

NORMALIZING VERTICAL GROUND REACTION FORCE PEAKS TO BODY WEIGHT IN HEEL-TOE RUNNING

Jay T. Worobets and Darren J. Stefanyshyn
Human Performance Laboratory, Faculty of Kinesiology, University of Calgary

INTRODUCTION

Studies of the mechanics of running typically include the vertical ground reaction force as an analysis variable; the specific aspects most commonly analyzed being the magnitudes of the active peak and, much more predominately, the impact peak. Many study designs require that comparisons of these peak forces be made between individual and/or groups of subjects. It is apparent in the literature that the majority of authors wish to make these comparisons of peak forces without the influence of body weight, as it has become common practice to normalize these peak forces by linearly scaling them to body weight. Whenever one variable is to be normalized to another, it is important that the relationship between the two variables first be adequately described, and so the proper method of normalization can then be employed. An adequate description of the relationship between peak active or impact force and body weight, however, does not exist in publication. Studies have shown that vertical ground reaction force peaks increase with body weight (Frederick & Hagy, 1986; Kinoshita et al, 1990) but whether the relationships are in fact linear have yet to be elucidated. It was therefore the purpose of this study to: explore linear and nonlinear correlations between vertical ground reaction force peaks and body weight; examine the appropriateness of normalizing by linearly scaling these peak forces to body weight; and test the effectiveness of new normalizing methods.

METHODOLOGY

83 recreational runners (42 male, 41 female) were recruited for the study. The body weight of the subjects ranged from 437.5 to 914.3N, with an average of 677.9N and standard deviation of 94.2N. Data were collected on the left foot of each subject while heel-toe running at 4m/s (± 0.2 m/s) in a standard adidas running shoe. The ground reaction forces were measured with a Kistler force plate sampling at 2400Hz. A fourth-order low-pass Butterworth filter (cutoff frequency of 100Hz) was used to smooth the data before analysis was conducted using Kintrak software. The analyzed variables were peak vertical impact force (F_{VI}) and peak vertical active force (F_{VA}). Average values for each subject were calculated from five trials, then each variable was plotted against body weight. Linear and power curves were best fit to the data, and regression analyses were performed to test the significance of the correlations. The force data were then normalized by linearly scaling to body weight, re-plotted against body weight, and analyzed for linear correlation. Finally, the original force data were again normalized, this time by dividing by body weight to the power of a scaling exponent, then re-plotted against body weight, and analyzed for linear correlation.

RESULTS AND DISCUSSION

Each of the peak force versus body weight plots are shown in Figure 1. The left plots depict the relationship between the non-normalized peak forces and body weight. For both F_{VA} and F_{VI} , the linear and power curves both yielded statistically significant correlations between peak force and body weight (all p-values < 0.01), and similar R^2 values. However, 95% confidence interval estimates of the exponents of the best fit power curves for both F_{VA} and F_{VI} did not include '1' (0.56 – 0.89 & 0.08 - .71, respectively), which indicates that the relationship between these peak forces and body weight is not in fact linear. This provides evidence which suggests that normalizing peak forces by linearly scaling to body weight is not an appropriate normalization method.

Despite finding that the relationships between the peak forces and body weight were not linear, the plots of linearly scaled peak forces versus body weight were still analyzed in order to understand what effect this normalizing procedure had on the data (middle plots of Figure 1). For both F_{VA} and F_{VI} , statistically significant correlations were found between normalized peak force and body weight (both p-values < 0.01). This indicates that the 'normalized' peak forces are still influenced by the variable that they have been normalized to, which suggests that normalizing by linearly scaling is not an appropriate method. Further, this statistical significance was found to be practically significant as well, as the percent differences in normalized peak forces between

individuals 600 and 870N were predicted by the linear regression models to be 10% and 28% for F_{VA} and F_{VI} , respectively.

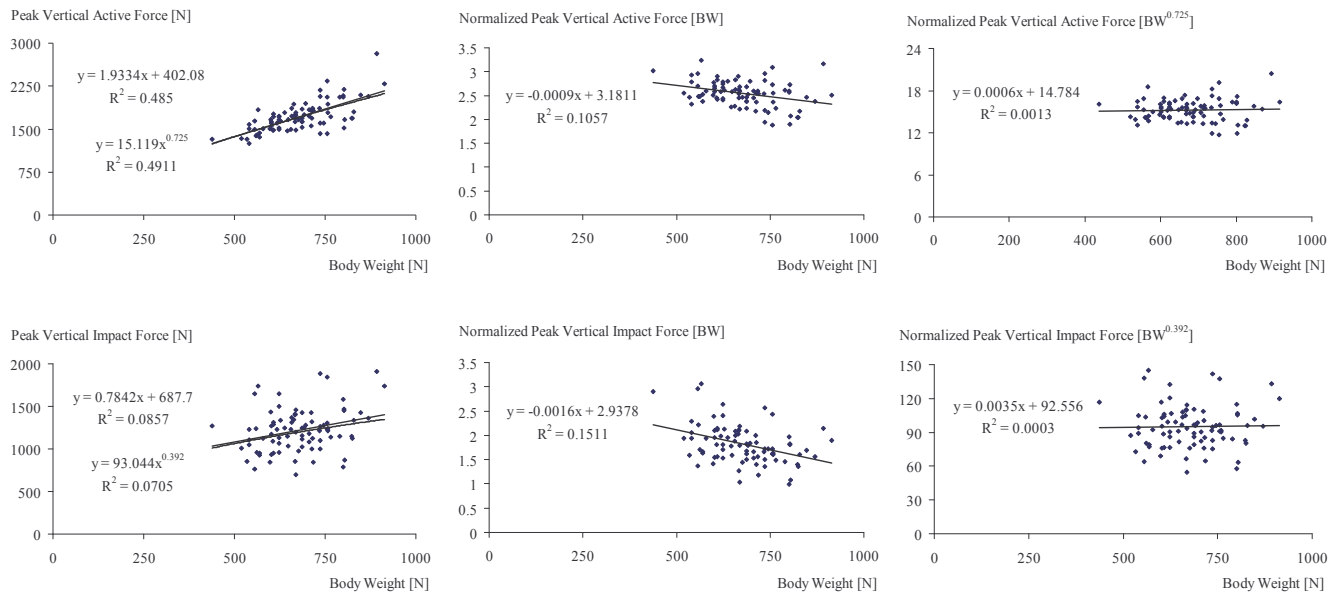


Figure 1. Peak active (top row) and peak impact (bottom row) forces plotted against body weight. The peak forces of the left plots are non-normalized and are best fit with linear and power curves. The peak forces of the middle plots are linearly scaled to body weight and are best fit with linear curves. The peak forces of the right plots are scaled to $BW^{0.725}$ and $BW^{0.392}$ (top and bottom plots, respectively) and are best fit with linear curves.

Since normalizing by linearly scaling was found to be inappropriate, a normalization method based on the best fit power curve was tested. In this way, F_{VA} was normalized by scaling to $BW^{0.725}$, and F_{VI} by $BW^{0.392}$, as these were the exponents in the best fit power curve equations. When these normalized peak forces were plotted against body weight (right plots of Figure 1), no statistically significant correlations were found (both p-values > 0.7). When comparing two individuals weighing 600 and 870N, the percent differences as predicted by the linear regression models were less than 1%. This indicates that normalizing the peak forces by dividing by body weight to the power of an appropriate scaling exponent (as dictated by the best fit power curve) effectively eliminates the influence of body weight on the data set, and so can be considered a successful normalization method.

SUMMARY

The relationships between vertical ground reactions force peaks and body weight during heel-toe running in this study were found to be nonlinear. When normalized by linearly scaling to body weight, the force peaks were found to be still influenced by body weight to a statistically and practically significant degree. It is therefore strongly recommended that the common practice of linearly scaling vertical ground reaction force peaks to body weight as a method of normalization be discontinued.

REFERENCES

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