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BIOMECHANICS OF WEIGHTLIFTING

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Abstract: *Low back pain (LBP) is a common cause of job-related disability, usually related to idiopathic spine injury such as muscle sprain or so called ‘slipped disc’ due to lifting heavy object, which has around 80 % occurrence among injuries at the low back. That represents dual economical effect to society in form of reduced working force, and simultaneously the higher cost of the health care. In some cases the person face the risk to lose its job due to inability to carry heavy objects. Research already done doesn’t suggest any solution how to prevent LBP and injuries. Ability to lift a heavy object has almost every healthy person but not all have the right physical condition to lift heavy objects. The presented work briefly shows the difference between two subjects with different physical background. Subject A represents the ordinary young lad visiting a gym while subject B represents young athlete with regular trainings for competition. Both subject had an experience with deadlifting, and were knowledgeable of the correct posture. Their lifting trials were recorded and processed to obtain forces, moments, angles, velocities, and acceleration of each segment of lower limb. An observation and some results are presented in this paper.*

Keywords: Low back pain, Kinematics of lifting, VICON system, AnyBody.

1. Introduction

Low back pain (LBP) is still largely considered as an idiopathic most common cause of job-related disability. Present research recognized more than one hundred factors that are considered as a risk factors of LBP. Majority of the research concentrates on the activity of lifting heavy objects under different conditions since the lifting of heavy objects impose a high mechanical stress at lumbar section of the spine. A study (Cole, 2003) showed that around 80 % of the reported work injuries related to lifting, were caused by strain in the lumbar spine. However the LBP issue needs further research to identify the relation between already known risk factors. The spine injury due to accidental trauma or lifting heavy objects can cause either the sprain of ligaments, strain of muscles, or a slip disc that might compromise the neurological pathways. These accidents are not only related to work, it can as well a case of young, sport oriented lads training at the gym with a heavy weights while using different types of lifting technique such as squat pattern, hip hinge pattern, shoulder pack, or neutral spine. A common technique used even outside of the gym is a technique called ‘deadlift’ that is described as a lifting of a stationary weight from the ground or elevated surface, up to waist height. In this paper we concentrate mainly on the biomechanical behaviour of a lower part of the body during deadlifting, and the consequence related to the large joints and muscles involved. The two subjects of the same age were selected but their history of physical activity is different since one subject is an active athlete while the second subject is just practicing recreational exercise at the gym.

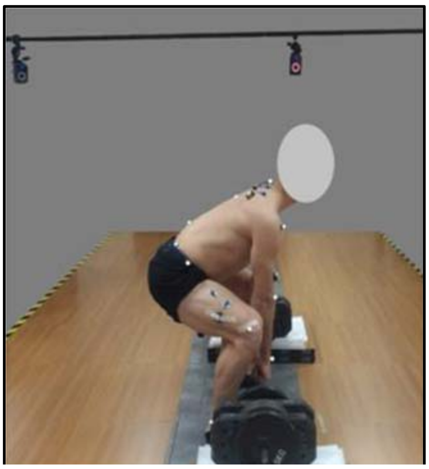

Fig. 1: Deadlift Starting Posture side view.

The deadweight lifting technique, selected for the presentation in this paper, can be performed using two initially different postures, the conventional and the sumo-deadlift. During the conventional deadlift the lifter’s feet are positioned to project the shoulder width,

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while toes are pointing straight, parallel with the sagittal plane of the lifter. The hand grip is slightly wider than shoulder width, just outside of the thighs. This position requires greater lumbar flexion, which is increasing the risk of low back injury (Cholewicki, 1991).

The sumo-deadlift starting posture, shown in Fig. 2 has a wider stance with toes under the axial rotation at the transverse plane thus they follow the direction of lifter's thighs while the hand grip is between thighs. Sumo-deadlift posture is more upright at liftoff due to reduced trunk angle as a result of the wide foot stance. These enables to keep bar closer to body, which results in reduced lever arm distance. This lifting style offers some biomechanical benefits if the technique will be used properly, and might urge for flexibility of lower body (McGuigan, 1996).

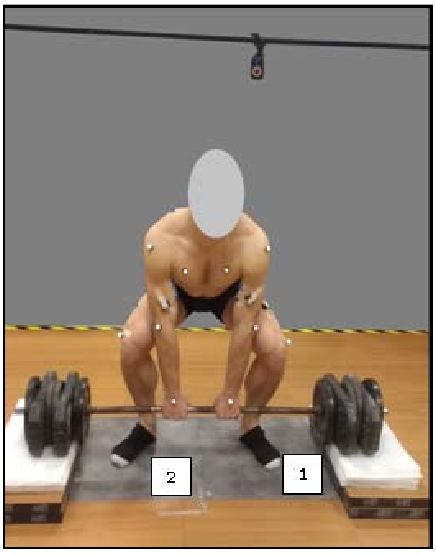

Fig. 2: Sumo-deadlift Starting Posture.

The deadlift movement has three phases. In the initial posture, phase one, both feet are flat while the body is lowered to a crouching position, and the bar is held at an equidistant side from the centre of mass with both hands fully pronated. During the second phase, the pull, the major leg muscles generate a force, the core muscles are contracted, and the arms are completely straightened out. The final phase, lockout, requires a hip extension thus involving the gluteus maximus and the anterior core muscles, which is timed to 80 % of the lift, and lock the back to an erect position.

2. Methods

Selected lifting technique was described with identification of three phases of the lifting. This work requires knowledge of anatomy, physiology, kinematic analysis of each segment movement, kinetics - representing the forces actively acting at the segment, and inverse dynamics. To proceed with these tasks, the subject's body were marked using the passive reflective markers as shown in Fig. 3, at the positions identified by the standard marking scheme for a full body. The VICON system that consists of eight high frequency infrared cameras, and two force plates, records the trajectories of the reflective markers. Prior to the use, the VICON system was calibrated to eliminate any reflective artefacts at the camera active space, and then the cameras were calibrated, and the origin of the coordinate system was set, using an active wand. The force plates were zeroed to record the static position of the subject. To obtain data about the muscular activity a surface electromyography system (sEMG) was used to monitor the muscle activation. The main leg muscle groups used during the deadlifting are the anterior chain muscles (quadriceps and the tibialis anterior), and the posterior chain muscles (glutes, hamstring group, calf group). The sEMG can be placed on surface muscles only, to avoid the cross-talk thus vastus lateralis from the anterior group, and semitendinosus from the posterior group were selected as shown in Fig. 3. Then a so called match-stick model was created in VICON system to visualize body segments, and necessary anthropometric data were inputted into the system for each subject. Following this procedure both subjects performed and recorded multiple lifts with a light (21 kg) and a heavy weight (70 kg). Due to some dropout of markers that occurred during the recording of raw data the post-processing was necessary to correct marker's trajectories. After the data were cleaned, the recorded trials were cropped, and data was exported in .c3d and .csv format to be analysed using Mokka, AnyBody open software (SW) and Excel.

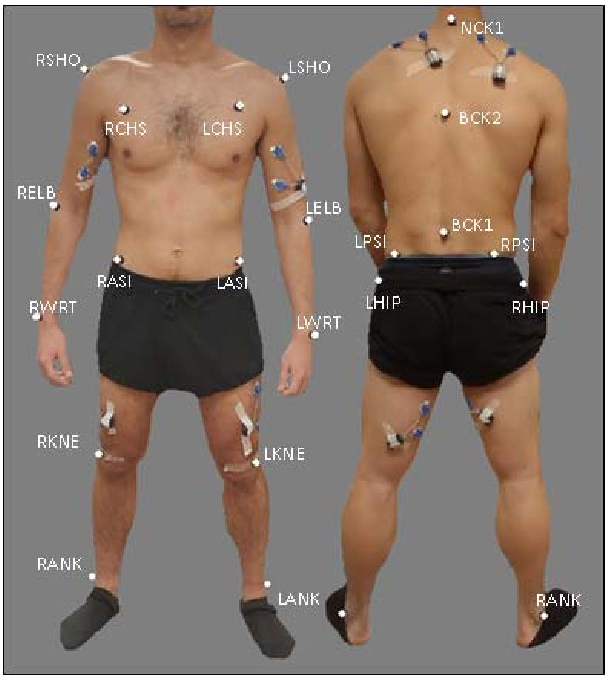

Fig. 3: Full body marked subject.

2.1. Analysis of the deadlift using Mokka software

Open source, cross-platform SW is widely used to analyze biomechanical data written in .c3d format. All data related to motion kinematics and kinetics were imported to the SW, including numbering of all slides carrying the data recorded with frequency 1000 Hz. It allows to provide analysis of all, or only selected slides. In this work the Mokka SW was used to extract the necessary data for further analysis, to provide distinction between left and right side based on the markers description, to plot the vertical component of the ground reaction force (GRF) from each force plate, and identify lifting phases of each trial. Further to this, all frames of interest were cropped, and the events were marked on the frame line. Then data containing time, frame number, marker position, event labels, and GRF were exported to be merged with .csv data obtained from VICON, which included velocity and acceleration for each marker.

2.2. Modelling lifting in AnyBody SW

AnyBody SW comprises repository of models that can be used, and altered, to create suitable model according to user's need. All model in repository were validated and verified for a specific activity thus there is a limit related to alteration of the model as such. The user's motion data in .c3d format can be inputed using 'MoCapModel' function to any model that satisfies user's physical activity. Due these specific motion parameters, drivers, and markers placed for a specific task, our model had to be created by using the generic 'Standing Model' with feet fully supported and constrained to a floor. The possibility

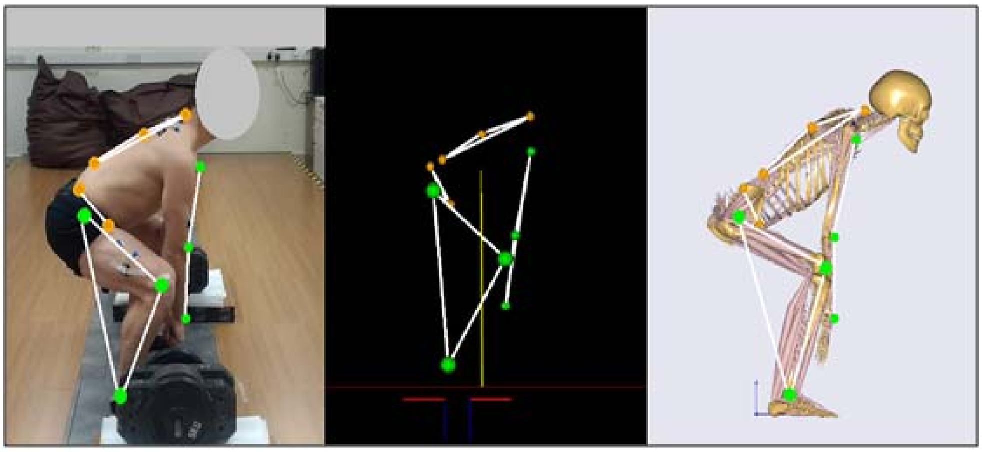

Fig. 4: Mapping the posture in Mokka and AnyBodySW.

of altering the posture of this model, and the pre-defined points that allow applying a load to the model were favourable feature thus we used this model for the first simulations. Since this model doesn't have installed markers thus cannot be driven by the .c3d data, the first results will be simulating static rather than dynamic task. Then 'Standing Model' was scaled for each subject based on the collected anthropometric data. In the next step, the previously selected frames at Mokka were used to map the body postures at eight different stages of the lifting to be analysed. The selection of the analysed events was based on the plot of GRF-z component against frame time that indicated the pull phase, while 'LOOKUP' function used in the Excel sheet to obtain the maximum GRF-z. Then five equal time intervals were selected from the pull phase and additional three intervals were equally distributed over the lockout phase. The data measured by VICON were transferred to AnyBody model on the selected frames.

3. Results

There were three sets of results – one of GRFs from VICON system, recording the changing reaction force, which provides information about load distribution between left and right leg. When compared the two diagrams Figs. 5 and 6 demonstrating the

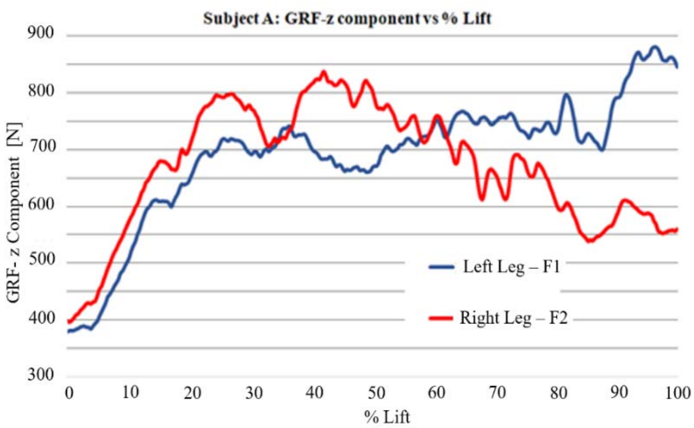

Fig. 5: GRF of subject A during lifting 70 kg.

reaction force during lifting the weight of 70 kg. Subject B stabilised his position at the end of first quarter of the lifting event with less than 100 N difference between left and right leg, while subject's A stability was not very strong showing a difference of 300 N between the two legs. Both subjects use the left leg to control stability of their posture while the right is the dominant power leg producing the movement. Both subjects show relatively smooth increase of forces for both legs, at the beginning of the pull phase event. There is only time difference, when each subject reached the maximum force. That indicates that subject B has better coordination of muscles due to his athletic background. The second batch of results from ***AnyBody*** simulation provides joints reaction forces at the lower limb during the lifting. The comparison of the two subjects results shown in Fig. 7 comply with the results of reaction forces measured by force plates. Both subjects had a similar gradient of the hip reaction that smoothly reached the maximum of 3451 N for subject B, while subject A reached its maximum of 2628 N at 25 % of the lifting. The initial computation of reaction forces using the simplified model that didn't take into account muscular force offered the maximum force at the knee joint contrary to AnyBody results. Validation for the AnyBody results was done by obtaining a set of maximum joint force data for the lumbosacral joint L5 - S1, which were compared to literature (Stambolian, 2016) conducting similar experiments for lower back evaluation, using the same AnyBody software. The computed results were also compared to data from literature studies (Hwang, 2009).

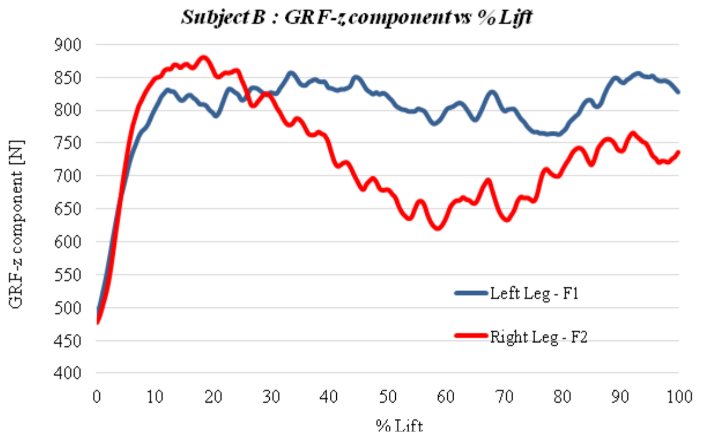

Fig. 6: GRF of subject B during lifting 70 kg.

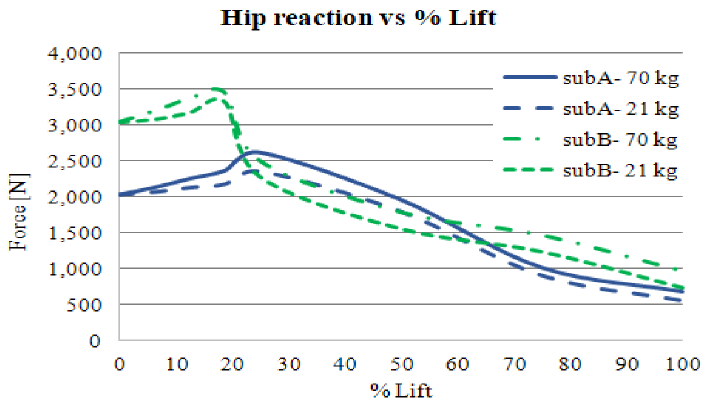

Fig. 7: Hip reaction force computed via AnyBody SW.

4. Conclusion

These results shows that estimation of the forces based on the simple statics and motion equations without consideration of muscles might provide in some case a suitable results but never precise enough for a serious computation. The obtained AnyBody results at a particular position are closer to reality than the analytical solution but the dynamical effect of the pull event of the lifting might change these results. The only way how to get better result is to create AnyBody model with full body markers, which allows to run the simulation using the full inverse dynamics.

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