Pergamon

0021-9290(95)00017-8

J. Biomechanics, Vol. 28, No. 10, pp. 1257-1261, 1995

0021-9290/95 $9.50 + .00

ISB RECOMMENDATIONS FOR STANDARDIZATION IN THE REPORTING OF KINEMATIC DATA

Ge Wu and Peter R. Cavanagh

The Center for Locomotion Studies, Penn State University, University Park, PA 16802, U.S.A.

Since 1990, the Standardization and Terminology Committee of the International Society of Biomechanics has been working towards a recommendation for standardization in the reporting of kinematic data. The paper, which is a result of those efforts (including broad input from members of the Society), is intended as a guide to the presentation of kinematic data in refereed publications and other materials. It is hoped that some uniformity in presentation will make publications easier to read and allow for the more straightforward comparison of data sets from different investigators. It is not intended to restrict individual investigators in the manner in which they collect or process their data. Rather, it could be viewed as a "output filter" applied to a variety of data formats to provide uniformity in the final product.

The ISB is cognizant of the various attempts at standardization that are being pursued by other organizations—such as CAMARC in Europe, the Clinical Gait Laboratory Group in the U.S.A., and the efforts of individual professional groups such as the Scoliosis Research Society. Where possible, we have sought unanimity with these groups, but on issues where the members of our society expressed strong opinions, we have—at times—stated a contrary view. One example in point is the use of center of mass-based segmental reference frames. Since such reference frames are needed for conventional dynamic analysis, we make the recommendation that such frames should be routinely used. We anticipate that extension to the present document in the future will include recommendations for joint coordinate systems and the definition of anatomical landmarks for locating other segmental reference frames.

The committee recognizes that standardization of the description of movement at individual joints is best left to those who are intimately involved in the study of those joints, and we have therefore appointed subcommittees for various joints to provide recommendations. Groups are currently active for the ankle, hand, shoulder, spine, temporomandibular joints, whole body and wrist; members with interests and expertise in other joints are being actively sought. The initial recommendations of some of these groups have already been published in the ISB Newsletter, and once these recommendation have been discussed by the membership, a subsequent document on joint coordinate systems will be published.

The present recommendations are presented as a framework on which future progress can be based. We are grateful to former members of the Standardization and Terminology Committee (notably Professors John Paul, David Winter, and Don Grieve) and to the many ISB members who have commented on earlier drafts of this recommendation. The present paper owes much to the work of Sommer (1991).

Part 1: Definition of a global reference frame

Need:	A Global Reference Frame with the direction of the global axes being consistent, no matter which activities or subjects are being studied, or which investigator is conducting the experiment.
Notation:	X, Y, Z
Recommendation:	A right-handed orthogonal triad fixed in the ground with the $+Y$ axis upward and parallel with the field of gravity, X and Z axes in a plane that is perpendicular to the Y axis.
Notes:	(a) Where there is clear direction of travel or work (as is the case for level gait), the $+X$ axis is defined as the direction of travel or work (see Fig. 1). (b) In case of locomotion on inclined planes, the Y axis will remain vertical and the X and Z axes will be in the same horizontal plane. (c) Where there is no clear direction of travel or work (as is the case for insect flight), the $+X$ axis should be defined by the investigator. (d) In tasks such as exercise in zero gravity, the $+X$ axis should be defined according to some arbitrary but visible surface in the environment and in the direction that is meaningful to the task.

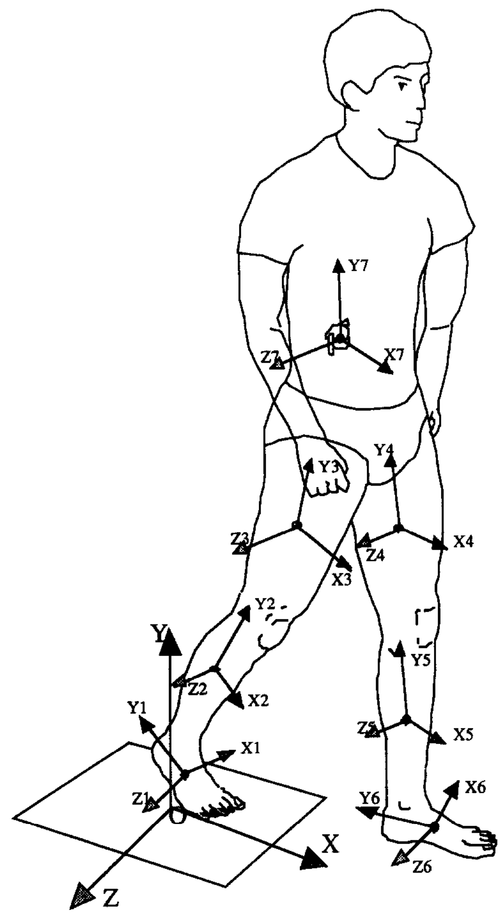

Fig. 1. Conventions for global reference frame and segmental local center of mass reference frame.

(e) We acknowledge that there may be situations where non-Cartesian axes are more appropriate to the task being studied (for example, cylindrical coordinates are useful for the study of asymmetric manual exertion). Since the majority of studies use a Cartesian approach, it will be left to individual investigators to devise systems for the reporting of more specialist situations.
(f) The directions of the X, Y and Z axes have been chosen so that for those conducting two-dimensional studies, X, Y will lie in a sagittal plane. This will be consistent with the three-dimensional convention.

Part 2: Definition of segmental local center of mass reference frames

Need: A coherent frame to describe segment pose (position and orientation) with respect to the global frame.

Notation: X_i, Y_i, Z_i

Recommendation: A series of right-handed orthogonal triads fixed at the segmental centers of mass with the $+X_i$ axis anterior, $+Y_i$ axis proximal, and $+Z_i$ being defined by a right-hand rule.

Notes: (a) In general, the anterior–posterior, proximal–distal, and medial–lateral directions are defined in relation to the standard anatomical position.
(b) The use of right-hand reference frames for both left- and right-body segments implies that for the segments on the right side of the body the $+Z_i$ is pointing laterally, and for the segments on the left side of the body the $+Z_i$ is pointing medially (Fig. 1). As a result, the positive movements about the X_i and Y_i axes of a segment on the left side of the body will have opposite effects of movements of similar sign on the right side of the body (Fig. 2). This difference should

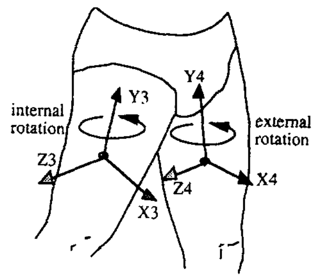

Fig. 2. The same rotations about segmental local center of mass reference frames produce anatomically different motions on the left and right sides of the body.

be accounted for by describing the movements in their anatomical terms in any presentation of the data.

Part 3: Global displacement

Need: Specification of displacement of a segment with respect to the Global Reference Frame.

Notation: x_i, y_i, z_i

Recommendation: Report the coordinates of the origins of the Segmental Local Center of Mass Reference Frames with respect to the global origin in meters. The position of the local origin will be represented by the first column of the 4×4 matrix in the Local to Global transformation matrix $[T_{lg}]$ (see below).

Part 4: Global orientation

Need: Specification of orientation of a segment with respect to the Global Reference Frame.

Notation: $\alpha_i, \beta_i, \gamma_i$

Recommendation: A standard ZYX decomposition (Sommer, 1991) of the 3×3 rotation submatrix of the 4×4 matrix will be used to define the Local to Global transformation matrix $[T_{lg}]$:

$$[T_{lg}] = \begin{bmatrix} 1 & 0 & 0 & 0 \\ x_i & C_{11i} & C_{12i} & C_{13i} \\ y_i & C_{21i} & C_{22i} & C_{23i} \\ z_i & C_{31i} & C_{32i} & C_{33i} \end{bmatrix},$$

where $C_{11i}, C_{21i}, C_{31i}$ are the direction cosines of the local X_i axis with respect to the Global X, Y and Z axes, respectively.

Note: If $\alpha_i, \beta_i, \gamma_i$ is an ordered series of rotations about Z_i, Y_i, and X_i axes, respectively, then

$$[T_{lg}] = \begin{bmatrix} 1 & 0 & 0 & 0 \\ x_i & c\alpha_i c\beta_i & c\alpha_i s\beta_i s\gamma_i - s\alpha_i c\gamma_i & c\alpha_i s\beta_i c\gamma_i + s\alpha_i s\gamma_i \\ y_i & s\alpha_i c\beta_i & s\alpha_i s\beta_i s\gamma_i + c\alpha_i c\gamma_i & s\alpha_i s\beta_i c\gamma_i - c\alpha_i s\gamma_i \\ z_i & -s\beta_i & c\beta_i s\gamma_i & c\beta_i c\gamma_i \end{bmatrix},$$

where $s\alpha_i = \sin(\alpha_i)$ and $c\alpha_i = \cos(\alpha_i)$.

The individual angles can be found as follows:

$\beta_i = -\arcsin(C_{31i})$,

$\alpha_i = \arcsin(C_{21i}/\cos(\beta_i))$,

$\alpha_i = \arccos(C_{11i}/\cos(\beta_i))$,

$\gamma_i = \arcsin(C_{32i}/\cos(\beta_i))$,

$\gamma_i = \arccos(C_{33i}/\cos(\beta_i))$.

Part 5: Relative orientation

Need: A frame (or system) to express the relative orientation of the body segments with respect to each other.

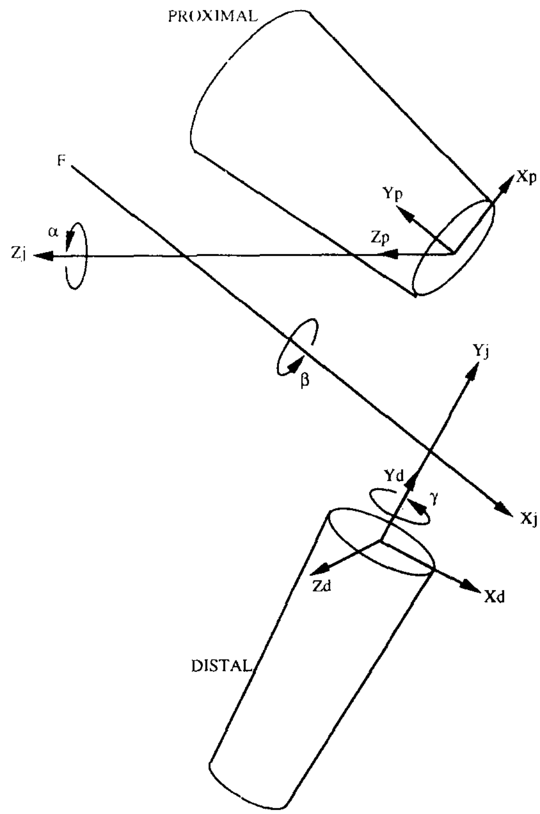

Fig. 3. A joint coordinate system for the knee joint.

Notation: α: rotation about one axis of the proximal segment's Local Reference Frame;
γ: rotation about one axis of the distal segment's Local Reference Frame;
β: rotation about the floating axis.

Recommendation: A joint coordinate system (which might better be called a joint rotation convention) is defined for each joint individually. This system allows rotations about axes which can be anatomically meaningful at the sacrifice of establishing a reference frame with non-orthogonal axes. As long as forces and moments are not resolved along these non-orthogonal axes, this does not present a problem. This approach allows the preservation of an important linkage with clinical medicine where the use of independent paired rotations (ab/ad, internal/external, etc.) is common usage.

The most well-known examples of such systems are those developed for the knee by Grood and Suntay (1983) and Chao (1986) (Fig. 3). Two body fixed axes are established relative to anatomical landmarks, one in each body on opposing sides of the joint. The third axis, called the floating axis, is defined as being perpendicular to each of the two body fixed axes.

Notes: (a) The orientation of the axes in the Local Reference Frames of the proximal and distal segments must be clearly specified.

(b) The choice of the location of the origins drastically affects the distraction displacement terms.

(c) The Euler angle set in Part 4 (Global orientation) should match the angle decomposition for the joints as closely as possible.

REFERENCES

Chao, E. Y. S. (1986) Biomechanics of human gait. In *Frontiers in Biomechanics* (Edited by Schmid-Schonbein, G. W., Woo. S. L.-Y. and Zweifach, B. W.). Springer, New York.

Grood, E. S. and Suntay, W. J. (1983) A joint coordinate system for the clinical description of three-dimensional motions: application to the knee. *J. Biomechanical Engng.* **105**, 136–144.

Sommer, H. J. III (1991) *Primer on 3-D Kinematics.* Handout to the American Society of Biomechanics Meeting. Tempe, AZ, USA.

EDITORIAL COMMENT

The following recommendations on terminology for the reporting of kinematic data represent a thoughtful approach arising from a committee of the International Society of Biomechanics. The material was developed over some years, and involved a number of individuals so credited. The recommendations are published without peer review, since they arose from a committee of one of our participating organizations, and since they represent a compilation of commonly accepted practices.

R. A. Brand
Editor