0.7575	0.7520	0.7466	0.7413	0.7361	0.7310	0.7260	0.7210	0.7162
100	0.7114	0.7067	0.7020	0.6975	0.6930	0.6886	0.6843	0.6800	0.6758	0.6717
110	0.6676	0.6636	0.6596	0.6557	0.6519	0.6481	0.6444	0.6407	0.6371	0.6335
120	0.6300	0.6265	0.6231	0.6197	0.6163	0.6130	0.6098	0.6066	0.6034	0.6003
130	0.5972	0.5942	0.5912	0.5882	0.5853	0.5824	0.5795	0.5767	0.5739	0.5712
140	0.5684	0.5657	0.5631	0.5605	0.5579	0.5553	0.5528	0.5502	0.5478	0.5453
150	0.5429	0.5405	0.5381	0.5358	0.5334	0.5311	0.5289	0.5266	0.5244	0.5222

sample-specific exponent for M is an empirical process and, therefore, often yields exponents that are not exactly the expected value of 2/3. One might suspect, then, that "arbitrary" and widespread use of the 2/3 exponent as suggested here would lead to situations of not taking M fully into account when comparing individuals or groups. An argument can be made, then, that such scaling should be sample specific and should only serve as a sort of analysis of covariance. Two key points must be considered in response, however. First, although many different exponents have been reported, all contain a 95% confidence interval within which all suitable exponents lie, assuming favorable distributional characteristics of the sample (meaning that using any of them will yield $S \cdot M^{-a}$ & S correlations not different from zero, a necessary condition for an appropriate scaling expression). As mentioned previously, when all confounding factors such as training status, body fatness, and pubertal status are considered, most studies report confidence intervals that contain the 2/3 value. Second, the value of "1" has often not been found in the same confidence intervals (thereby strengthening the argument for not using the ratio method). Third, use of different sample-specific exponents can be quite problematic as different units result from each and interpretation becomes even more difficult. In short, an argument can be made that the 2/3 mass exponent for S, while not perfect, is probably the *single* best adjustment technique.

Table 3. Example of Individual Comparison for Men.

Subj	*S (kg)*	*M (kg)*	*$S \cdot M^{-1}$ (kg/kg)*	*Sadj (kg)*	*%stronger Abs*	*%stronger Ratio*	*%stronger S_{adj}*
A	75	65	1.15	81.04	15.4		3.2
B	65	55	1.18	78.50		2.60	

More research is needed to investigate how isokinetic and isotonic measures of strength scale by various body dimensions. Though the contributions of neural, biomechanical and physiological factors might tend to confound the simple theory underlying the 2/3 exponent, an argument could be substantiated that these factors are just as important in isometric and variable resistance measures of strength. Given that these latter measures have had the 2/3 body mass exponent empirically validated, then the use of Tables 1 and 2 for isokinetic and isotonic measures appears prudent for routine comparison of the strength of individuals. The one caveat worth repeating is that the simple indices proposed in this paper are most useful and appropriate for individual and not group comparisons, in which some type of analysis of covariance is warranted for the latter.

In conclusion, as the new index, I (based on the 2/3 exponent for M), appears to have empirical and theoretical support and is probably superior to simple ratio standards, it may be widely used for individual comparisons of M-adjusted S. The enclosed tables of indices provide a simpler (though mathematically equivalent) way to base individual comparisons on the 2/3 M exponent when related to measures of S.

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