A PROPOSED STANDARD FOR ASSESSING THE MARKER-LOCATION ACCURACY OF VIDEO-BASED MOTION ANALYSIS SYSTEMS

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Introduction

The accuracy of the joint angles, moments, and powers measured using video-based motion analysis is determined in large part by how accurate the motion system is at locating markers within the collection volume. Marker-location accuracy is influenced by many factors, including camera placement, camera linearization, effectiveness of the calibration, lighting, and post-processing procedures. Manufacturer-supplied measures of accuracy vary between manufacturers and the methods for their calculation are often proprietary and thus not available for evaluation by motion laboratory researchers or manuscript reviewers. Most authors who report on motion studies in journal articles either do not perform or do not describe tests of marker-location accuracy in their manuscripts, which is not surprising given the space limitations imposed by most journals. There is thus a need for the establishment of a standard assessment of motion system accuracy that could be employed and cited by investigators who use motion systems in their research. Such a standard assessment would also be of use to those seeking accreditation for a clinical motion analysis laboratory. The purpose of the present study was to modify a previously-proposed device for the assessment of marker-location accuracy [1] and test this device in several laboratories to establish thresholds of acceptable accuracy.

Statement of Clinical Significance

The proposed standard will enhance the accuracy of kinematic and kinetic measures made during clinical motion analysis and will permit more rigorous evaluation of peer-reviewed manuscripts describing clinical outcome studies.

Methods

The device used to quantify marker-location accuracy was adapted from a design previously described by Richards [1]. It consists of a motorized arm that rotates relative to a fixed base at 60 rpm with six markers (12.7 mm in diameter) mounted on the arm and one marker mounted on the base (Figure 1). A precision milling machine was used in the construction of the device to fix D_{12} = 500 mm and $D_{34} = D_{45}$ = 100 mm, where D_{ij} represents the distance between the centers of markers *i* and *j*. Six 4 s trials were collected with the position of marker 7 varied in each to make D_{67} = 0, 10, 20, 30, 40, or 50 mm plus one marker diameter. The following measures were used to assess marker location accuracy: E_{12} (the RMS error in D_{12} determined over the trial); E_{35} (the RMS error in D_{35}); E_{345} (the RMS error in the angle formed by collinear markers 3, 4, and 5); and $E_{7\text{-}0,10,..,50}$ (the maximum distance between marker 7 and its mean location when D_{67} = 0, 10, …, 50 mm). Testing was performed in seven laboratories, each with different motion systems, collection volumes, numbers of cameras, and methods for post-processing marker data.

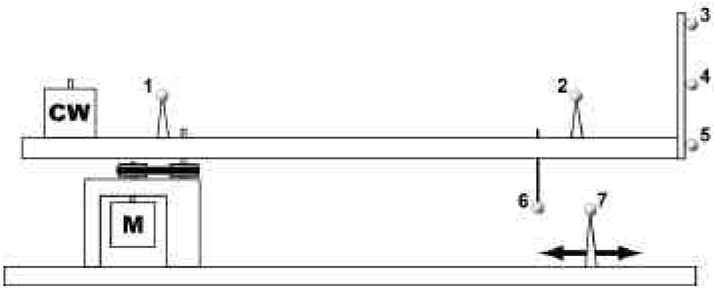

Figure 1. The device used in testing. Markers 3 – 5 are mounted on a plate at the end of the arm, preventing these markers from being seen by all cameras at once. Marker 6 passes near Marker 7 once per revolution, making resolution of these markers challenging.

Lab	System Type	Volume Dimensions (m)	Volume (m^3)	Number of Cameras	Frame Rate (Hz)
A	Digital	3.5 x 2.0 x 1.5	10.5	6	100
B	Digital	8.5 x 2.7 x 2.3	52.8	12	120
C	Analog	4.5 x 1.6 x 1.5	10.8	8	120
D	Digital	4.6 x 2.1 x 2.6	25.6	8	60
E	Digital	6.7 x 1.8 x 1.8	21.7	8	60
F	Analog	3.7 x 1.2 x 1.8	8.0	8	120
G	Digital	6.0 x 2.5 x 2.1	31.5	8	60

Table 1. Motion system characteristics for the seven laboratories tested.

Results

The marker-location errors obtained in each laboratory are presented in Table 2. Results were for the most part consistent across laboratories, with $E_{7\text{-}0}$ being a notable exception, indicating that some of the laboratories' motion systems did poorly at resolving two markers that actually touch during a trial while some did quite well.

Lab	E_{12}	E_{35}	E_{345}	$E_{7\text{-}0}$	$E_{7\text{-}10}$	$E_{7\text{-}20}$	$E_{7\text{-}30}$	$E_{7\text{-}40}$	$E_{7\text{-}50}$
A	0.30	0.32	0.34	8.76	2.41	1.63	1.33	1.24	1.62
B	0.24	0.11	0.13	1.30	1.72	0.60	0.25	0.33	0.53
C	0.27	0.21	0.46	0.20	0.08	0.20	0.26	0.43	0.08
D	0.34	0.25	0.57	5.19	1.26	0.99	1.01	1.23	0.89
E	0.70	0.17	0.39	0.53	0.61	0.46	0.59	0.72	0.54
F	0.23	0.28	0.23	8.35	1.51	0.86	0.80	0.53	0.89
G	0.52	0.13	0.18	0.20	0.21	0.46	0.25	0.22	0.17
Mean	0.37	0.21	0.33	3.50	1.11	0.74	0.64	0.67	0.67
Std. Dev.	0.17	0.08	0.16	3.86	0.85	0.47	0.43	0.42	0.52
Standard	**1.00**	**1.00**	**1.00**	**--**	**4.00**	**2.00**	**2.00**	**2.00**	**2.00**

Table 2. Marker location errors for each lab. All errors are in mm except E_{345}, which is in degrees. The bottom row contains the threshold values proposed by the authors as a minimum standard of accuracy for a clinical motion analysis laboratory.

Discussion

Proposed minimum standards for each of the error measures have been specified that approximate twice the worst errors seen in any of the laboratories tested. No standard has been proposed for $E_{7\text{-}0}$ because of the inconsistent results found across laboratories. It is recognized by the authors that these standards are somewhat arbitrarily imposed, but it is their hope that the threshold values will be refined as they are applied in greater numbers of laboratories in the future.

Reference

[1] Richards, J.G. (1999) *Hum. Movement Sci.* 18:589-602.