Validation of two-dimensional kinematic analysis of walk and sit-to-stand motions in dogs

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Objective—To assess the intra- and interobserver repeatability of 2-dimensional (2-D) kinematic analysis of walk and sit-to-stand motions in dogs.

Animals—10 healthy adult Labrador Retrievers.

Procedures—10 dogs were filmed during walk and sit-to-stand motions. Five trials were recorded for each dog, 3 of which were digitized. Two observers manually marked 15 landmarks on each frame during the motions of interest for these 3 trials. Each observer repeated the procedure approximately 1 week later. The 2-D joint angles were calculated. Intra- and interobserver coefficients of multiple correlations (CMCs) were calculated for each joint angle–time history.

Results—Intraobserver repeatability, assessed as the mean CMCs of 12 joint angle measurements made for 10 dogs by 2 observers, was good or excellent in 23 of 24 (96%) mean CMCs of the joints measured. Interobserver variation, assessed by comparing CMCs of measurements made by 2 observers on 10 dogs on 2 days, was good or excellent in 161 of 240 (67%) CMCs of joints measured.

Conclusions and Clinical Relevance—Intraobserver repeatability of 2-D kinematic measurements made on digitized videotapes was excellent. Interobserver repeatability of these measurements was acceptable. (*Am J Vet Res* 2007;68:277–282)

Kinematics is the science of the mechanics of body motion and has been used to describe features of normal gaits in dogs.[1-10] Kinematics has also been used to describe changes in the motion of abnormal joints, particularly the stifle (femorotibial)[8,11-13] and hip joints.[14,15]

Kinematic analysis may be performed on 3-D images, which requires multiple synchronized cameras and extensive calibration, or on 2-D images by use of a single camera and simple calibration.[6,7] Motion pictures used in kinematic analysis are most often digitally acquired images from visible light cameras, infrared cameras, or high-speed radiographic equipment.[2,4,9] Two-dimensional analysis is technically simpler to perform than 3-D analysis and is considered appropriate for the analysis of motion occurring in a straight line.[16,17] Two-dimensional kinematic analysis has several limitations, compared with 3-D kinematic analysis, including decreased accuracy and sensitivity and a slower, less computerized analysis of videotape sequences. Two-dimensional kinematic analysis can be undertaken on a single videotape that is digitized before analysis.[18,19] Because 2-D kinematic analysis is simpler and costs less than 3-D kinematic analysis, 2-D analysis could be used in clinical settings as an advanced diagnostic tool for assessment of lameness or to assess an animal's response to treatment. Two-dimensional whole-body video analysis yields reliable information about movement in humans, but there is a paucity of information available regarding the reliability of this form of analysis in dogs.[6,19]

The purpose of the study reported here was to evaluate the reliability and repeatability of 2-D kinematic analysis of digitized videotapes in dogs. We undertook the task of assessing the repeatability of 2-D digitized video analysis of canine walking and sit-to-stand motions. The study design matched the design of validation studies[19-21] of motion analysis in humans. Analysis was accomplished by having 2 examiners digitize videos independently twice on days approximately 1 week apart. We hypothesized that reliable information would be obtained with low intra- (same observer repeating measures on separate days) and interobserver (2 observers measuring the same dogs) variability.

Abbreviations

3-D	3-dimensional
2-D	2-dimensional
CMC	Coefficient of multiple correlations

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Materials and Methods

Animals—Ten adult Labrador Retrievers randomly selected from a local breed field trial organization were included in the study. Dogs were eligible for inclusion if they were older than 18 months of age; were registered with the American Kennel Club; did not share parents or grandparents; and had no history of lameness, orthopedic disease, or traumatic injury. A veterinarian evaluated the dogs for orthopedic disease within 1 week of data collection.

Experimental protocol—Data collection took place indoors or outdoors, according to lighting and weather conditions, in areas where there was ample space for dogs to walk and perform a sit-to-stand maneuver (**Figure 1**). A super-video home system camcorder[a] was positioned on the right side of the dog during the walking and sit-to-stand tasks. We assumed that the walking and sit-to-stand movements occurred in the dogs' sagittal plane and in the motion plane perpendicular to the optical axis of the camcorder. At least 1 movement cycle was captured in the field of view. A 1.83-m-long rigid ruler with 10 black-and-white strips, placed in the field of view on the floor and perpendicular to the optical axis of the camcorder, was used as a linear scale. That linear scale was used to convert the 2-D video coordinates into real-world 2-D coordinates.[b] Five trials of both movements were recorded at 60 Hz for each dog, each of which was led by a handler. Videos were digitized.[c] Fifteen points were marked, starting at least 5 frames before and after the entire movement cycle.[c] The points were as follows: 1 reference point at each end of the linear scale; metatarsophalangeal, tarsal, stifle, and hip joints; wing of ilium; scapular spine; shoulder, elbow, carpal, and metacarpophalangeal joints; neck; head; and nose

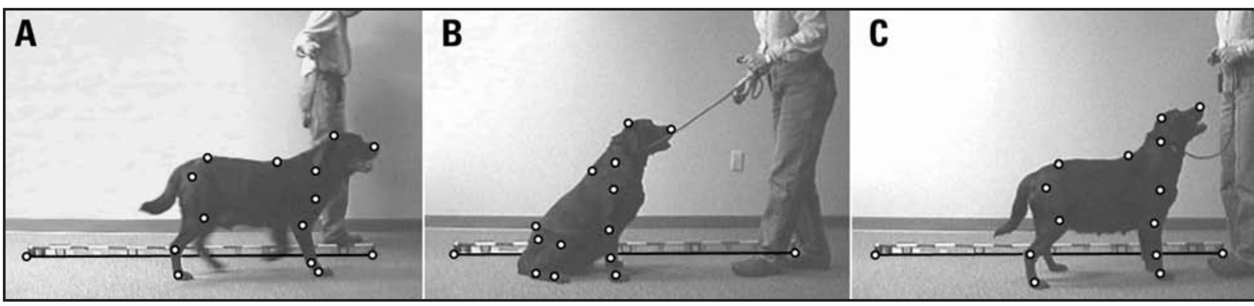

Figure 1—Digitized videotape images of a Labrador Retriever walking (A) and performing a sit-to-stand movement (B, C) in a study in which intra- and interobserver repeatability of 2-D kinematic analysis of these movements were evaluated. Dots were manually placed on joints and on the edge of the calibration device on the floor by observers.

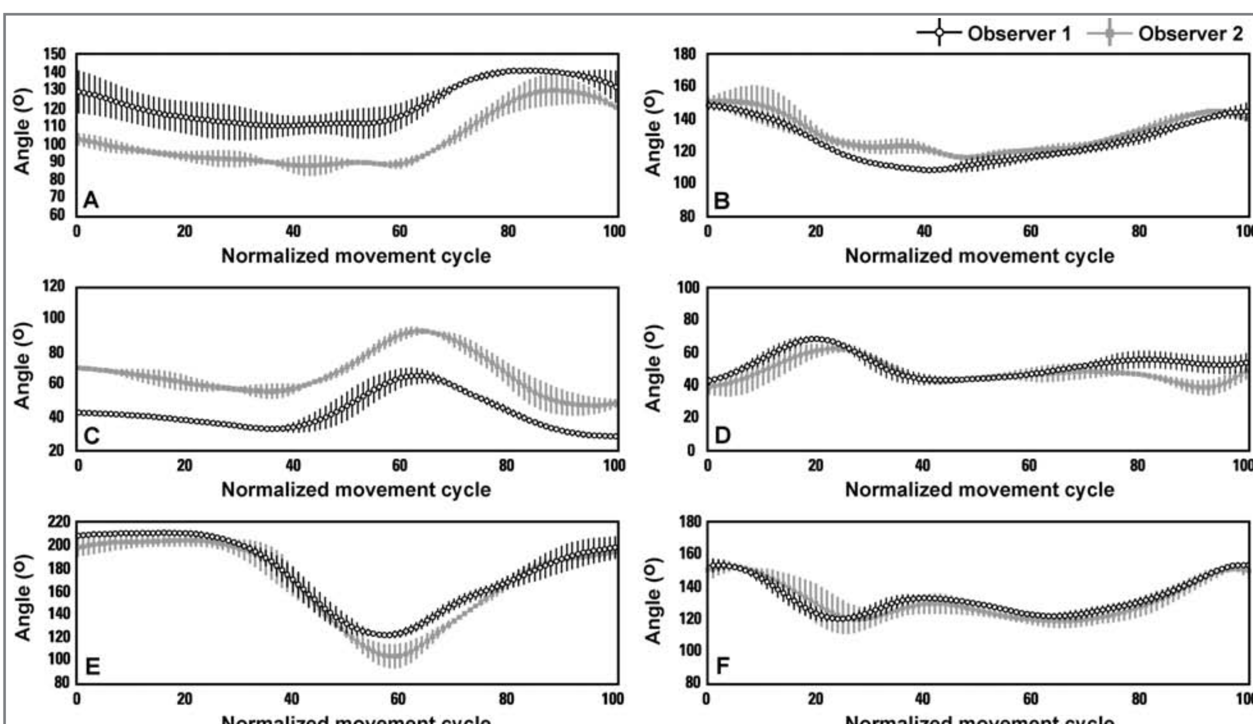

Figure 2—Diagrammatic representations of joint angle measurements obtained by 2 observers from various joints of 10 Labrador Retrievers during walking. Each observer measured movement at the shoulder (A), hip (B), Elbow (C), stifle (femorotibial; D), carpal (E), and tarsal (F) joints. Curves represent mean ± SE values of 3 measurements made on 2 days by 2 observers. Means were derived from 100 normalized time frames representing percentages of the movement cycle. The values in all curves represent joint angles except the values in the elbow and stifle joint curves, which represent 180° minus joint angles. The first frame is the beginning of the swing phase of the right hind limb.

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(**Figure 1**). Every landmark was digitized frame by frame throughout the motion of interest by 2 observers working independently. A walking movement cycle was defined as forelimb strike to ipsilateral forelimb strike, or forelimb or hind limb off the ground to ipsilateral forelimb or hind limb off the ground. A sit-to-stand cycle was defined from the instant the forelimb started to move until there was full extension of all limbs. The definition of a movement cycle was clear across all trials for each dog.

Two-dimensional coordinates were smoothed by use of a Butterworth digital filter at a cut off frequency of 7.14 Hz.[b] Joint angles were calculated from the points digitized on each proximal and distal segment and were defined as the angle between 2 adjacent segments.[b] Each joint angle obtained during a movement cycle was normalized to 100 time frames for comparison across trials and between dogs. A successful trial was defined as one that contained a complete cycle in which anatomic landmarks and markers were clearly visible during data processing. Three successful trials of each movement for each dog were randomly chosen among successful trials, and a mean was calculated and used for calculation of the CMC (**Appendix**). The intraobserver CMC was calculated for each joint angle-time history for each dog between days 1 and 2.[21] Interobserver joint angle–time history CMCs were calculated to assess interobserver reliability. A CMC < 0.7 was considered to be poor, a CMC ≥ 0.7 and < 0.8 was considered to be good, and a CMC ≥ 0.8 was considered to be excellent.[21,22]

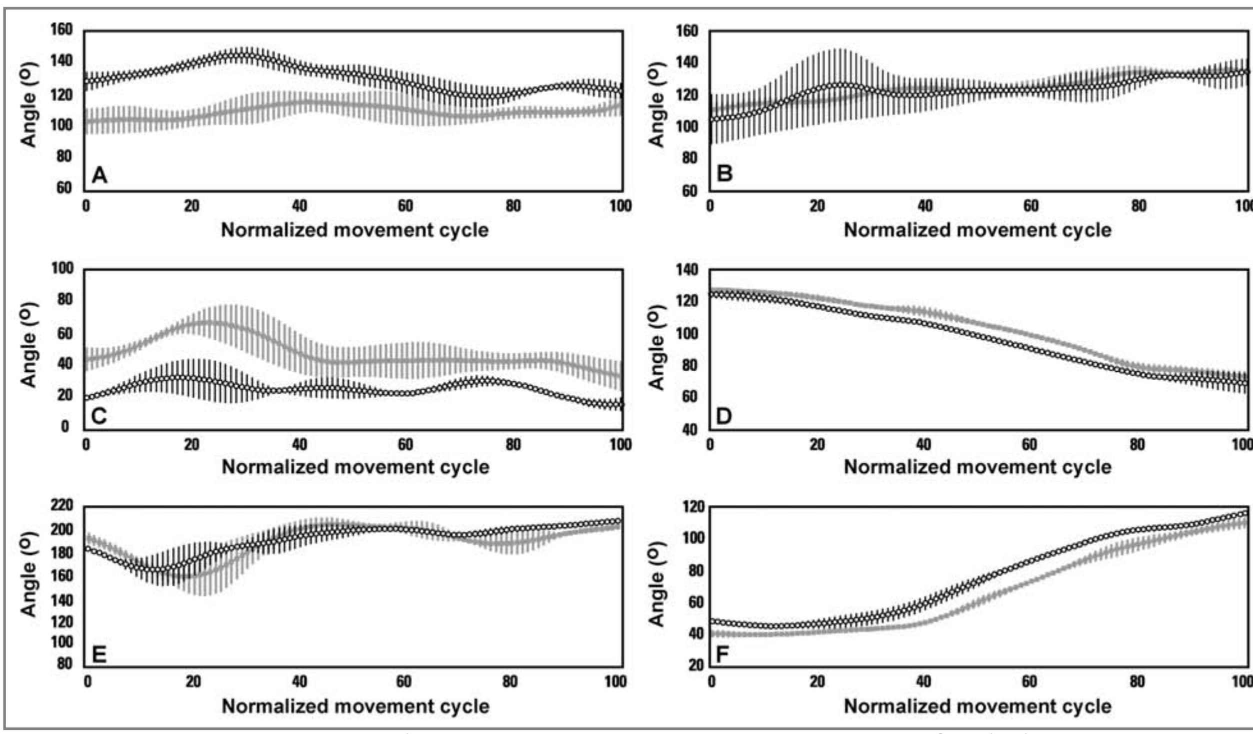

Figure 3—Diagrammatic representations of joint angle measurements (shoulder [A], hip [B], elbow [C], stifle [femorotibial; D], carpal [E], and tarsal [F] joints) during sit-to-stand movement in the same 10 dogs as in Figure 2. The first frame is the beginning of the sit-to-stand movement. *See* Figure 2 for remainder of key.

Table 1—Mean ± SD (range) of intraobserver CMCs for measurements made in 6 joints during walking and sit-to-stand motions in 10 dogs on 2 days by 2 observers.

Joint	Walk*	Sit-to-stand*	Walk†	Sit-to-stand†	Overall
Carpus	0.976 ± 0.061 (0.803–0.999)	0.941 ± 0.050 (0.837–0.995)	0.684 ± 0.333 (0.084–0.995)	0.915 ± 0.106 (0.669–0.996)	0.879 ± 0.207
Elbow	0.970 ± 0.021 (0.930–0.995)	0.884 ± 0.084 (0.745–0.995)	0.790 ± 0.174 (0.446–0.992)	0.868 ± 0.123 (0.541–0.977)	0.878 ± 0.128
Shoulder	0.872 ± 0.104 (0.642–0.989)	0.785 ± 0.168 (0.407–0.945)	0.816 ± 0.176 (0.458–0.982)	0.845 ± 0.138 (0.600–0.980)	0.829 ± 0.147
Tarsus	0.977 ± 0.020 (0.936–0.995)	0.981 ± 0.026 (0.924–0.999)	0.737 ± 0.206 (0.390–0.979)	0.989 ± 0.011 (0.961–0.999)	0.921 ± 0.147
Stifle (femorotibial)	0.965 ± 0.028 (0.895–0.991)	0.960 ± 0.036 (0.903–0.998)	0.741 ± 0.203 (0.430–0.926)	0.966 ± 0.045 (0.849–0.998)	0.908 ± 0.141
Hip	0.895 ± 0.107 (0.655–0.991)	0.703 ± 0.241 (0.273–0.975)	0.772 ± 0.197 (0.334–0.964)	0.848 ± 0.110 (0.603–0.934)	0.804 ± 0.182

*Observer 1. †Observer 2.

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Results

All dogs enrolled fit the inclusion criteria. Motions of the tarsal, stifle, hip, carpal, elbow, and shoulder joints were measured **(Figures 2 and 3)**. Data for neck-motion measurements were considered inaccurate because of potential head movement of dogs during trials and are not reported.

Mean ± SD and range of intraobserver CMCs for the 12 joint angle measurements made by 2 observers on the 10 dogs were summarized **(Table 1)**. Mean CMCs were good or excellent for 23 of 24 measurements. The CMC of carpal motion during walking for observer 2 was slightly less than good (0.684 ± 0.333). Omission of 1 outlying measurement (0.084) from 1 of the 10 dogs raised that mean CMC to 0.751 ± 0.273.

The mean ± SE value of 3 joint angle measurements obtained for 12 joint positions by 2 observers was reported for walking and sit-to-stand motions (Figures 2 and 3). The mean ± SD interobserver CMCs for the 10 dogs were good in 78 of 120 (65%) measurements during walking and 83 of 120 (67%) measurements during sit-to-stand motion **(Tables 2 and 3)**. Mean CMCs were good or excellent for measurements of carpal, tarsal, stifle, and hip joints made during walking and during the sit-to-stand motion. Mean CMCs were fair for the elbow and shoulder joint measurements made during walking and sit-to-stand motion. The CMCs did not improve during the second set of measurements, compared with the first set of measurements. Ranges of motion of joints were summarized **(Table 4)**.

Table 2—Mean ± SD (range) of interobserver CMCs for measurements made in 6 joints during walking and sit-to-stand motions in 10 dogs on 2 days by 2 observers.

Joint	Walking	Sit-to-stand	Overall
Carpus	0.784 ± 0.272 (0.100–0.994)	0.936 ± 0.044 (0.842–0.992)	0.860 ± 0.207
Elbow	0.712 ± 0.153 (0.304–0.9670	0.581 ± 0.157 (0.338–0.885)	0.647 ± 0.167
Shoulder	0.642 ± 0.191 (0.231–0.896)	0.572 ± 0.181 (0.265–0.905)	0.607 ± 0.187
Tarsus	0.724 ± 0.301 (0.140–0.980)	0.976 ± 0.020 (0.938–0.999)	0.850 ± 0.246
Stifle	0.805 ± 0.178 (0.453–0.986)	0.967 ± 0.036 (0.897–0.999)	0.886 ± 0.151
Hip	0.811 ± 0.147 (0.344–0.981)	0.747 ± 0.159 (0.284–0.954)	0.779 ± 0.155

Table 3—Number of CMCs (%) rated as good or excellent (ie, ≥ 0.7) among interobserver CMCs from measurements made by 2 observers on 6 joints during walking and sit-to-stand motions in 10 dogs on 2 days.

Measurement	Walk	Sit-to-stand	Overall
First	35/60 (58)	43/60 (72)	78/120 (65)
Second	43/60 (72)	40/60 (67)	83/120 (69)
Total	78/120 (65)	83/120 (69)	161/240 (67)

Table 4—Mean maximal degrees of flexion and extension and mean ± SD ranges of motion (degrees) for 10 dogs during walking and sit-to-stand motions. Values were calculated from 120 measurements: data were collected 3 times from 10 dogs on 2 days by 2 observers.

Joint	Walk	Sit-to-stand
Carpus	128.0–238.8 (110.9 ± 17.6)	132.6–202.0 (69.5 ± 21.4)
Elbow	91.4–146.3 (54.8 ± 17.9)	109.2–146.6 (37.4 ± 12.9)
Shoulder	88.3–125.0 (36.8 ± 13.2)	91.3–118.6 (27.4 ± 9.0)
Tarsus	111.4–145 (33.6 ± 8.2)	95.2–130.5 (66.4 ± 6.0)
Stifle	111.0–145.9 (34.9 ± 8.7)	45.9–108.2 (62.3 ± 11.5)
Hip	111.2–146.8 (35.7 ± 10.0)	48.7–115.1 (35.3 ± 9.8)

Discussion

Two-dimensional kinematic analysis of digitized videotapes was associated with excellent intraobserver repeatability and acceptable interobserver repeatability. To our knowledge, this is the first report of use of this 2-D kinematic analysis method in dogs. Repeatability was equivalent to repeatability of the method in human studies. Interobserver repeatability in the present study was lower for the elbow and shoulder joints than for other joints. That lower repeatability was most likely a result of the fact that the shoulder joint could not be clearly identified on the digitized videotapes because of the absence of clear anatomic landmarks associated with lighting conditions, coat color, and lower resolution of the videotapes that were being digitized. Enhancing lighting conditions and setting guidelines for identification of the shoulder joint during image processing could enhance interobserver repeatability. The limitations of our imaging methods did not appear to negatively impact intraobserver repeatability of the analyses used in the study, probably because each observer chose a location of the shoulder joint on the basis of identical observer-specific factors that were followed when processing both sets of images. Intra- and interobserver repeatability of measurements of the carpal, tarsal, stifle, and hip joints was good or excellent. Repeatabilities were highest for the carpal, tarsal, and stifle joints, likely because these joints were easily identifiable on the images. Despite the fact that our video camera captured only 60 images/s, joint velocity during motion did not appear to negatively influence the repeatability of our measurements. This was supported by the fact that joint velocity in hind limb joints is highest in the stifle joint, lower in the tarsal joint, and lowest in the hip joint.[3] Measurements in the present study appeared to be more repeatable in the stifle joint than in the hip joint.

The accuracy of measurements made in this study could not be directly determined from the data collected because of the absence of a gold-standard assessment method; therefore, ranges of motions may be used as a measure of accuracy. The ranges of motion of joints during walking in the present study were similar to previously reported values during walking for the hind limb (mean differences ranging from 1.1° to 2.9°), but were less similar to previously determined ranges of motion in forelimbs (mean differences ranging from 6.7° to 19.8°).[4] The accuracy of specific joint measure-

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ments made in the present study was negatively influenced by variations in dot placement. Variation would be most likely for joints that were difficult to identify during the digitizing process. For example, the difference in measured shoulder and elbow joint angles between the 2 observers was likely a result of the different choices in selection of digitized marks for calculation of shoulder and elbow joint angles. Inconsistency in selection of digitized marks between observers may result in a different absolute joint angle value (Figures 2 and 3). Such differences in joint angles were not detected in joints other than the shoulder and elbow joints.

Dogs with clinical lameness were not evaluated in the present study. Therefore, it cannot be concluded that the 2-D kinematic analysis method used in this report would accurately detect lameness. With lameness, the range of motion of affected joints would likely decrease, and such a decrease could influence the reliability of measurements. Because joint measurements were not less reliable in joints with a small range of motion (ie, carpal motion at a walk was < 30°) than in joints with large ranges of motion (ie, stifle joint motion at a walk was > 100°), it is fair to assume that the method would be similarly accurate if an abnormal stifle joint underwent a narrower range of motion than a normal stifle joint. Because lameness is variable among dogs and within a given dog over time, including dogs with clinical lameness, the method described in this report would have increased the variation in lameness between and within subjects. This increase in variation would have impaired our ability to assess within- and between-observer reliability.

The protocol for 2-D kinematic analysis used in the present report was technically simple, compared with 3-D kinematic methods. Neither observer had prior experience in kinematic analysis. The high intraobserver repeatability and lack of difference in interobserver repeatability when the first and second sets of measurements were compared suggest that both observers learned the image analysis protocol at first attempt. This protocol could be used clinically to assess joint motion in dogs with orthopedic problems. It could also be used to assess breed-specific differences in joint motion during standard tasks. A more complete assessment of the method's accuracy in clinical patients, wherein dogs would be simultaneously evaluated under identical experimental conditions by use of 2-D and 3-D kinematic analysis methods, is warranted.

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a. Panasonic camcorder AG-456 UP, Panasonic Corp of North America, Secaucus, NJ.
b. MS2DVA, MotionSoft Inc, Chapel Hill, NC.
c. PEAK Performance video system, version 6.1, Peak Performance Technology Inc, Englewood, Colo.

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Appendix

Equation used to calculate the intersubject CMC.

$$\mathrm{CMC}_{\mathrm{Inter-subject}} = \sqrt{1 - \frac{\sum_{k=1}^{S}\sum_{j=1}^{N}\left(y'_{k,j} - y''_{j}\right)^2}{\sum_{k=1}^{S}\sum_{j=1}^{N}\left(y'_{k,j} - y''\right)^2}}$$

where k is the subject number, S is total number of subjects, $y'_{k,j}$ is the mean of y of subject k in frame j, y''_{j} is the mean of y of S subjects in frame j, and y'' is the overall mean of y of S subjects in N frames. The intersubject CMC calculated in this way can be used as a measure of the similarity of time-history curves of S subjects. An intersubject CMC value close to 1 suggests good similarity or reliability of the waveform or pattern of the time-history curves produced by S subjects. An intersubject CMC value close to 0 indicates poor similarity or reliability of the waveform or pattern of the time-history curves produced by S subjects.

The intersubject CMC can also be used as a measure of the similarity of time-history curves of the same subject in different testing sessions if k is the session number and S is the number of sessions. If the intersubject CMC is calculated this way, an intersubject CMC value close to 1 suggests good similarity or reliability of the waveform or pattern of the time-history curves produced by the same subject in S sessions, whereas an intersubject CMC value close to 0 indicates poor similarity or reliability of the waveform or pattern of time-history curves produced by the same subject in S sessions. In this situation, the intersubject CMC can be referred to as between-session CMC.

The intersubject CMC can also be used as a measure of the similarity of time-history curves of the same subject in different tasks if k is the task number and S is the number of tasks. If the intersubject CMC is calculated this way, an intersubject CMC value close to 1 suggests good similarity or reliability of the waveform or pattern of the time-history curves produced by the same subject in S tasks, whereas an intersubject CMC value close to 0 indicates poor similarity or reliability of the waveform or pattern of time-history curves produced by the same subject in S tasks.[21,22]

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