Generation and Validation of Two Motions in OpenSim Representing a Deadlift Performed With Proper and Improper Form With a Focus on Spinal Curvature

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Abstract

The common claim that deadlifts are a dangerous exercise despite their reputation as a fundamental exercise for strength and hypertrophy training has not been adequately supported by peer reviewed articles. The objective of this study was to generate and validate two deadlifting motions in OpenSim with the purpose of contributing to combating this potential spread of misinformation. The validated open-source Full-body Lifting Model was used as the base of the motions. Two motion capture (MOCAP) methods were then conducted to measure the trajectory of various landmarks on the body and spine during a deadlift with both proper and improper form. Improper form can be distinguished by an exaggerated curvature in the spine. The MOCAP data was then associated with corresponding markers in OpenSim, and the model was scaled to match the anatomy of the MOCAP subject. An inverse kinematics simulation was then used to generate the motions. Both motions were successfully created but with a degree of accuracy unsuitable for use in research. For this reason, the models were not successfully validated.

1 Introduction

Deadlifts have become a commonly scrutinized exercise in the weightlifting community on the grounds that the risk of injury they introduce does not outweigh their benefits in terms of strength and hypertrophy. This claim is controversial given the deadlift has a reputation as one of the fundamental exercises for strength and hypertrophy training [1, 2]. Deadlifts are a popular full-body compound exercise that serves to target muscles around the knees, hip, and lower back [3]. Several types of deadlifts exist, and different grips are often used to mitigate the need for well-developed grip strength when deadlifting heavier weights. For the purpose of this study, conventional deadlifts with a pronated grip will be modelled.

Injuries in any sport are a common occurrence. It is problematic to claim that deadlifts cause a greater risk of injury when compared to other weightlifting exercise due to the lack of evidence found in peer reviewed articles. This is partly because it is difficult to quantify the risk of injury caused by an activity. Specifically, it is unrealistic to find benchmarks for applied torques or loads that guarantee the occurrence of an injury.

2 Background

Narrowing the scope of this analysis involves determining what injuries are most prevalent in deadlifters. Lumbosacral spinal cord injuries are recognized as the most common injuries in the deadlifting community [3, 4]. Of these lumbosacral spinal cord injuries, 85% to 90% occur between the L4-L5 and the L5-S1 vertebrae [4, 5]. The prevalence of spinal cord injury occurrence in deadlifters can potentially be attributed to the greater degree of spine curvature observed in athletes deadlifting with poor form Figure 1. A study by Tony Leyland aimed to prove this hypothesis by comparing the compressive, joint, and sheer forces in the L4-L5 intervertebral disc in deadlifts with both proper and improper form [4]. However, Leyland's results were limited by his modelling approach. First, he used a static model, meaning reaction forces in the vertebrae could not be analyzed over time throughout the duration of the deadlift. Additionally, the software used to calculate the joint reaction forces between the vertebrae is intended for use in occupational analyses. This is problematic given the loads applied to the lower back during a deadlift and in an occupational setting are drastically different. For example, NIOSH states that the maximum weight to be lifted with two hands in ideal conditions is 51 pounds yet the average deadlifter will lift significantly greater loads [6].

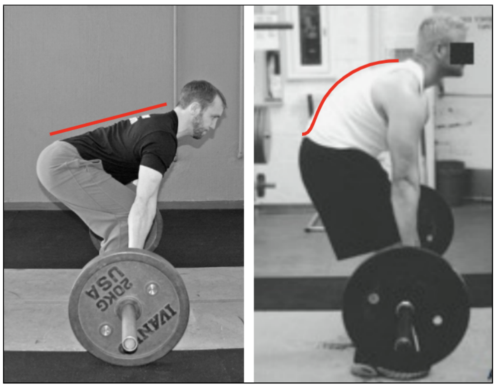

Figure 1: Greater degree of spinal curvature observed in athletes deadlifting with poor form [4].

OpenSim then presents itself as a suitable modelling software alternative, given it allows users to measure reactions to applied loads over time throughout a motion. In order to model deadlifts effectively in OpenSim, a full body model with a focus on lifting is required. There are a wide array of available open-source OpenSim models available to the public, however, very few exist to estimate spinal loads during lifting patters [7]. Among the few validated models that exist, there are no publicly available OpenSim motion files that model lifting patterns like the deadlift.

3 Project Objectives

The primary objective of this study was to create two motions in OpenSim that model deadlifts performed with proper and improper form, where improper form is conducted with a curved spine instead of the widely accepted neutral/flat back. Another objective is to then validate the created motions by comparing the resulting marker trajectories and internal forces with experimental data found in literature. The motions will be generated with the intended use of performing a dynamic analysis of the joint reaction forces in the lumbosacral spinal cord using an inverse dynamics simulation once experimental external loading data is collected.

4 Methodology

4.1 Motion Capture

Experimental data was collected using two different motion capture (MOCAP) techniques simultaneously. The MOCAP setup involved two laptop cameras; one camera filming the anterior view and one filming the right lateral view of the deadlift subject as seen in Figure 2. The two MOCAP techniques used were MediaPipe Pose and a custom colour isolating algorithm. Before each deadlift recording was taken, the lights were flickered in order to sync the timing of each camera's footage.

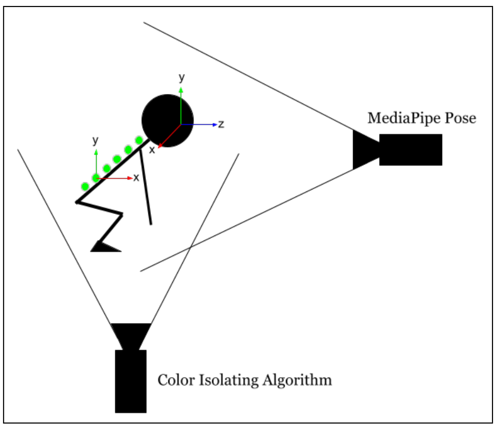

Figure 2: Sketch of motion capture setup with labelled coordinate frames.

The footage from the anterior view was run through the MediaPipe Pose machine learning algorithm, which uses markerless pose tracking and background segmentation masking to infer the 3D location of 33 body landmarks [8]. Note that none of these 33 landmarks are located along the spinal cord, therefore a second MOCAP technique was necessary to analyze spine curvature. MediaPipe records the 3D position of each landmark in meters, with the ori-

gin centred between the two hip landmarks. The coordinate
frame used by this MOCAP technique involved the x-axis pointing right along the frontal axis, the y-axis pointing in the superior direction along the longitudinal axis, and the z-axis pointing in the anterior direction along the sagittal axis. For the purpose of this study, only 4 landmarks from this motion capture technique were used: the right and left shoulder and hip markers. These markers were chosen because the focus of the model is primarily on spine curvature, and the additional markers introduced unexpected movement in the model.

The footage from the right lateral view was run through a custom colour isolating algorithm which filtered by hue and saturation to isolate for the bright green markers on the subject's back. Six green markers were glued along the subject's spine 9 cm apart from each other as seen in Figure 3. The second marker from the top was placed vertically inline with the shoulder markers from the other MOCAP technique to facilitate the alignment of the coordinate frames in later steps. This algorithm recorded 2D coordinate data for each of the 6 markers, with pixels as the unit. This 2D coordinate frame involved the y-axis pointing in the superior direction along the longitudinal axis and the x-axis pointing in the anterior direction along the sagittal axis. The MediaPipe Pose coordinate frame was chosen as the master frame since it was in an appropriate unit and more closely matched the coordinate system in OpenSim. The colour isolating data was transformed to fit the MediaPipe Pose coordinate frame by changing the x coordinates to z coordinates and setting all the x coordinates to 0 based on the assumption that the spine does not move laterally during deadlifting. The coordinates were scaled from pixels to meters using the aspect ratio of the screen as well as known distances in the video. Additionally, the coordinates underwent a translation that placed the origin where x = 0 and y, z, were on the hip marker from the MediaPipe MOCAP data. The coordinate system in OpenSim has the z-axis pointing right along the frontal axis, the y-axis pointing in the superior direction along the longitudinal axis, and the x-axis pointing in the anterior direction along the sagittal axis. To accommodate this coordinate system, the x and z values from the MOCAP data were switched. Figure 4 shows the MediaPipe pose coordinates as well as the transformed coordinates from the colour isolating algorithm plotted on the same graph in MATLAB to visually verify that the transformations were all correct. The experimental data was then converted to the necessary .trc file format expected in OpenSim.

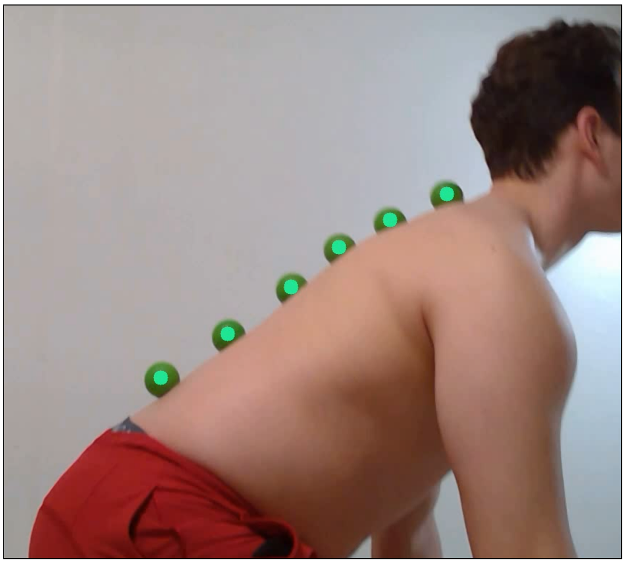

Figure 3: Image of the marker placement for the colour isolating MOCAP technique.

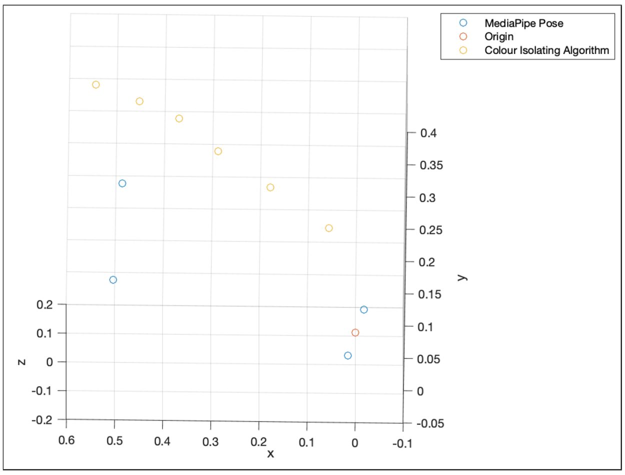

Figure 4: Transformed MOCAP data plotted in MATLAB.

4.2 Marker Association and Scaling

The subject used to perform the proper and improper deadlift trials was a 20-year-old, 5'10", 90 kg male. Using the open source Full-Body Lifting model from SimTK, all 10 experimental markers were placed on the OpenSim model at approximately the same locations as they were on the subject.

One marker on the anterior part of each shoulder, 1 marker on the anterior part of each hip, and six markers along the spine. Next, the scaling tool was used to scale the model to the size of the actual subject and place it in the initial pose of the deadlift. This was done by inputting the subject's weight, marker locations, known distance ratios (e.g. width$_{hip}$:width$_{shoulder}$), and motion data for the first few milliseconds of the movement. Figure 5 shows the original and scaled markers of the proper form lifting model, shown in pink and blue, respectively.

4.3 Inverse Kinematics Simulation

Once the scaling was complete, the inverse kinematics tool was used to create a motion file from the input kinematics data. This was done by inputting the marker data and the entire set of motion data.

4.4 Validation

To validate the generated motions, a sanity check was conducted to qualitatively assess whether the motion was a good representation of a deadlift performed with proper or improper form. This involved comparing the generated motions to the videos used to collect the motion capture data, and assessing how closely they resemble each other. Additionally, plots for the internal moments in the L4-L5 intervertebral disc as functions of time were generated to determine whether they would change as expected during the deadlift. Then, plots of the internal flexion and extension moments for the T12-L1 to the L5-S1 intervertebral discs as functions of time were compared with bending moments experienced during deadlifts found in literature

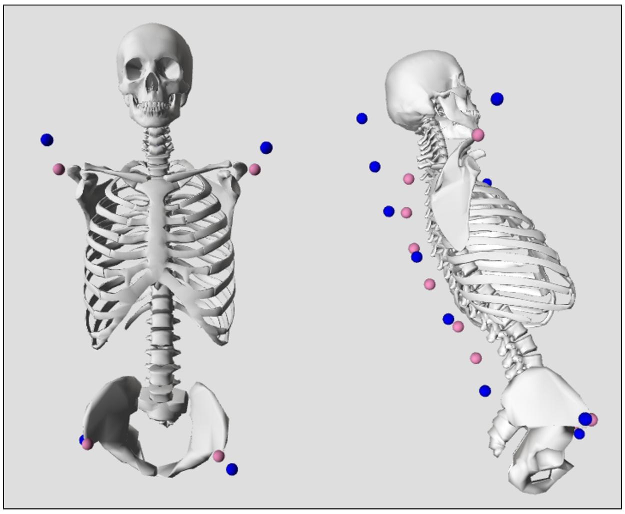

Figure 5: Original and scaled markers of the proper form lifting model shown in pink and blue, respectively.

5 Results and Discussion

A motion was successfully generated for a deadlift with proper form and with improper form[1]. Toward the end of the exercise with proper form it seems as though the hip coordinates are fixed which forces an unnatural curvature in the lumbosacral region of the spine. However, the back remained in a neutral position up until this point which was as expected. The deadlift with improper form did not appear as expected. The scaling process used did not adequately fit the markers to the spine given the Full-Body Lifting Model used did not effectively accommodate an exaggerate spine curvature. Additionally, an unexpected axial rotation of about 90 degrees to the anatomical left of the model is observed toward the end of the motion. This is the result of inaccuracies in the MOCAP data collection method for the shoulders.

Figure 6 demonstrates the axial, lateral, and flexion/extension internal moments in the L4-L5 intervertebral disc during the proper deadlifting motion. In this plot, the lateral and axial moments appear as expected. Throughout a deadlift, the body should not rotate laterally or axially and thus the internal axial and lateral moments experienced in the L4-L5 intervertebral disc should remain low and constant. This same result was observed for the lateral bending, but not in the axial rotation during the deadlift performed with improper form as seen in Figure 7. As previously mentioned, there is a sharp axial rotation of about 90 degrees during the deadlift motion with improper form which

[1]Clicking on the hyperlinks will lead to a video of the corresponding motion.

can be seen at 2.4 seconds in Figure 7. Neither of the motions demonstrated the expected results for internal flexion/extension moments. During a deadlift, the centre of mass of the body gradually moves closer to the hips assuming the starting position is with the bar on the ground, and the finished position is upright [9]. This also suggests that the distance from the L4-L5 intervertebral disc to the centre of mass of the body gets smaller as the motion progresses. As the moment arm gets smaller, the resulting internal flexion/extension moment in the vertebrae should also get smaller until reaching a steady state at the peak of the exercise. This is observed from the 0.5 to 2 seconds in Figure 6, but otherwise does not occur in either of the motions.

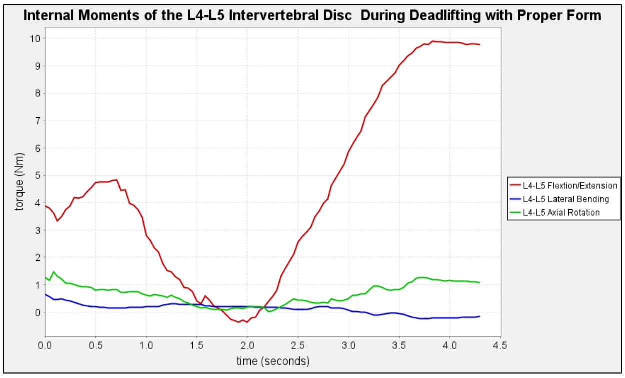

Figure 6: Internal moments of the L4-L5 intervertebral disc during deadlifting with proper form.

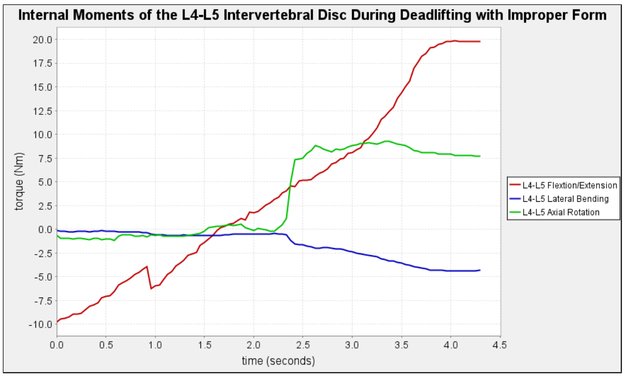

Figure 7: Internal moments of the L4-L5 intervertebral disc during deadlifting with improper form.

Figure 8 and Figure 9 illustrates the internal flexion/extension moments experienced by the T12-L1 to the L5-S1 intervertebral discs. The magnitudes of the internal flexion/extension moments at the intervertebral discs somewhat followed the expected pattern based on the claim that the L4-L5 and L5-S1 intervertebral discs are at greater risk of injury during a deadlift. The L4-L5 intervertebral disc experienced the greatest internal flexion/extension moment, and each intervertebral disc above it experienced a lesser internal moment with the T12-L1 experiencing the smallest. The L5-S1 was the only outlier which had a moderate magnitude compared to the other discs when it was expected to have one of the highest magnitudes. This can perhaps be attributed to the lack of markers placed on the lumbosacral region of the spine. Given the objective of the study was heavily motivated by risk of lumbosacral spinal cord injury, modifications to the MOCAP data collection process should include as many markers along the spine as possible without sacrificing the accuracy of the collected data. A study conducted with the goal of examining the axial, compressive, shear, and bending moments in the lumbar spine found that there was no significant difference between the bending moments experienced in the L2 to the L5 vertebrae [5]. The above results do not agree with this finding. Additionally, the exact values of the torques could not be compared given the deadlift motion generated in this study did not incorporate external loads.

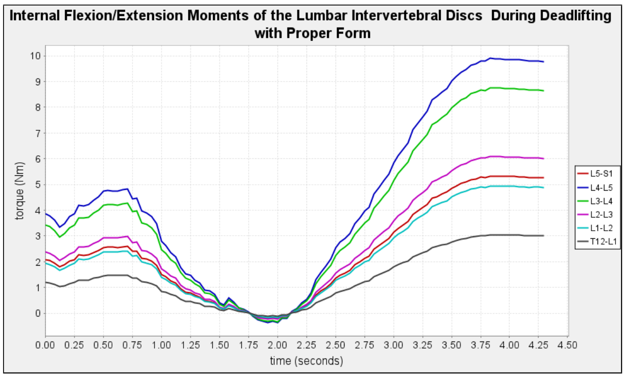

Figure 8: Internal flexion/extension moments of the lumbar intervertebral discs during deadlifting with proper form.

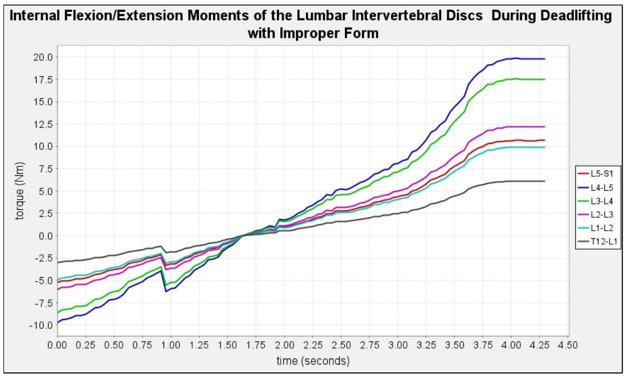

Figure 9: Internal flexion/extension moments of the lumbar intervertebral discs during deadlifting with improper form.

To perform a more thorough analysis, the inverse dynamics tool could have been used. This tool however requires both kinematic and dynamic data of externally applied loads as inputs. During the data collection process, the means for collecting dynamic data were not available and thus it could not be obtained. Further recommendations for this analysis would be to collect more meaningful motion capture data and corresponding dynamic data of externally applied loads using a professional MOCAP lab. This data could then be used to generate more accurate motions and facilitate their validation under realistic conditions with an external applied force representing the load of the bar as well as the corresponding ground reaction forces.

6 Impact

Although free to use computational biomechanics tools like OpenSim are rising in popularity, there are a lack of accessible libraries equipped with pre-existing validated models and motions for many purposes. As was previously mentioned, there exists a very limited number of validated open source full body OpenSim models for lifting, and none of the existing models have associated lifting motions. Multiple studies on muscle and joint reaction forces during deadlifts have been conducted in OpenSim, [10, 11], yet none have released their resulting motions or data files to the public. Additionally, it requires a technical background that is not prevalent in experts within the weightlifting community to thoroughly understand the OpenSim documentation and tutorials. Tony Leyland's study is a perfect example of this disparity given his results were limited by a lack of familiarity with biomechanical computer modelling tools [4]. The availability of open source motions, such as the ones in this study, are then immensely valuable in facilitating the conduction of research in industries like the fitness community. Ultimately, facilitating this research will promote safer and more productive weightlifting practices.

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