SPECTRAL DECOMPOSITION OF VERTICAL GROUND REACTION FORCE CURVES

T. R. Derrick, C. A. Knight, B.C. Heiderscheit, J. Hamill

Biomechanics Laboratory, University of Massachusetts Amherst

INTRODUCTION

Ground reaction forces are the external forces on the body that decelerate the center of mass during the stance phase of locomotion. They are often used as a measure of the load placed on the human body. The vertical component of the ground reaction force (VGRF) has the greatest magnitude of the orthogonal reaction forces and it typically has two peaks during heel-toe running. The first peak (impact peak) is caused by the impact between the foot and the ground. It is responsible for changing the velocity of the support leg during the initial impact phase of stance. The second peak has a lower frequency and is caused by the vertical braking of the body followed by vertical push-off. The second peak is often called the active peak because it is under control of active muscles. Even though the active peak has a higher magnitude, it is generally the impact peak that is analyzed in order to estimate injury potential. The reasoning is that the high frequency nature of the impact peak creates greater stress on the biological tissues of the body.

Bobbert *et al.* (1991) proposed a method of decomposing the VGRF into the contributions of the support leg and the rest of the body by double differentiation of segment center of mass locations. The impact curve could be constructed by calculating the support leg center of mass acceleration and then multiplying by the support leg mass. The active curve was constructed by calculating the acceleration of the remaining body segments and multiplying by the remaining body mass. This decomposition allowed the authors to determine the magnitude of the impact peak independent of the rest of the curve. The advantage of this procedure is that changes in the timing of the impact peak will not cause changes in the magnitude of the impact peak. This may be important because running shoe midsoles are known to produce both timing and magnitude changes (Foti and Hamill, 1993). These changes are not independent in a typical time domain analysis but they can be disassociated in a frequency domain analysis. The purpose of this study was to investigate a method of decomposing the VGRF curve that does not require differentiation of position data but relies on the frequency characteristics of the impact and the active portions of the VGRF.

METHODOLOGY

Five male recreational runners completed 5 trials in 3 different running shoes. The average mass of the subjects was 70.8 ±12.4 kg. The shoes differed only in the density of the midsole material (soft: 40, medium: 55, hard: 70 shore A scale). After signing an informed consent document, the subjects were asked to run down a runway at 3.83 m/s. Velocity was monitored with infrared timing lights placed 2.5 m on either side of the force platform. Trials were accepted if the subject was within 5% of the desired speed, the entire right foot landed on the force platform and there was no visible alteration of the stride as the subject ran across the platform. VGRF data were recorded from the force platform at 1000 Hz using a 12-bit analog to digital converter. Commercially available software (DADiSP) was then used to transform the stance phase of the VGRF data of each trial into the frequency domain using a Fast Fourier transform. Inverse transforms were performed on the resulting coefficients twice - once to reconstruct the frequencies below 3 Hz and once using the frequencies above 3 Hz. The 3 Hz cutoff was used because it produced the best separation of the impact from the VGRF curve. This spectral decomposition procedure resulted in two separate time series curves representing the impact and the active portions of the original VGRF curve. Figure 1 illustrates a typical VGRF curve and the resulting active and impact curves. The peak magnitude (PK) and the time to peak magnitude (TPK) values were recorded for each of the decomposed VGRF curves.

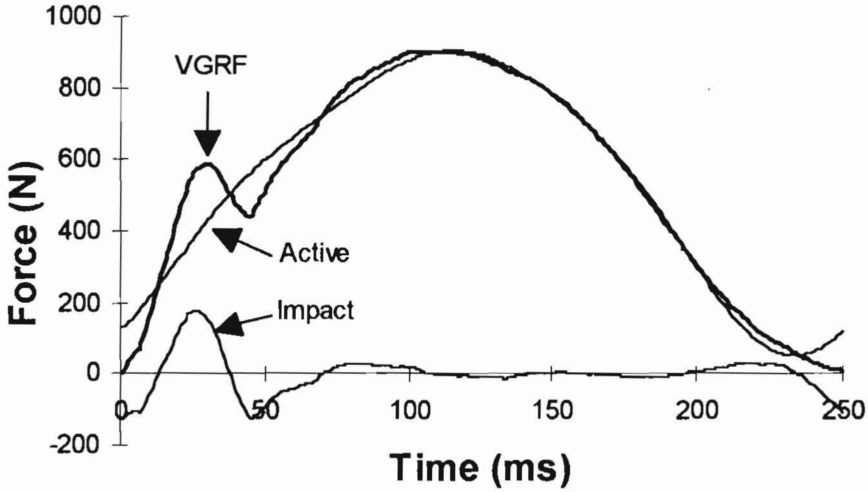

Figure 1 - VGRF decomposition.

RESULTS AND DISCUSSION

The active and the impact curves of Figure 1 always sum to equal the VGRF curve but the separation is not perfect. There are frequencies present at the beginning and the ending of the VGRF curve that are slightly higher than 3 Hz. The active curve contains only the frequencies below 3 Hz, therefore the general shape of the VGRF curve is imperfectly represented by the active curve in the area of the endpoints. The endpoints could be more accurately represented if a cutoff value of 4 Hz. was used instead of 3 Hz but then the active curve would start to show a small peak occurring at the time of peak impact.

The decomposed impact curve shows characteristics of damped oscillations. The peak impact occurs slightly before the peak impact of the VGRF curve. Subsequent oscillations are greatly reduced in magnitude. The average peak magnitudes and times of both the impact and active curves are presented in Table 1. The impact peak for the soft shoe had a greater magnitude than the medium or hard shoes. This may indicate that this shoe midsole experienced maximum compression during the heel strike or that the subjects perceived the softness of the midsole and adjusted their kinematics resulting in larger impact forces. These results were consistent with the peak impact values of the VGRF curve (soft: 1273.7, medium: 1173.9, hard: 1231.9 N). It would be expected that the values of the impact peak would not be consistent with the VGRF values if there were a larger difference in impact TPK between the shoes. In this case the impact curve would be summed with the active curve so that impact peaks that occur closer to midstance would appear to have a greater magnitude in the VGRF curve. The timing would not affect the magnitude of the decomposed impact curve. There were essentially no differences in the active PK in either the VGRF curves or the active curves. This suggests that shoe midsole density has a greater influence on the impact peak than the active peak.

Table 1.
Mean values for PK and TPK variables.

Midsole	Soft	Medium	Hard
Impact PK (N)	240.1	212.8	238.7
Impact TPK (ms)	28.3	26.1	26.6
Active PK (N)	1241.2	1233.4	1244.7
Active TPK (ms)	107.9	108.7	104.0

CONCLUSIONS

Since the impact peak component is of a higher frequency than the active component, it is possible to separate the two curves using spectral techniques. This process is analogous to Bobbert's method of separating the impact by calculating the contribution of the support leg center of mass deceleration to the total VGRF. The spectral decomposition procedure has the advantage of dealing directly with the VGRF data from the force platform rather than twice differentiated position data. This results in a procedure that is simpler to collect and to analyze. These results indicate that this decomposition procedure can be used to separate the impact characteristics of the VGRF from the remainder of the curve.

REFERENCES

Bobbert, M.F., Schamhardt, H.C. and Nigg, B.M. (1991). Calculation of vertical ground reaction force estimates during running from positional data. *J Biomech*, Vol 24:12, 1095-1105.

Foti, T.A. and Hamill, J. (1993). Shoe cushioning effects on vertical ground reaction force during running. In *Proceedings of the XIVth Congress of the International Society of Biomechanics I*, 418-419.

Soudan, K. and Dierckx, D. (1979). Calculation of derivatives and Fourier coefficients of human motion data while using spline functions. *J Biomech*, Vol 21, 21-26.