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NOVEL METHODS FOR EVALUATING MARKER PLACEMENT ERROR

[1,2]Sean T. Osis, [1]Blayne Hettinga, [1]Shari Macdonald, and [1]Reed Ferber
[1]University of Calgary, Calgary, AB
[2]Corresponding author; email: stosis@ucalgary.ca, web: www.runninginjuryclinic.com

SUMMARY

A continuing challenge for biomechanical research is the standardization of gait analysis techniques, particularly methods of marker placement when constructing an anatomical model. The current study applies morphometric methods in a unique manner to quantify discrepancies in marker placement relative to a reference database. This method of quantifying marker error allows for more in-depth studies of training methods, inter-tester differences, and the effects of placement error on downstream kinematic calculations.

INTRODUCTION

Three-dimensional gait analysis has become a ubiquitous and essential tool in clinical biomechanics. As more researchers adopt this technique, it has become increasingly important for the research community to ensure that gait analysis methods are consistent to facilitate comparisons of results between examiners and between gait laboratories.

Marker placement error has been identified as the single greatest source of error in gait analysis [1], resulting in errors up to 25 degrees in kinematic calculations [1,2,4]. In order to address this challenge, a method must be identified to account for both individual anatomical variation as well as the potential for marker placement error. The field of morphometrics has addressed similar challenges, such as classifying biological specimens based on anatomical structure. One recent approach utilized a nearest-neighbor comparison of generalized least-squares (GLS)-normalized anatomical coordinates [3]. This approach can potentially be modified to analyze anatomical data from humans, which can then be classified in terms of variation relative to a comparable database sample.

Therefore, the purposes of this study were to: (1) examine the structure of anatomical variance across subjects; (2) use this variance to define a GLS-normalization procedure for anatomical data; and (3) use scaled reference data to assess errors in data collected by a novice biomechanist.

METHODS

Anatomical data were collected on 400 patients participating in either clinical or research activities at the Running Injury Clinic and all patients gave informed consent.

Spherical retro-reflective markers were placed on anatomical landmarks of the lower extremities and pelvis. Three-dimensional coordinate data were collected using eight high-speed digital video cameras. Patient standing position was standardized using a graphic template placed on the floor, and the patient was instructed to stand motionless while 1 second of data was captured (200 Hz).

The marker placements of two testers were used: an Expert (*n=340*) and a Novice (*n=60*). Both testers placed markers according to the same anatomical model. The Expert was a clinician with 14 years experience in clinical anatomy, and more than 500 marker placements performed for gait analysis. The Novice was also a clinician, but with no previous biomechanics or gait data collection experience.

The marker placements of the Expert were considered to be a gold-standard, to be used as a basis for comparison of the Novice data. Principle component analysis (PCA) identified key variances in the Expert anatomical coordinate data. Based on these variances, a modified GLS Procrustes analysis was performed to transform all anatomical data into a common reference frame. Data were first translated to a common origin, identified as the mean of left and right malleoli markers. Data were then scaled to a root-mean-square distance of 1.0 m from the origin. Two optimized rotations were then applied in the sagittal plane: first, about the ankle joint to optimize marker positions at the knee, and second about the knee joint to optimize marker positions at the hip and pelvis. After scaling, Procrustes residuals were computed for each Expert data set.

The same procedure was applied to the Novice marker data to transform them into the same reference frame as the Expert data. The Procrustes residuals of each Novice data set were compared against the residuals of all Expert data sets, and a subset of Expert data was selected using a nearest-neighbor analysis.
The scaled-coordinates of each joint marker from the Novice data set were scored according to the interquartile-range ratio (IQRR), which was calculated as the distance of the Novice data coordinate from the median of the subset, divided by the interquartile-range (IQR) of the subset. The IQRR scores were then compared between Early (first 10 collections) and Late (last 10 collections) Novice data that occurred 1 year later.

RESULTS AND DISCUSSION

The variances described by the PCA for the Expert data corresponded with the GLS Procrustes analysis scaling methods. PC1 was correlated with subject height (r=0.93), PC2 was correlated with thigh segment angle (r=0.94), PC3 was correlated with pelvis height (r=0.56) and PC4 was correlated with the forward lean of the body (r=0.70). These four components accounted for 74% of the total variance.

The PCA results are consistent with variations in anatomical relationships. In general, anatomical bony landmarks, and subsequent marker placement, varies according to relative scaling of the segments, and rotations in the sagittal plane. Furthermore, the variance in the data supports previous research of anatomical relationships demonstrating correlations between segment lengths and total height [5]. This evidence seems to support the use of the modified GLS Procrustes analysis to transform anatomical data into a common reference frame in order to minimize marker placement error.

The nearest-neighbor comparison of Procrustes residuals resutled in the selection of unique subsets for each *n=60* Novice data set (Figure 1). Furthermore, the subsets tended to include those data that were anatomically similar to the Novice data, which produced a distribuion of potential neighbors described by a median and interquartile range in each coordinate.

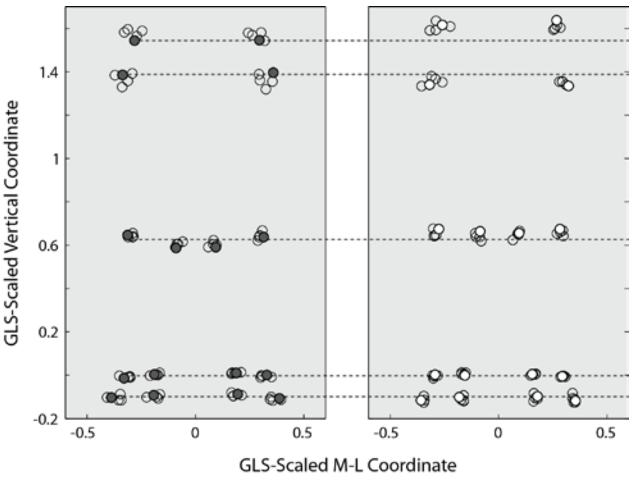

Figure 1: Comparison of selected markers from two Novice data sets (dark/light circles) and closest neighbors from Expert subsets (open circles).

A comparison of Early and Late IQRR scores demonstrated qualitative improvement in consistency between the Novice and Expert data over time (Figure 2). These results suggest that experience and training improve the consistency of marker placement. However, despite an improvement in the scores, systematic differences remained for certain marker coordinates, and these differences were not caught by the instructors advising the Novice. Thus, we postulate that the current methods are perhaps more sensitive to differences in marker placement than human instructors.

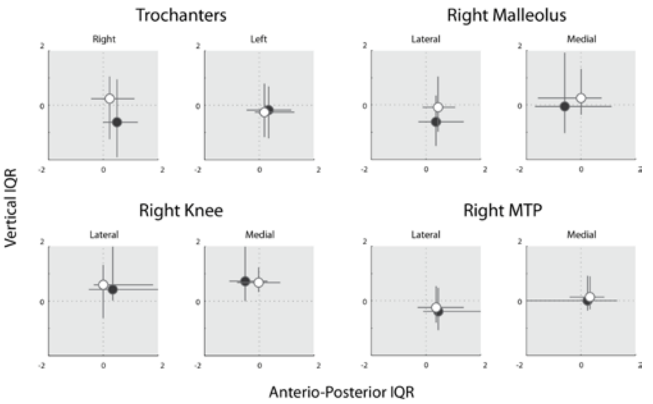

Figure 2: Medians (circles) and ranges (bars) for Early (dark) and Late (light) IQRR scores of selected markers.

Although researchers have attempted to address the challenge of consistency in marker placement through training and devices, marker placement error is still the single largest contributor to inaccuracy in kinematic variables [1]. The methods presented herein provide two potential avenues to improve reliability of kinematic data by quantifying discrepancies in marker placement.

First, by automating the process of identifying discrepancies in maker placement, a novice biomechanist can obtain real-time feedback. The IQRR score provides a quantifiable means to identify errors in marker placements and thus an opportunity to revise maker placement prior to the data collection. Second, by retrospectively examining maker placement data for discrepancies, the tester could exclude subjects based on either potential error in marker placement, or anatomical outliers for whom the standard anatomical model might be inappropriate.

CONCLUSIONS

The current study provides a method to standardize anatomical models for biomechanical gait data. Results have shown quantitative differences in marker placement between an Expert and a Novice tester, suggesting that, although training improves consistency, human instructors may not catch subtle inter-tester differences in marker placement. The variance in anatomical data corresponds well with our current understanding of anatomical differences across subjects, and provides the tools needed to quantitatively detect marker placement errors. The next phase of inquiry will be to determine the effect of marker placement error on downstream calculations of kinematic variables.

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