MUSCULOSKELETAL GEARING OF THE LOWER EXTREMITIES ACROSS SUMAXIMAL LOADS IN WEIGHTLIFTING

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The purpose of this study was to determine if an increase in lift weight is associated with an increase in the effective mechanical advantage (EMA) of the lower extremity joints. Five weightlifters performed cleans at 65, 75, and 85% of their 1-repetition maximum while a motion analysis system and a force plate were used to calculate net joint impulse and EMA of the hip, knee, and ankle extensor muscle groups. The EMA differed significantly between lift loads. As lift weight increased, EMA of extensor muscles also increased. The increase in EMA may allow lifters to generate greater ground reaction forces without a concomitant increase in the net joint impulse. This would suggest an increase in lift weight is, at least, partially associated with an increase in efficiency in the dynamic gearing of the lower extremities.

KEY WORDS: effective mechanical advantage, clean, biomechanics

INTRODUCTION: An increase in the load that is lifted during a weightlifting exercise (e.g., clean) is not always associated with a concomitant increase in torque production of the lower extremity joints (Kipp et al., 2011). It is conceivable, however, that instead of lifting heavier weights by increasing the torque output at a joint, lifters manipulate the effective mechanical advantage about the joint through careful control of the ground reaction force vector (Baumann et al., 1988). Baumann and colleaugues (Baumann et al., 1988) used biomechanical data from two participants during the 1985 world weightlifting championships to calculate lower extremity knee joint torques and the external moment arm of the ground reaction force vector about the knee joint. These data showed that the gold medal winner in the super-heavyweight category, Krastev (body weight: 150 kg, snatch weight: 202.5 kg), used smaller knee joint torques and better control of the moment arm than Tsintsanis (body weight: 136 kg, snatch weight: 160 kg) – a lifter from the lower group in the same category.
The mechanical principle illustrated by these data relate to the dynamic gearing of a joints' effective mechanical advantage (EMA) (Biewener et al. 2004; Carrier et al. 1994; Karamanidis & Arampatzis 2007). The effective mechanical advantage is influenced by changes in limb posture with respect to the ground reaction force vector, which affects the leverage of muscle forces and their ability to generate joint torques/impulses (Biewener et al. 2004). Changes in the effective mechanical advantage can thus directly affect the muscular impulse required to generate ground reaction forces during movement (Biewener et al. 2004; Carrier et al. 1994). In the case of weightlifting, dynamic gearing of a muscle groups' EMA may therefore enable a lifter to generate greater ground reaction forces, and lift heavier weights, without the need for greater concomitant muscle forces.
The purpose of this study was to systematically investigate lower extremity mechanics during a weightlifting exercise across a range of loads. We hypothesized that if dynamic gearing affects the mechanical advantage of lower extremity joints during weightlifting exercise, then an increase in lift weight would be associated with an increase in the effective mechanical advantage of the lower extremity joints, while the net joint impulse remains constant.

METHODS: Five collegiate-level weightlifters (mean±SD; height: 1.85±0.09 m; mass: 106.0±13.2 kg; absolute 1-RM clean: 126.4±22.9 kg; relative 1-RM clean: 1.19±0.11 kg/kg) performed cleans at 65%, 75%, and 85% of their 1-repetition maximum (RM). A motion analysis system (Vicon, Los Angeles, CA, USA) was used to record kinematic data of the right-side pelvis, thigh, shank, and foot segments at 250 Hz (Kipp et al., 2011). A force plate (Kistler Instrument Corp., Amherst, NY, USA), which was built into an 8'x8' weightlifting platform, was simultaneously used record kinetic data from the right foot at 1250 Hz.

Kinematic and kinetic data were low-pass filtered at 6 Hz and 25 Hz, respectively. Euler angle rotation sequences were used to calculate ankle, knee, and hip joint angles, which were numerically differentiated to obtain the respective joint angular velocities. Kinematic and kinetic data then were combined with published anthropometric data (DeLeva 1996) and used to solve for ankle, knee, and hip joint torques with an inverse dynamics approach in three planes of motion. Calculated joint torques represent net internal torques. Net extensor impulse was calculated by numerically integrating the body-mass normalized torque time-series data with respect to time whenever an extensor torque was present. All kinematic and kinetic time-series data were trimmed from the time the barbell broke contact with the platform to the time the vertical ground reaction force fell below 10 N. This time frame therefore captured the first and second pull phase of the clean, along with the transition between these phases.

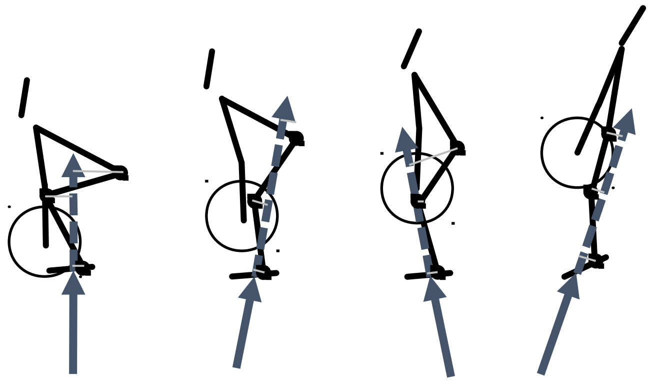

Figure 1: Ground reaction force vector (dotted lines) and its external moment arms (grey lines) about the centers (black circles) of the hip, knee, andk ankle joints during the pull phase of the clean.

The external moment arm was calculated as the perpendicular distance between the ground reaction force vector and each respective lower exremity joint (Carrier et al. 1994). Figure 1 depicts the time-varying characteristics of the ground reaction force vector about the lower extremity joint centers. The internal moment arms of the major extensor muscle group of the ankle, knee, and hip joints were calculated with regression equations (Herzog & Read 1993; Maganaris et al. 1998; Németh & Ohlsén 1985). The instantaneous gear ratios of the hip, knee, and ankle extensor muscle groups were calculated as the ratio between the internal moment arm of the of the respective muscle group about the joint it crosses and the moment arm of the ground reaction force vector about the joint (Karamanidis & Arampatzis 2007. Gear ratio data were numerically integrated over the course of the pull phase to obtain the total effective mechanical advantage (EMA) during a lift (Biewener et al. 2004).
The statistical analysis included two dependent variables (i.e., EMA and Impulse) and two independent variables (i.e., load and joint). Two seperate analyses of variance with repeated measures (i.e., one for each of dependent variable) were used to investigate differences among independent variables. In each case, load was treated as the repeated measure. Mauchly's test of Sphericity was used to assess whether the data met the statistical assumptions of the test statistics. A priori alpha-levels for statistical significance and statistical trends were set at 0.05 and 0.10, respectively. Post-hoc comparisons were made with dependent t-tests. Data are presented as Mean±SD. All statistical analyses were performed in SPSS 20 (IBM, New York, NY, USA).

RESULTS: The statistical analysis for net impulse showed that assumptions of sphericity were met. Further, the ANOVA showed a significant main effect for load (p = 0.001, η^2 = 0.42) and joint (p = 0.001, η^2 = 0.73), but there were no significant interactions between the two variables (Figure 2). The post-hoc analysis showed that the net impulse at the ankle joint differed significantly between 65% and 85% (p = 0.03), in addition there was also a small trend for a difference in net impulse between 65% and 75% (p = 0.06). The post-hoc analysis

also showed that there was a significant difference in hip extensor impulse between 65% and 85% (p = 0.01) and between 65% and 75% (p = 0.05).
The statistical analysis for EMA showed that assumptions of sphericity were met. Further, the ANOVA results showed a significant main effect for load (p = 0.019, η^2 = 0.25) and joint (p = 0.004, η^2 = 0.55), but there were no significant interactions between the two variables (Figure 3). The post-hoc analysis showed that for the ankle joint EMA differed between 65% and 85% (p = 0.05). At the knee joint, EMA differed between 65% and 85% (p = 0.03). There was also a slight trend for a different EMA between 75% and 85% at the knee joint (p = 0.06). At the hip, EMA differed 65% and 85% (p = 0.01). In addition, there were also a slight trends for a differences in hip joint EMA between 65% and 75% (p = 0.06), and between 75% and 85% (p = 0.09).

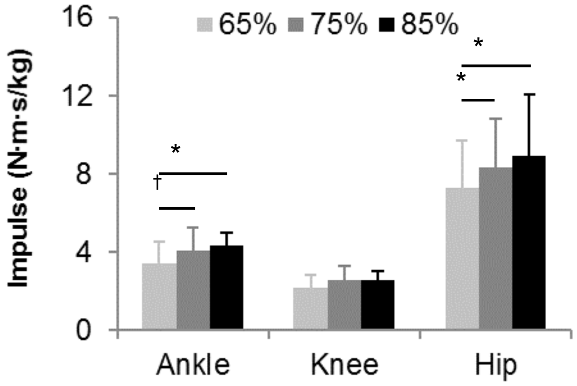

Figure 2: Net mechanical joint impulse across all lift loads for the ankle, knee, and hip joints. Note: * $p < 0.05$, † $p < 0.10$

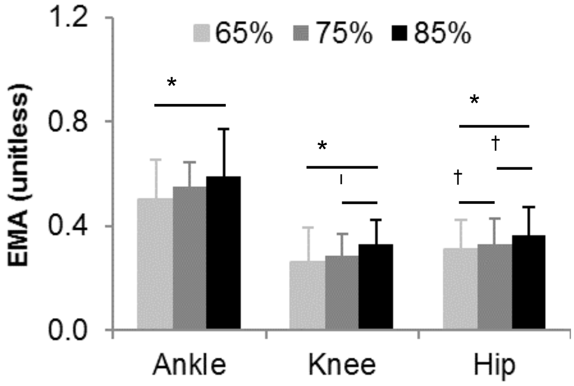

Figure 3: Effective mechanical advantage across all lift loads for the ankle, knee, and hip joints. Note: * $p < 0.05$, † $p < 0.10$

DISCUSSION: In general, as lift weight increased from 65% to 85% of 1-RM the effective mechanical advantage of the hip, knee, and ankle extensor muscle groups also increased. An increase in effective mechanical advantage may have two net effects. First, it would allow for the development of similar ground reaction forces while the amount of needed muscle force would decrease (Biewener et al., 2004). Second, it may allow for the generation of greater ground reaction forces (to lift a greater load) with similar muscle force requirements. Both scenarios would lead to an increase in lift efficiency (Carrier et al. 1994). Dynamic gearing of the effective mechanical advantage would thus allow lifters to generate greater ground reaction forces without a concomitant increase in the torque production and muscular effort of the respective muscle group. This would suggest an increase in lift weight is, at least, partially associated with an increase in efficiency of lower extremity joint mechanics.
A question that arises from the interpretation of these results is by what means do the lifters increase the effective mechanical advantage of the lower extremities? Arguably, body posture and alignment would most certainly influence the external moment arm of the ground reaction forces about the lower extremity joints (Biewener et al., 2004) and decrease the required magnitude of muscle force needed to perform the lift (Enoka, 1979). It should therefore be of interest to characterize the kinematic postures and patterns of the lower extremity during the clean and to determine how they relate to the effective mechanical advantage. This would then provide coaches with direct information about how to best optimize the effective mechanical advantage in quest for better performance.

CONCLUSION: Lifting heavier loads in the clean appears to be partially related to the effective mechanical advantage of the lower extremity joints. Since a change in effective mechanical advantage affects lift efficiency, it may present a technical element that could be used by coaches and sports scientists to improve and monitor weightlifting performance.

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