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BARBELL KINEMATICS SHOULD NOT BE USED TO ESTIMATE BARBELL AND BODY SYSTEM CENTRE OF MASS POWER IN THE BACK SQUAT

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This study compared measures of barbell-and-body system centre of mass (CM) power obtained by multiplying ground reaction force (GRF) by a) barbell velocity, b) CM velocity derived from 3D motion analysis, and c) CM velocity derived from GRF during back squat performance. Results showed that the barbell was displaced (13.4%; $p<0.05$) more than the CM at a velocity that was 16.1% ($p<0.05$) greater than the CM (both GRF and 3D derived), which resulted in the GRF by barbell velocity power been 18.7% ($p<0.05$) greater than the GRF by 3D derived CM power. These were underpinned by significant differences between the velocity of the barbell and the trunk, upper-leg, and lower-leg ($p<0.05$), demonstrating that a failure to consider the kinematics of body segments during back squat performance can lead to a significant overestimation of CM power.

KEY WORDS: back squat, methodology, strength and conditioning.

INTRODUCTION: Resistance exercise power is an important measure that is often used to assess neuromuscular function and prescribe resistance training loads (Li *et al.,* 2008). Its measurement relies on an understanding of the mechanical principles that underpin it, and the ability to record accurate measures of the force applied to the resistance of interest, and its resultant velocity (Li *et al.,* 2008), where the resistance of interest tends to be the barbell or CM. However, investigators have recently suggested that accurate measures of power can only be obtained if barbell and CM parameters are combined, multiplying the velocity of the barbell by the force applied to the CM (GRF) (Cormie *et al.,* 2007).
This approach is based on the assumption that the velocity of the barbell represents the velocity of the CM (Cormie *et al.,* 2007), but ignores the contributions made by large body segments to CM motion. There is evidence to suggest that failure to consider these contributions can lead to a significant overestimation of the velocity of the CM and the power applied to it (Li *et al.,* 2008). However, the limitations of this methodology remain largely unchallenged and require urgent research attention so that overestimations of the velocity of the CM and the power applied to it are avoided.
Analysis of the CM using three-dimensional (3D) motion and force platform analysis enables comparison of power that is obtained by multiplying GRF by the velocity of the barbell, and the velocity of the CM. Further, it enables study of the affect that differences between the displacement and velocity of the barbell, the CM, and its composite body segments, has on differences in CM power. Thus, it is critical that research using this type of analysis is undertaken so that methodological concerns about the misapplication of the combined method can be investigated and insight about differences in CM power obtained using the different methods gained.
Therefore, the aim of this study was to compare measures of power obtained by multiplying GRF by the velocity of the barbell, and the velocity of 3D motion analysis derived CM, and to establish differences between the velocity of the GRF and 3D motion analysis derived CM. It was hypothesized that multiplying GRF by the velocity of the barbell would lead to a significant overestimation of CM velocity and power.

METHODS: Subjects attended two laboratory based testing sessions. During the first session maximal back squat strength (one repetition maximum: 1 RM) was established. Seven days later subjects returned to the laboratory to perform power testing, where after a warm up they performed three maximal effort single back squats with 60% 1 RM, with two minutes rest between each lift. This load was selected because it is the load with which power tends to be maximized during back squat performance (Siegel *et al.,* 2002). The descent phase of squat performance continued until the tops of the thighs were parallel to the ground, after which subjects were instructed to perform the ascent phase as quickly as possible.

Before data collection 17 spherical, retro-reflective markers illuminated by spotlights positioned behind each camera were affixed to the left and right barbell end, and anatomical landmarks. Three high speed digital cameras (Basler A602fc-2, Ahrensburg, Germany) positioned around the front of and approximately 5 m from the subject recorded squat performance after first recording a 17 point calibration frame (Vicon Motus, Oxford, UK). Simultaneously, vertical GRF of both feet were recorded from two 0.4 by 0.6 m force platforms (Kistler, Alton, UK). Motion and GRF data collection was synchronized using a Vicon MX control unit. Motion was captured at a sampling frequency of 100 Hz, and GRF at 500 Hz. Vicon Motus 9.2 software was used to digitize the top of the head, sternal notch, left and right shoulder, elbow, wrist, hip, knee, and ankle joint centres, mid-toes, and barbell ends, from which an 18 point, 13 segment digital model of the barbell, head, trunk, upper and lower arms, upper and lower legs, and feet was created; hand mass was combined with barbell mass. Markers affixed to the barbell ends were digitized automatically, but the anatomical markers were not used to identify the remainder of the points of interest because back squat performance led to significant hip and shoulder marker drop out, and shoulder marker skin artefact. Therefore, remaining points of interest were digitized manually.

Following digitization, data were reconstructed using Vicon Motus 9.2 software and raw data smoothed using a low pass Butterworth filter with a cut off frequency of 6 Hz that was selected using residual analysis described by Winter (1990). Body segment parameters (considering barbell mass in relation to body mass) proposed by de Leva (1996) were inputted into the motion analysis software to enable the calculation of CM kinematics, which were then interpolated to 500 Hz. The propulsion phase of each trial was then identified using the methods described by Sanchez-Medina *et al.* (2010), and time normalized using the methods described by Frost *et al.* (2008).

Data of interest were barbell and 3D derived CM displacement; the velocity of the barbell, 3D derived vCM, and GRF derived vCM; the force applied to the 3D derived CM ((acceleration + *g*)*CM) and GRF; and power calculated by multiplying GRF by the velocity of the 3D derived CM, by multiplying GRF by the velocity of the GRF derived CM, and by multiplying GRF by the velocity of the barbell. Time normalized data from each subject's three trials was then averaged for further analysis. Two-way repeated measures analysis of variance was used to determine differences between displacement, velocity, force and power (dependent variables) obtained from the different methods (independent variables) across the time normalized propulsion phase. Further, velocity of the different body segments CM was compared to the velocity of the barbell using a one-way analysis of variance. An alpha value of 0.05 was used to indicate statistical significance, and post hoc analysis was performed applying the Holm-Sidak correction. All statistical analysis was performed using SPSS version 17.0 for Windows (SPSS Inc., Chicago, Il).

RESULTS AND DISCUSSION: Key results are presented in Figure 1, which illustrates the significant difference found between the displacements and velocities of the barbell and 3D derived CM, and their affect on power. These results supported the hypothesis that the multiplication of GRF by the velocity of the barbell would lead to a significant overestimation of CM velocity and power. This finding is of critical importance to strength and conditioning practitioners and investigators because it shows that the combined method is not valid. Calculations of power, the product of the force applied to a resistance and its resultant velocity must be based on force and velocity components that are recorded from the resistance of interest. Therefore, the velocity of the barbell should only be considered when barbell power is of interest, and GRF should only be considered when the velocity of the CM, derived from 3D motion analysis or GRF, is available, and CM power is of interest.

There were no significant differences between 3D derived CM force and GRF (P=0.125), and the velocity of the 3D and GRF derived CM (P=0.961), indicating that the velocity of the CM can be accurately derived from GRF, countering suggestions made in recent research to the contrary (Cormie *et al.,* 2007).

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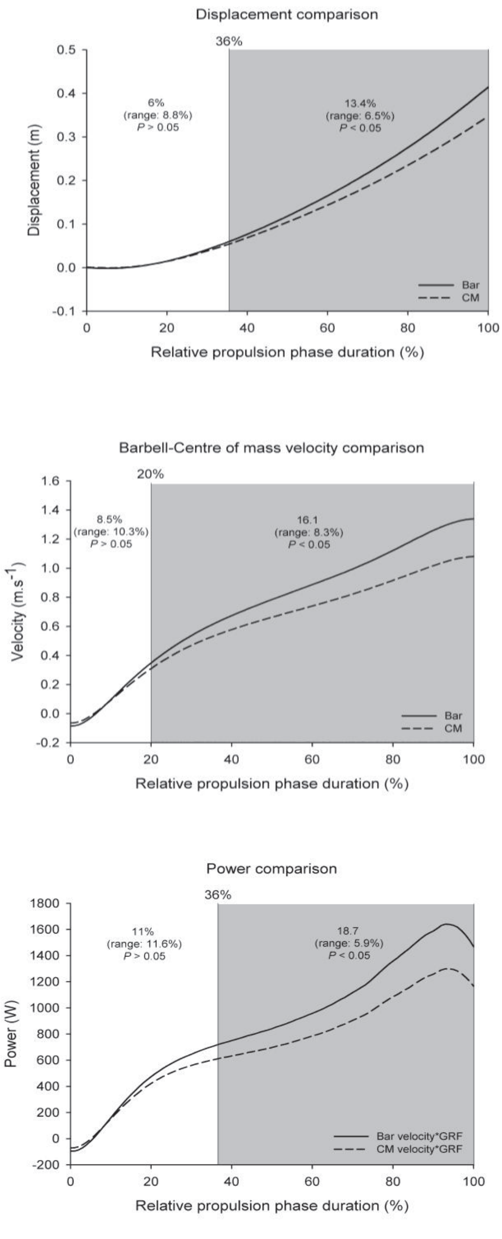

Figure 1: Comparison of time normalized barbell and CM displacement, velocity and power. Shaded areas indicate sub-phases that were significantly different.

Figure 2 illustrates the velocity of the barbell and body segment centres of mass, with time normalized across the propulsion phase. The peak and mean propulsion phase velocity of the barbell was significantly greater than the velocity of the foot (peak: 98.2%, mean: 99.2%), lower-leg (peak: 91.9%, mean: 94.3%), upper-leg (peak: 56.9%, mean: 56.7%), and trunk (peak: 18.8%, mean: 14.4%) segment centres of mass. However, differences between the velocity of the barbell and head, lower-arm, and upper-arm segment centres of mass did not exceed 5% (*P*>0.05). This finding explains the factors that underpin the apparent underrepresentation of the velocity of the CM when derived from GRF (Cormie *et al.,* 2007), further questioning the validity of the combined GRF multiplied by the velocity of the barbell method. Peak and mean propulsion phase velocity of the trunk, which represented 21.5 (± 3.1) % of mean barbell and body system mass was 18.8 (±4.3) and 14.4 (± 2.4) % less respectively than the velocity of the barbell; peak and mean propulsion phase velocity of the upper-leg, which represented 14 (± 2) % of mean barbell and body system mass was 56.9 (± 7.8) % and 56.7 (± 3) % less respectively than the velocity of the barbell.

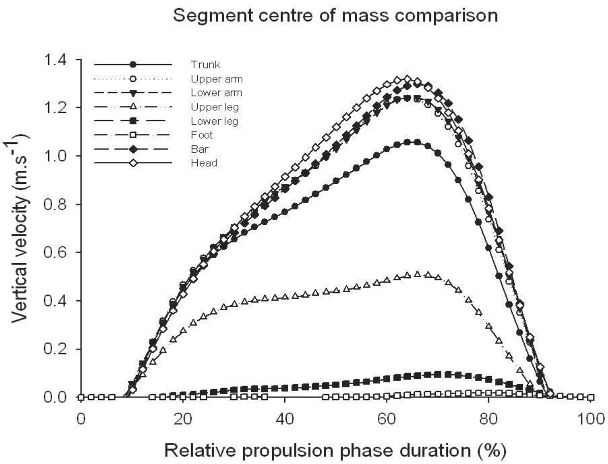

Figure 2: Comparison of the velocity of the barbell and segment CM, with time normalized across the propulsion phase.

This suggests that strength and conditioning practitioners and investigators must be cognizant that a considerable portion of the CM is displaced at a rate that is significantly slower than the barbell during back squat performance, and that this will affect the method that should be used to obtain measures of resistance exercise power.

CONCLUSION: The velocity of the barbell significantly overestimates the velocity of the CM, and should not be used to calculate the CM power of lower-body resistance exercise.

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