A Biomechanical Analysis of Energy Flow in Basketball Free Throws

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Introduction

This project, conducted as part of the SPL x UTSPAN Data Challenge, aims to analyze and optimize energy transfer during basketball free throw attempts. Understanding how energy is transferred during a free throw is crucial because efficient energy transfer can maximize shooting accuracy and reduce fatigue, while inefficient energy transfer can lead to performance issues and increase the risk of injury. The project is structured in three phases: visualizing energy transfer, analyzing inefficiencies and stress points, and applying modeling techniques to optimize the process. The data was provided by Maple Leaf Sports and Entertainment, capturing body movements through markerless, computer vision technology.

I will be presenting my ongoing work at the poster competition during the Carnegie Mellon Sports Analytics Conference in November 2024.

Phase 1: Visualizing Energy Transfer (Completed)

The first phase focused on calculating kinetic energy and transfer efficiency throughout the body and creating engaging visualizations that show how energy is transferred during a free throw. Visualizing energy transfer can help understand the mechanics of a successful free throw. By breaking down the flow of energy between body parts, we can identify potential inefficiencies and points of stress (Phase 2), providing insight into how to improve shooting form (Phase 3).

Kinetic Energy Calculation

The kinetic energy for each body part (arms, torso, legs, etc) was calculated using the sum of both translational and rotational kinetic energy. Both translational and rotational kinetic energies are key to analyzing the free throw because the body moves in complex ways during the motion. Translational energy represents the linear movement of body parts, while rotational energy captures the angular motion around joints, both of which contribute to the overall mechanics of the shot.

$$KE_{\text{total}} = KE_{\text{trans}} + KE_{\text{rot}}$$

These calculations were performed using Python, which used the positional data of each joint to compute the translational and rotational kinetic energies of each body part (arms, legs, and torso).

Translational Kinetic Energy

The translational kinetic energy, which represents the energy due to linear motion, was calculated using the formula:

$$KE_{\text{trans}} = \frac{1}{2}mv^2$$

where m is the mass of the body part, and v is the velocity. The mass of each body part was estimated using a proportional mass distribution (e.g., the head is approximately 6.94% of the overall mass, etc).

Rotational Kinetic Energy

For the rotational kinetic energy, which represents the energy due to angular motion, the following formula was used:

$$KE_{\text{rot}} = \frac{1}{2}I\omega^2$$

where I is the moment of inertia of the body part, and ω is the angular velocity. The moment of inertia depends on the shape and was estimated using approximations (e.g., the limbs were modeled at limbs, the head was modeled as a sphere, etc). The angular velocity was derived from the change in angular position over time.

Kinetic Energy Transfer Efficiency Calculation

The kinetic energy transfer efficiency measures how effectively energy is transferred from one body part to the next through a joint (e.g., upper arm to the forearm through the elbow). The transfer efficiency is calculated as the ratio of the kinetic energy transferred from a joint to a subsequent body part relative to the kinetic energy available in the initial body part. The formula used is:

$$\text{Efficiency} = \frac{KE_{\text{out}}}{KE_{\text{in}}}$$

where:

- KE_{out} is the kinetic energy leaving a joint to a body part (e.g., the energy leaving the elbow to the forearm).

- KE_{in} is the kinetic energy entering a joint from the initial body part (e.g., the energy from the upper arm entering the elbow).

The closer the efficiency ratio is to 1, the more effective the transfer of energy. Efficiency values less than 1 indicate energy loss in the transfer, perhaps due to inefficient mechanics or external factors like friction.

Dynamic Visualizations

Dynamic visualizations were created to show how energy flows through different body parts—legs, torso, and arms—during the shot. These visualizations helped highlight the energy and transfer efficiency across key joints, such as the knees and elbows.

Kinetic Energy Flow

One visualization showed the kinetic energy for each body part, color-coded to indicate higher (red) or lower (blue) energy levels throughout the motion.

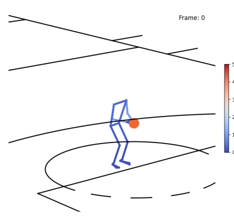

Figure 1: Preparation

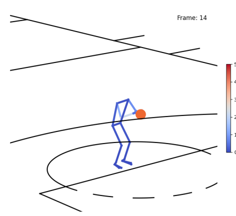

Figure 2: Acceleration

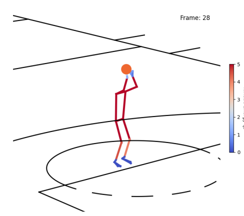

Figure 3: Shooting

Energy Transfer Efficiency

The other visualization showed the kinetic energy transfer efficiency for each joint, color-coded to indicate higher (yellow) or lower (purple) efficiency.

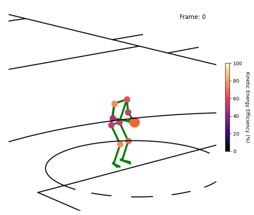

Figure 4: Preparation

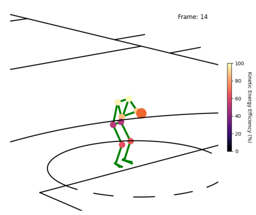

Figure 5: Acceleration

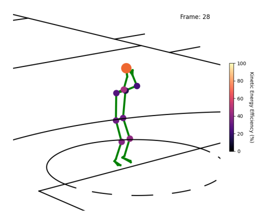

Figure 6: Shooting

Phase 2: Identifying Inefficiencies and Stress Points (In Progress)

The second phase, currently underway, focuses on analyzing the data to identify inefficiencies and stress points in the free throw process.

Kinetic Energy Flow

When plotting kinetic energy over time, we found a characteristic pattern in the motion of the different body parts. Given the repetitive motion of a free throw, this characteristic pattern was expected and may be used to identify key points in the motion through the data.

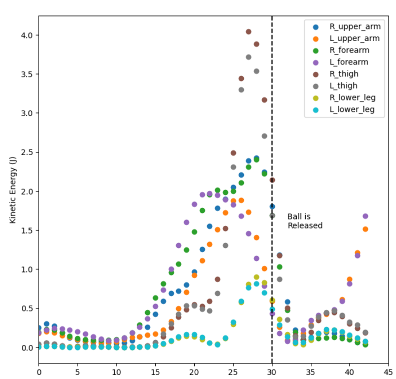

Figure 7: Trial 1

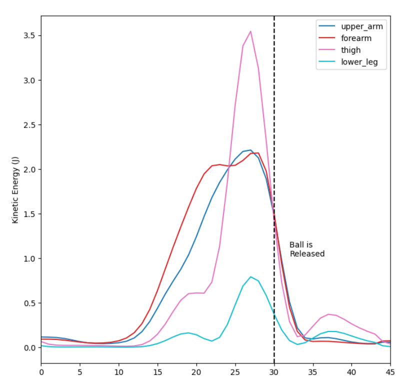

Figure 8: Average of all Trials

Right vs. Left Body Contribution

We also conducted an analysis comparing energy contributions from the right and left sides of the body to identify any imbalances that might affect the shot's performance. Initial analysis of the right vs. left body contributions showed no significant imbalance in overall energy contribution between the two sides. However, more detailed analysis into specific body parts is needed to explore whether subtle imbalances in joints like the shoulders or hips could affect performance

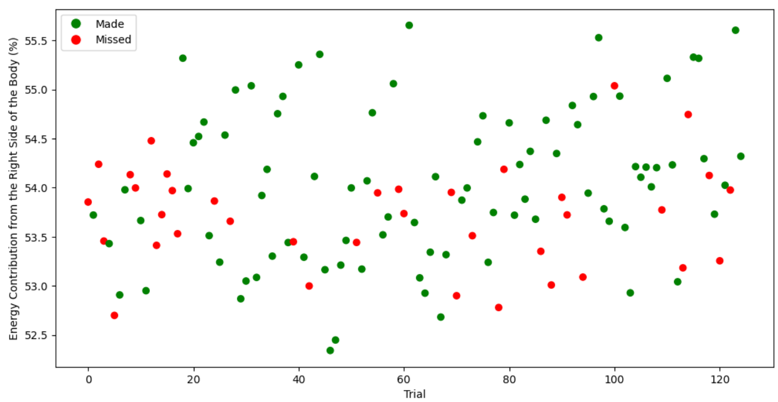

Figure 9: Energy Contribution from the RIGHT Side of the Body

Identifying Inefficiencies in Energy Transfer

By analyzing the data on energy transfer efficiency over the course of the free throw, the goal is to pinpoint moments where energy is lost or transferred inefficiently.

Force Application and Points of High Stress

We will also examine how force is applied during the free throw motion and identify weak points in the motion where joints experience high amounts of stress. The goal will ultimately be to reduce the risk of injury or strain.

Phase 3: Optimizing Energy Transfer Efficiency (Future Work)

The third and final phase will involve applying modeling techniques to optimize energy transfer throughout the free throw process. Planned steps include:

Gathering More Data

Currently, I only have 125 trials from a single shooter. Additional data must be gathered to improve the accuracy of the model.

Predicting the Most Efficient Shot Form

The model will simulate different shooting forms to predict which movements maximize energy transfer and increase shot performance. This process will involve training models using key features from the data, such as joint velocities, angles, and kinetic energy at different points in the motion.

Conclusion

This project is structured in three phases, starting with the visualization of energy transfer (completed), followed by ongoing data analysis to identify inefficiencies and stress points (in progress), and finally, modeling to optimize energy flow (future work). The completed visualizations have provided valuable insights into how energy moves through the body during a free throw, while ongoing data analysis will refine those insights and highlight critical points in the motion. Ultimately, modeling will be used to optimize the free throw technique, with the goal of improving performance and reducing injury risk.