LOOKING FOR OPTIMAL BIOMECHANICAL CONFIGURATIONS IN WEIGHTLIFTING AND POWERLIFTING : THEORETICAL AND EXPERIMENTAL APPROACHES

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This work is part of a big project whose goal is to combine mechanical principles with the physical characteristics of athletes to develop a personalized virtual model optimized to help lifters improve their performance while reducing their injury risks. This study concentrates on the qualitative comparison between a virtual skeleton model of a squatting athlete numerically designed on MATLAB and the squatting patterns of elite athletes of the French national team (n=15). Comparing the results of the two approaches revealed differences in the Center Of Pressure (COP) movement during the squat as well as motor behaviour and velocity. After discussion with the athletes and their coaches it seems that the model lacked reality and more studies are needed.

KEYWORDS: sport, performance, injury, lifting

INTRODUCTION:

Weightlifting has been in the Olympic Games since 1896, it consists in two events: the snatch (lifting a barbell overhead in one movement) and the clean and jerk (lifting a barbell overhead in two movements) (Stone et al., 2006). Powerlifting requires maximal strength on 3 lifts, the squat, the bench-press and the deadlift (Ferland & Comtois, 2019). More than Olympic and World games recognised sports, it has been shown that strength training helps athletes of other sports increase their performance (McGuigan et al., 2012). Even though the injury rate of gym training is less than 4 injuries per 1000 hours of training (‘Active Living and Injury Risk’, 2004), it is important for lifters to use a correct technique to limit those risks and improve fitness and performance.
In the literature, it seems widely accepted that different anthropometrical characteristics induce different movement strategies (Cholewa et al., 2019), yet most studies on performance don’t take segments lengths into account. This oversight, once transferred to the gyms, induce that the same technical instructions are often given to lifters with different anthropometry and training history. As they are not individualized, these instructions could be at best suboptimal for most athletes, not allowing them to express their full potential and, at worst, dangerous and causing injuries. The most striking example being to keep the knees from moving past the toes (Fry et al., n.d.)
This study is part of a big project which aim is the development of an optimized personalized virtual human model based on experimental measurements on athletes with an evaluation of the risk of injury at the limits of performance. Models calculating optimal technique based on limb length as well as joint torque production capabilities could be implemented in training to help the athletes visualise the difference between how they move and how they should. This could accelerate the learning phase hence improve performance and reduce injury risk.(De Stefani et al., 2020). The objective of this study was the development of the first skeletal model with the testing of its major hypothesis on elite athletes.

METHODS:

The parallel back squat movement was chosen to begin with, the model and the experiments were developed and conducted according to the International Powerlifting Federation guidelines (International Powerlifting Federation, 2022).

The choice was made to start by developing a virtual model on Matlab. Simplifying hypothesis were made such as:

1. the ascent velocity is constant,
2. movement is symmetrical and only occurs in the sagittal plane,
3. limbs can be modelled by rigid bodies,
4. friction at the joints can be neglected
5. the centre of pressure can move freely above the base of support.

To develop the model, segment lengths and height were taken from previous biplanar X-ray data of lifters, their bodyweight at their last competition was used and the joint mobility was assessed based on literature. Once the model was developed, it was set into motion using the laws of mechanics as well as a genetic algorithm. The objective function was chosen from the literature(Leboeuf, & Lacouture, n.d.) and was to minimize the energy expenditure of the concentric phase.

In the meantime, an experiment was designed to capture the movement of international lifters. To do so, a force plate and motion capture cameras were installed around a squat cage with Figure 1. Then, reflecting markers were placed on the following points:

- Bar geometric centre
- 7th Cervical Vertebra
- 1st lumbar vertebra
- 5th lumbar vertebra
- Hip greater trochanter of femur
- Knee lateral articulation
- Ankle lateral malleolus of the fibula
- 1st Distal Phalange of the Foot

Figure 1: Experimental setup

As the subjects (n=15) were expert lifters of the national team, it was assumed that they knew their estimated 1 Repetition Maximum (e1RM) at the time of the experiment and did not need testing it. To replicate competition conditions, athletes were asked to warm up and lift up to 75% of their e1RM following these steps: a) unrack the bar b) get into the start position and wait for the start command c) do one squat repetition d) wait for the rack command e) rack the bar. The displacement of the points, as well as the force vector applied of the force-plate, were measured between the start and rack commands and imported on Matlab.

Angular and linear velocities and acceleration were calculated thanks to a cubic spline and the fundamental principles of dynamics were applied to measure forces and moments of forces at the left ankle, knee and hip. Finally, experimental data were compared with results from our model.

RESULTS:

This work is a first step toward the development of a virtual avatar of athletes. It is planned that a second testing phase will be conducted with a bigger sample. Hence, quantitative data are only given on one male and one female lifters.

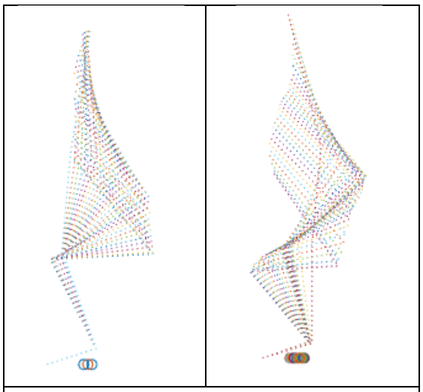

Figure 2 : Kinogram of the concentric phase of a squat obtained from the model (left) from the reality (right)

Female lifter / ***Male lifter***

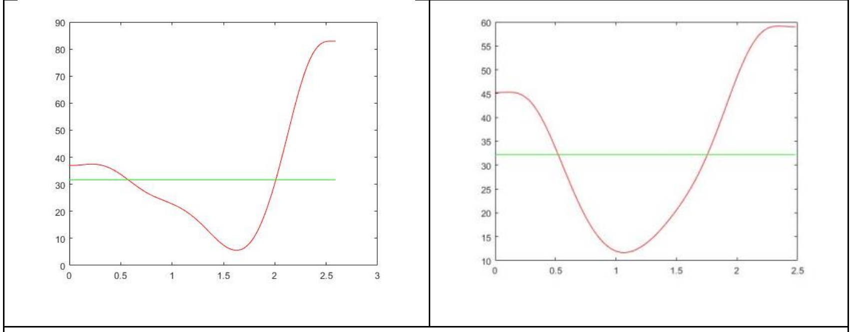

Figure 3 : Angular velocity of the thigh (deg/s) depending on time from the model (green) compared to the lifters (red)

	Model max ankle torque	Subject max ankle torque	Model max knee torque	Subject max knee torque	Model max hip torque	Subject max hip torque
Female	425 Nm	332 Nm	687 Nm	691 Nm	402 Nm	510 Nm
Male	793 Nm	539 Nm	811 Nm	837 Nm	548 Nm	595 Nm

Table 1: Torque differences between model and reality

Motor behaviour

As it is possible to see on Figure 2 as well as on Table 1, the motor behaviour differs between the models and subjects. The data suggest that the lifters tend to put more load on hips while the model has a bigger ankle torque.

Velocity

On the model, the assumption was made that the thigh angle would increase constantly from parallel to perpendicular relative to the floor. In reality, as the Figure 3 shows, the velocity decreases until a "sticking point" and then increases again. Its location can be seen by the change of darkness of the lines on the reality kinogram in Figure 2.

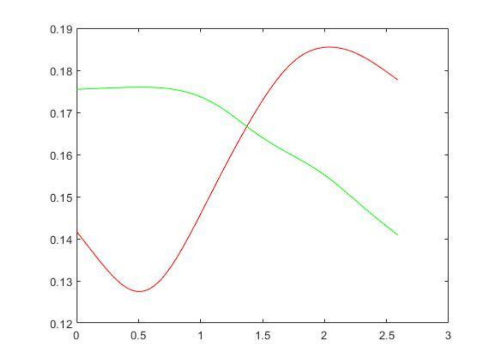

Figure 4: Distance between the front of the foot and the CoP depending on time from the model (green) compared to the lifters (red)

Centre of pressure (CoP)

As shown on Figure 4, the CoP moves during the concentric phase of the squat. This motion has been measured to be up to 7cm and on the opposite of what the algorithm considers optimal, the lifter tend to put more pressures on the toes at the beginning of the lift.

DISCUSSION:

There is currently only one study on motor behaviour prediction (Rahmati & Mallakzadeh, 2014) in weightlifting and none in powerlifting. As most studies are kinetics analyses of elite lifters without any clustering, no consensus exists on the motor behaviour changes to adopt based on athlete's anthropometrics. These reports motivated the optimal avatar project whose first step was the development of a numerical model and its confrontation with testing on elite athletes. The differences visualized in the results in the CoP position as well as the movement velocity and motor behaviour support the importance of this development phase and were discussed with elite athletes and coaches. Some of them already tried being above heels at the beginning of the concentric phase and felt it was not a stable nor powerful position. Actually, some of them even expressed that they tend to fail lifts when they let their COP move toward heels too much, which indicates that the current model does not fit well the reality. The reasons for this can be divided in two main categories. First, the human is a complex system and a skeletal model is not enough to model all the movement strategies. This could be corrected by adding stability parameters in the contact between the feet and the ground as well as muscles on each segment. Then we chose as an objective function the minimization of energy expenditure. It may be better to only focus on torques at each joint to find the weakest link of this open chain system. To do so, further studies are needed.

CONCLUSION: Because a lack exists in the scientific literature, a project has begun on the development of an optimized personalized virtual human model. The objective of this study was the development of the first skeletal model with the testing of its major hypothesis on elite athletes.

The experimentation inlighted some errors in the hypotheses especially the constant velocity one that should be modified. Also, the COP movement through out the lift as well as the motor behaviour differed a lot between the simulation and the experimentation. The numerical model should be modified according to the results in order to better transcribe the squat movement and quantitative comparison with control group should be conducted next.

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