A Comparative Analysis of 2D and 3D Joint Angle Estimation for Sagittal Plane Hip Joint Kinematics

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Summary

This study investigates the accuracy and reliability of calculated two dimensional (2D) and three dimensional (3D) angle estimation methods in hip flexion and extension movements. While 3D motion capture systems are accurate for motion analysis, these labs are not readily available to most patients. Therefore the usage of 3D data in artificial intelligence (AI) models is not always ideal because of the lack of accessibility. This study investigates whether 2D angles calculated from 3D motion capture data are still an accurate representation of initial 3D measurements. The results suggest that 2D angle estimation methods may offer a reliable alternative, particularly in specific pose sequences, thereby challenging the necessity of 3D data for machine learning scenarios.

Introduction

2D data might be better for training AI models because it helps to create a more diverse model that can be deployed in a variety of settings [1]. Traditional 3D motion capture systems offer comprehensive tracking but can be costly and inaccessible. This inaccessibility can lead to less available data and less diverse populations within the participant pool. In recent years, pose estimation models have started to bridge the gap in motion analysis, but these models are trained using 2D data to increase the amount of training data available [1]. 2D data estimated from images has no way of verifying real world joint angles, but if 2D angles are calculated from 3D motion capture data this would allow for immediate verification of AI model outputs. This study compares 3D and calculated 2D angle measurements of hip flexion and extension to assess the validity of the calculated 2D angles.

Methods

Hip angles were extracted using two different approaches: 2D joint angle calculated from motion capture data and 3D motion analysis. For the 3D motion capture, sixteen participants (n=16) were filmed in the msk.ai motion capture lab. Participants wore eight reflective markers across the lower limb. To assess hip flexion, participants performed a knee to chest exercise and a prone leg lift exercise to assess hip extension. 2D hip angles were computed using two key points in the sagittal plane, relying on vector geometry to estimate joint motion. The hip (H), knee (K), and pelvis (P) are defined for 2D coordinates. For 3D estimation, we include the z-axis component as:

$$H = \left(x_h, y_h, z_h\right),\ K = \left(x_k, y_k, z_k\right),\ P = \left(x_p, y_p, z_p\right)$$

In a 2D plane from the sagittal view, the hip joint angle (Θ_{2D}) can be estimated using basic trigonometry as following:

$$(1)\ \Theta_{2D} = arccos\left(\frac{(H-K)\cdot(K-P)}{||H-K||||K-P||}\right)$$

The 3D hip joint angle (Θ_{3D}) is defined as:

$$(2)\ \Theta_{3D} = arccos\left(\frac{(H-K)\cdot(K-P)}{||H-K||||K-P||}\right)$$

Using Equations (1) and (2), we computed hip joint angles in both 2D and 3D. While Θ_{3D} incorporates depth (z-axis) for a more detailed representation of movement, Θ_{2D} assumes a uniplanar motion.

Results and Discussion

For each trial, the differences between the estimated angles from both methods were calculated. The mean values were then aggregated to assess accuracy and reliability. When assessing hip extension, the mean average difference between 2D and 3D measurements was 0.38°. 2D angle estimations were closer to the 3D measurements for hip extension. This suggests that, despite incorporating depth information, 3D tracking may introduce additional variability or noise in certain movement scenarios, potentially affecting accuracy. For hip flexion, the differences between 2D and 3D measurements were minimal, with a mean difference of 0.06°. This indicates that 2D tracking calculations closely align with 3D measurements and may be sufficient for accurately capturing hip flexion angles in most cases.

Conclusions

While 3D tracking is accurate and reliable, our findings show minimal differences in flexion angles between 2D and 3D data. This suggests that 2D calculated angles can be a practical alternative when 3D systems are unavailable. The strong alignment of 2D angle estimates with the 3D highlights their potential for clinical and sports applications. Future research should assess their broader applicability across different joints and movements.

References

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