Kinect v2 Accuracy as a Body Segment Measuring Tool

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Mild traumatic brain injury (mTBI) and/or concussion is the leading cause of injury related to recent U.S. military conflicts. Among other symptoms, injured service members often present with impaired balance. Several field-expedient test batteries have been developed to evaluate balance deficits in this context; however, such tests suffer from limitations associated with human observation and scoring. In order to address these limitations, we have developed the Automated Assessment of Postural Stability (AAPS) system, a computerized balance measurement tool which automates the frequently-administered Balance Error Scoring System [1], [2]. The AAPS is based on the Microsoft Kinect v2, a markerless, portable and low-cost alternative to laboratory–grade motion tracking systems. This hardware integrates an array of sensors including an HD camera, infrared, and depth sensors. The Microsoft proprietary skeletal tracking algorithm [3] estimates coordinates for up to 25 body joint centers which are used to recreate a stick model representation of the subject. All tracking data is encapsulated in a “body frame” stream generated at a variable frame rate of up to 30 fps.

Previous work has raised concerns over the accuracy and precision of the Kinect’s estimation of relative joint center positions, particularly in comparison to professional grade stereophotogrammetry systems [4]–[6]. The purposes of this research were to 1) quantify the accuracy of the Kinect by measuring the lengths of body segments under various “real-life” conditions and 2) identify the ambient conditions that provide optimal results when performing BESS-like balance tests. In order to quantify the Kinect’s accuracy, we recorded data from five healthy subjects, each performing 96 balance trials under varying combinations of clothing, footwear, and shelter. Balance trials were administered on two surfaces (solid ground and medium-density foam padding) per standard BESS test requirements [7]. Trials began with subjects facing the sensor with their arms spread out to their sides and feet shoulder width apart (the “T–pose”). Following the T-pose, the subjects performed a series of rehearsed “errors” in either Single Leg or Tandem stance. The Single Leg condition consisted of standing on the non-dominant leg whereas the Tandem condition required subjects to stand with feet in-line (heel-to-toe). These stance tasks were repeated under a variety of environmental conditions involving manipulation of 1) shelter (indoor vs outdoor), 2) clothing (shorts and t-shirts vs pants and sleeves), and 3) footwear (shoes vs barefoot). Segment lengths were calculated by taking the Euclidean distance between paired 3D joint center coordinates. Average segment lengths were obtained for each trial for both the left and right ulna, humerus, femur, and tibia segments. In order to quantify the system’s accuracy in measuring segment lengths, the Kinect v2 measurements were compared with the clinically-derived measurements as observed by a single investigator. The Normalized Root Mean Squared Error (N-RMSE) was calculated to gauge the Kinect’s inaccuracy of each body segment length. N-RMSE’s were then grouped by each unique permutation of the experiment’s variables: clothing, footwear, and shelter.

The results of our study indicate that overall accuracy was not affected by environmental conditions, except for cases in which subjects wore shoes, shorts and short-sleeve shirts, when increase in accuracy was detected. Under these conditions, segment length accuracy varied in a segment-dependent manner. Segment length estimates were most accurate for the femur and least accurate for the tibia. The latter appeared to be the segment most affected by the foam pad among those included in this study. Previous work had only tested AAPS indoors and with little control over subject clothing. This study therefore represents an initial step in field testing the AAPS and its real-world performance. Future AAPS work will seek to optimize BESS error detection under the varied conditions presented in this work.

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Introduction

- The AAPS (Automated Assessment of Postural Stability) is a system that automates balance measurements designed for the assessment of concussion in forward military setting. AAPS consists of a Windows computer, a custom designed software suite, and a Microsoft Kinect v2. The system was designed with the following priorities in mind:
- Must not require medically trained personnel or additional calibration
- Setup and test administration must be possible within 15 minutes
- GUI must be user-friendly
- System must be robust to field conditions

Overview

- The AAPS measures balance by utilizing a common series of balance tests known as the Balance Error Scoring System (BESS) test.

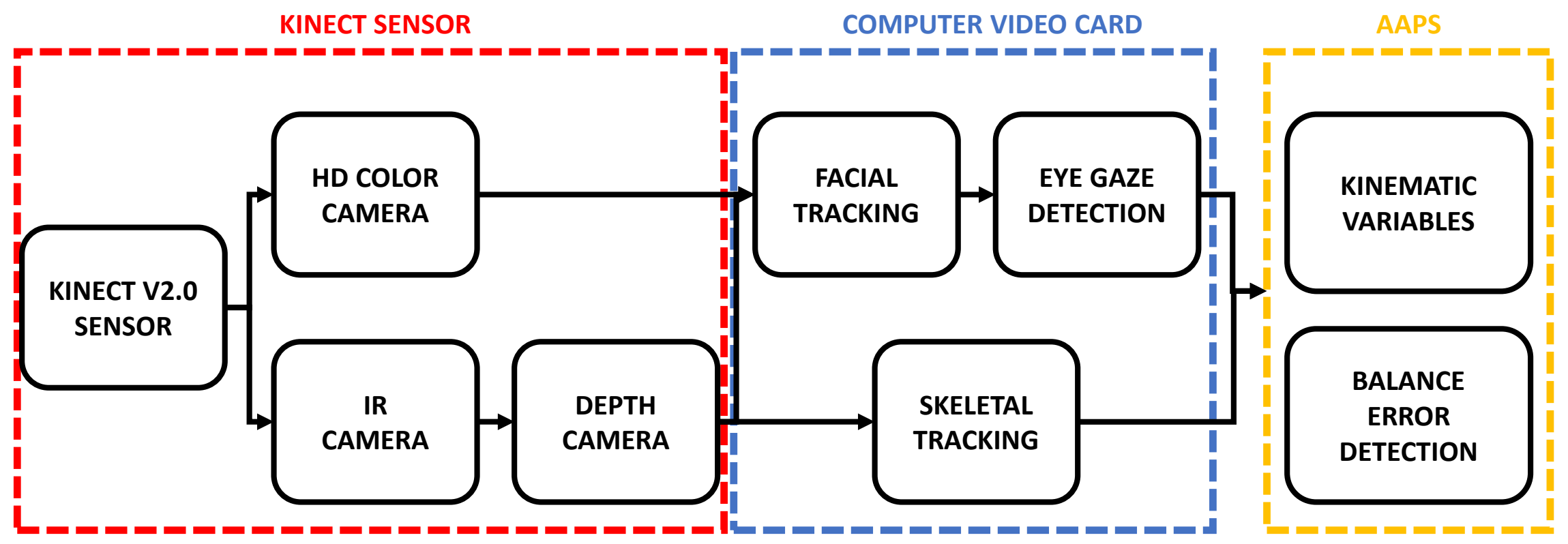

Figure 1: Workflow of the AAPS system

- Kinect v2 estimates 3D spatial coordinates for 25 joint centers per subject, up to 6 subjects, at up to 30 fps.
- The data analyzed in this work was gathered from the first stage of field testing the AAPS software.

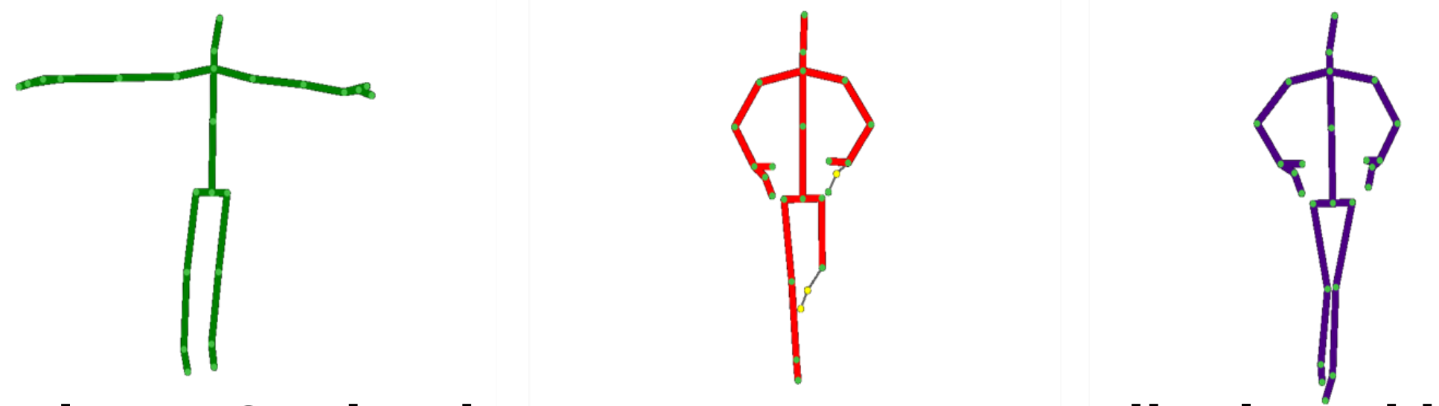

Figure 2: The three stance types as displayed in the AAPS user interface. From right to left: T-pose, single-legged, tandem.

Despite the convenience afforded by such a system, further development is limited by certain challenges:

- The proprietary Microsoft tracking algorithm may introduce joint center oscillations unrelated to user movement
- Tracking accuracy is variable and dependent on ambient conditions

Objectives

1. The objective of this work was to determine if the accuracy of the skeletal tracking data was affected by clothing, footwear, or ambient conditions.
2. If these variables do affect the Kinect's accuracy, find the optimal condition in terms of the mentioned variables in which the accuracy is least affected.

Variable	State 1	State 2
Environment	Indoor	Outdoor
Apparel	Long sleeve/ pants	Short sleeve/ shorts
Footwear	Shod	Barefoot

Materials and Methods

- In order to quantify the Kinect's skeletal tracking capabilities we compared clinically derived measurements with Kinect calculated measurements.
- Each subject performed 96 trials, each of which started with the T-pose, and was followed one of two standard BESS stances: single-legged or tandem.
- Each stance was repeated three times per each experimental ambient condition.
- Kinect derived body segment measurements were obtained by calculating the Euclidean distance between 3D coordinates defining a given joint segment.
- Clinically derived measurements were obtained by a single investigator using the following proximal and distal landmarks: acromion process to lateral humeral epicondyle (humerus); radial head to radial styloid (ulna); greater trochanter to lateral femoral condyle (femur); palpated joint space to lateral malleolus (tibia).
- This work included 5 human test subjects with the following clinically derived segment measurements.

Subject	Tibia (cm)	Femur (cm)	Ulna (cm)	Humerus (cm)
1	40.1	38.1	26.7	25.4
2	40.4	45.7	23.5	29.2
3	40.0	40.6	26.7	28.4
4	41.1	42.4	26.2	26.9
5	42.5	41.5	25.5	31.0

Results

- The Normalized Root Mean Squared Error (N-RMSE) was calculated for each segment in each of the 8 conditions during the T-pose stance. The 8 conditions represented all combinations of the independent variables: clothing, footwear, and environment.
- The T-pose stance was selected to identify optimal ambient conditions because it had the least amount of motion and allowed for optimal limb visibility.

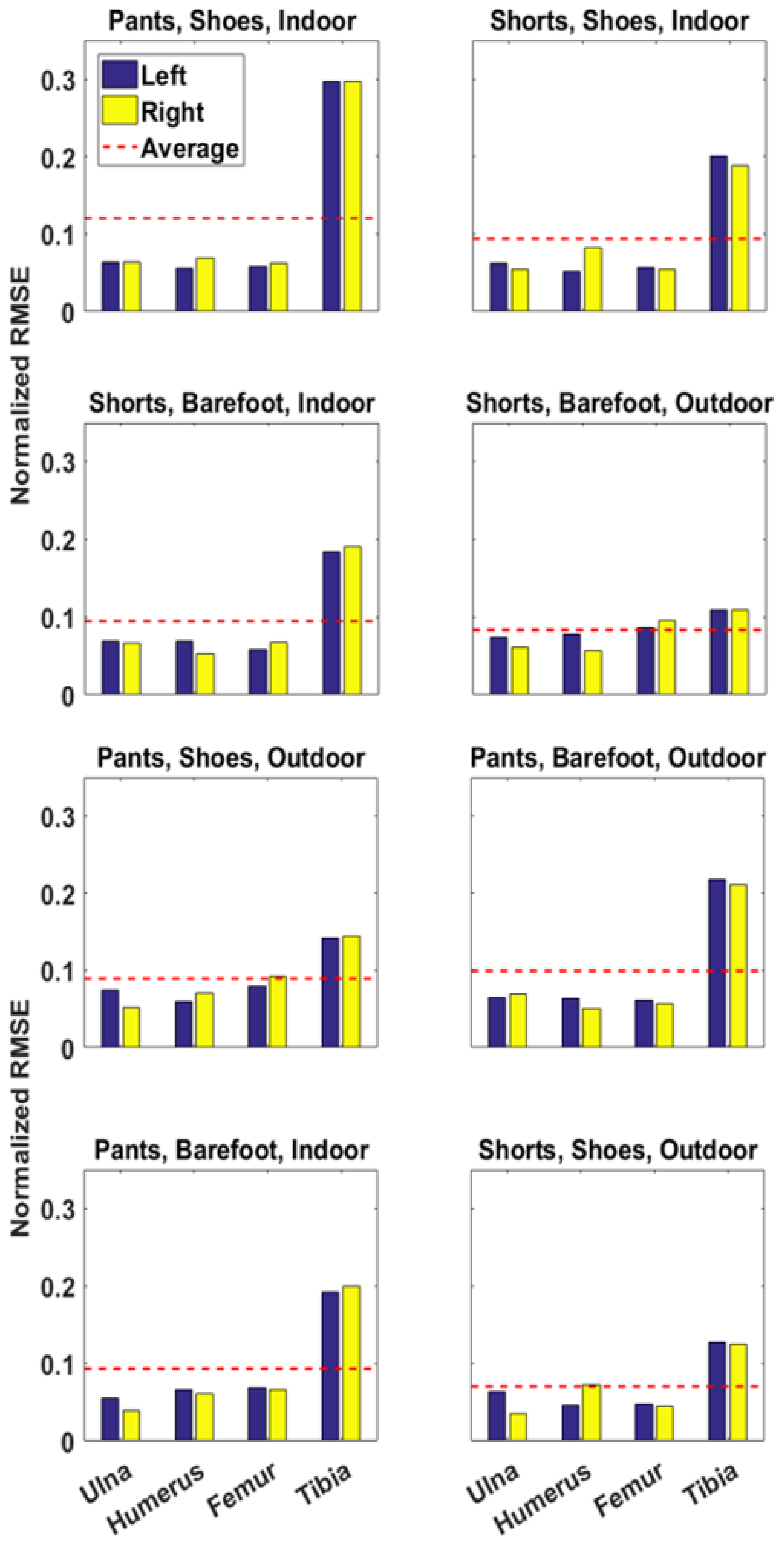

Figure 3: The Normalized RMSE for each segment in each condition of the T-pose stance. Blue and yellow bars represent body segment N-RMSE's respectively for left and right side of the body and the dashed red line is the overall average.

- Furthermore, we investigated the impact of stance and surface on the Kinect's skeletal tracking accuracy.
- In this portion of the study, two ambient conditions were analyzed; the optimal condition, and shorts, barefoot and indoors.
- This figure emphasizes how the tracking of lower extremities are negatively affected by the presence of the foam pad, especially in tandem stance.

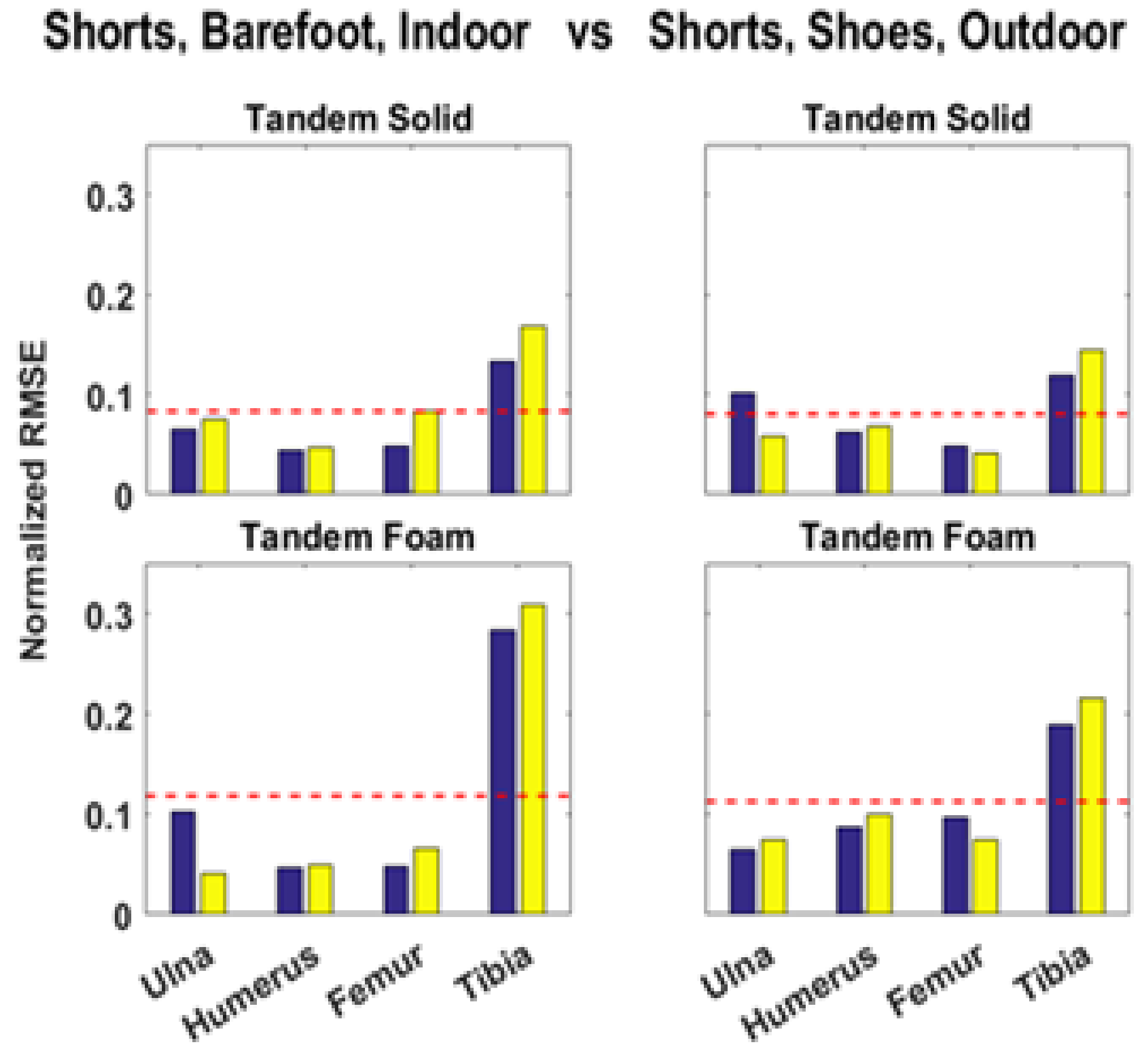

Figure 4: Comparison between the hypothesized ideal condition and actual ideal condition, left to right.

Summary

- Kinect-based segment length estimation showed no linear relationship to any of the permutations.
- Our results indicate that optimal segment accuracy was achieved by subjects wearing shoes and shorts while in an outdoor setting. Kinect-based segment length estimates were most accurate for the femur and least accurate for the tibia, which appeared to be the segment most affected by the foam pad, as required by the BESS.
- Our results suggest that the detection of ankle joint centers depends on the contrast between shoe and ground.

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