USING SIGNAL/NOISE RATIOS TO CHECK ATHLETE'S CG VALUES

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The purpose of this investigation was to indicate the reliability of total body center-of-gravity values calculated from cinematographical data. In biomechanical research studies in which film data are utilized, researchers have often overlooked the precision of the digitizing procedure employed in obtaining the data. Previous approaches to establishing reliability for the digitizing procedure have been single-faceted; that is, only intraploter or interploter error was investigated. Since there are several error sources, an approach should be taken that not only determines the contribution of each source to measurement imprecision but also determines the interactions of these sources. The application of generalizability theory, formulated by Cronbach et al. (1972), provides such a technique. By examining the sources of variability of total body center-of-gravity values calculated by the segmental method, signal/noise ratios were calculated to indicate the relative precision of the digitizing procedure.

The concept of signal/noise ratios has arisen from describing communication systems in which the ratio "compares the strength of the transmission to the strength of the interference" (Cronbach and Gleser, 1964, p. 468). If the signal is large in comparison with the noise, the resulting ratio is large and is indicative of the adequacy of the measurement procedure. However, if the signal is weak compared with the noise, the intended discriminations of the measurement procedure may not be observed.

Brennan and Kane (1977) have stated that the signal/noise ratio provides an index of the relative precision of the measurement procedure for either a domain-referenced or a norm-referenced interpretation of scores. The ratio is formed by comparing universe score variance with the appropriate error variance. If a domain-referenced interpretation of scores is required, absolute error variance is used. Relative error variance becomes the appropriate error term if a comparative interpretation of scores is needed.

METHODS AND PROCEDURES

Total body COG values were determined for 28 college-aged students who were filmed by a LOCAM camera at 100 fps while performing the basic locomotion skill of walking. Basic anthropomorphic information for the 14 females and 14 males is provided in Table 1. Each subject was attired in shorts, short-sleeved shirt, and athletic shoes so that anatomical landmarks could be identified in the digitizing process.

TABLE 1. ANTHROPOMORPHIC DATA OF SUBJECTS

	HEIGHT (cm)		WEIGHT (kg)	
	MEAN	S.D.	MEAN	S.D.
FEMALES (n=14)	163.83	5.74	57.74	6.05
MALES (n=14)	178.79	5.13	77.50	7.86

Film analysis was conducted on each subject using six frames of film depicting a one stride walking cycle consisting of right heel strike, right foot flat, left toe-off, left heel strike, left foot flat, and right toe-off. All film frames were marked to ensure that identical frames were digitized by the two investigators using two different digitizing sequences. The same digitizing instrument was used throughout the data collection process.

Two different digitizing sequences were used on alternate days by the two investigators. In Sequence 1, all segmental endpoints were digitized in a specified order for each of the six frames of film. Sequence 2 required the digitizing of each segmental endpoint in all 6 frames of the stride cycle. Then, in turn, the 2nd, 3rd, 4th, etc. anatomical landmark was digitized throughout the 6 film frames. Sequence 2 required almost a fourfold increase in the time for the investigators to complete the digitizing process in comparison with Sequence 1.

TABLE 2. ESTIMATED VARIANCE COMPONENTS IN CENTIMETERS AND PERCENTAGES OF TOTAL VARIANCE BY X- AND Y-COORDINATES FOR FRAME 4

SOURCE OF VARIANCE	X	% OF TOTAL	Y	% OF TOTAL
PERSONS	15.75	78.6	1.52	82.5
INVESTIGATORS	---	---	---	---
SEQUENCES	0.10	0.5	---	---
P x I	0.31	1.5	0.0*	0.0
P x S	0.35	1.8	0.0*	0.0
I x S	0.91	4.5	0.06	3.1
P x I x S	2.62	13.1	0.27	14.4

*NEGATIVE VARIANCES WERE REPLACED WITH ZEROS (BRENNAN, 1984)

Four COG values were then determined for each person filmed in each of the six positions of the stride cycle. Two similar FORTRAN computer programs used the same body segment parameters for calculating the COG values. Because of the two different digitizing sequences, the computer programs varied only with respect to the order of reading the segmental endpoint data. Also, an identical reference point was used in both programs and provided a common origin with respect to the four sets of COG values. X- and Y-coordinates for these COG values were analyzed separately by the BMD8V computer program using a fully crossed 3-way ANOVA design.

RESULTS AND DISCUSSION

Seven sources of variance were identified and are listed in Table 2. The "Persons" source represents the variation due to the subjects or the objects of measurement and are not considered as a source of error in generalizability theory. The "Investigators" and "Sequences" sources are the two facets of the study and are representative of the measurement error of the two plotters in the digitizing process and the two digitizing sequences, respectively.

Estimated variance components and percentages of total variance for the seven sources of variation were computed for the X- and Y-COG values for each of the frames analyzed. The data for Frame 4 is representative of the values determined in all six frames and is also presented in Table 2. In all frames, the major contributor to score variance was the variation among persons. Percentages of total variance for this source ranged from 78.4 to 80.2 for the X-coordinates and from 80.3 to 83.7 for the Y-coordinates. Residual error (P x I x S) was the second largest contributor to score variance across all frames for each X- and Y-coordinate (11.7 to 16.6%).

In the initial partitioning of total variance, several interaction terms had larger variances than did their main effects indicating that the proposed linear model was too elaborate. A different linear model was then defined with fewer terms. The linear model was collapsed in such a way that variance was attributed neither to Investigators for the X- and Y-coordinates nor to Sequences for the Y-values. Additionally, certain interaction sources had negative variances and were replaced by zeros.

The Investigator x Sequence interaction accounted for the third highest error source across frames and coordinate values. Values ranged from a low of 3.9% to a high of 4.6% for the X-COG coordinates. Corresponding values for the Y-COG coordinates were 2.3% to 4.0%. This interaction effect indicated that the way in which the two investigators identified segmental endpoints was different dependent upon the sequence being used. Across all frames, Investigator 1 had larger X-coordinates and smaller Y-values if Sequence 2 was followed whereas Investigator 2 had smaller X- and larger Y-coordinates for Sequence 2.

TABLE 3. COG MEANS IN METERS FOR INVESTIGATORS BY X- AND Y-COORDINATES FOR FRAMES 1, 4, AND 6

		INVESTIGATOR		
FRAME	COORDINATE	1	2	DIFFERENCE
1	X	6.57	6.63	-.06
	Y	7.11	7.10	.01
4	X	7.30	7.36	-.05
	Y	7.10	7.10	.00
6	X	7.72	7.78	-.04
	Y	7.13	7.13	.00

NOTE: DIFFERENCE EQUALS INVESTIGATOR 1 - INVESTIGATOR 2

TABLE 4. COG MEANS IN METERS BY SEQUENCES BY X- AND Y-COORDINATES FOR FRAMES 1, 2, AND 3

		SEQUENCE		
FRAME	COORDINATE	1	2	DIFFERENCE
1	X	6.66	6.54	.12
	Y	7.10	7.10	.00
2	X	6.89	6.77	.12
	Y	7.10	7.10	.00
3	X	7.08	6.96	.12
	Y	7.13	7.12	.01

NOTE: DIFFERENCE EQUALS SEQUENCE 1 - SEQUENCE 2

The decision to collapse the original linear model was also supported by inspection of the marginal means of both the X- and Y-coordinate values across Investigators and for the Y-coordinates across Sequences. Values for Frames 1, 4, and 6 exemplify the data for all frames by Investigators and are presented in Table 3. The average difference between Investigators across all frames was 6.0 and 0.1 cm for the X- and Y-coordinates, respectively.

Inspection of the marginal means across Sequences showed a different picture. Representative of the data for all frames are the values for Frames 1, 2, and 3 which are shown in Table 4. The average difference between Sequence 1 and Sequence 2 for the Y-coordinates was 1.0 cm. However, for the X-coordinate, this difference was 12.0 cm which supports retaining the Sequence source as a significant contributor to total variance.

In generalizability theory, the estimated variance components provide the means for determining the reliability of the specified universes of generalization. In this study, three universe score conditions were specified:

(1) I=2 and S=2 (2) I=2 and S=1 (3) I=1 and S=1

Signal/noise ratios using absolute, rather than relative, error variances were computed for the X- and Y-COG coordinates for each measurement condition. The ratio values for Frames 1, 3, and 6 are representative of the values observed in all six frames of film analyzed and are presented in Table 5.

Under Condition 1, the strength of the signal was 12.50 to 20.56 times greater than noise or measurement error for the X- and Y-coordinates. This universe score condition reflects the precision of the measurement procedure when two randomly selected plotters use two randomly selected sequences in the digitizing process. Likewise, Condition 2 represents the adequacy of the digitizing procedure when two randomly selected plotters use one randomly selected digitizing sequence. The signal/noise ratios ranged from a low value of 6.43 to a high value of 10.31. In Condition 3, which is representative of the usual digitizing process of using one plotter and one digitizing sequence, the signal/noise ratios ranged from 3.64 to 5.14. Across all frames and conditions, the signal/noise ratio was consistently larger for the Y-coordinate than for the X-value.

TABLE 5. SIGNAL/NOISE RATIOS FOR THE THREE UNIVERSE SCORE CONDITIONS FOR FRAMES 1, 3, AND 6

FRAME	COORDINATE	UNIVERSE SCORE CONDITIONS		
		CONDITION 1 (I=2,S=2)	CONDITION 2 (I=2,S=1)	CONDITION 3 (I=1,S=1)
1	X	12.50	6.43	3.64
	Y	16.31	8.15	4.08
3	X	13.42	7.14	4.06
	Y	17.57	8.79	4.39
6	X	12.58	6.73	3.78
	Y	20.56	10.31	5.14

NOTE: I = NUMBER OF INVESTIGATORS; S = NUMBER OF SEQUENCES

TABLE 6. STANDARD ABSOLUTE ERRORS IN CENTIMETERS FOR THE THREE UNIVERSE SCORE CONDITIONS FOR FRAMES 1, 3, AND 6

FRAME	COORDINATE	UNIVERSE SCORE CONDITIONS		
		CONDITION 1 (I=2,S=2)	CONDITION 2 (I=2,S=1)	CONDITION 3 (I=1,S=1)
1	X	11.31	15.76	20.96
	Y	3.01	4.25	6.01
3	X	11.29	15.48	20.53
	Y	2.89	4.09	5.78
6	X	11.49	15.72	20.95
	Y	2.60	3.76	5.32

NOTE: I = NUMBER OF INVESTIGATORS; S = NUMBER OF SEQUENCES

These signal/noise ratios reflect a definite loss in the precision of the measurement precedure for these three universe score conditions. Approximately a 50% loss in precision is observed when the measurement procedure exemplified in Condition 1 is changed to the measurement procedure represented in Condition 2. The loss in precision is of greater magnitude when comparing the signal/noise ratios for Condition 1 and Condition 3. As the number of measurements was reduced to one at each segmental endpoint, there was approximately a 71 to 75% loss in precision for the total body COG values.

As an indication of the dependability of the digitizing measurement process, two important facts are reflected by the obtained signal/noise ratios:

1. The precision of the measurement procedure was altered dramatically because of changes in the conditions of measurement
2. Greater measurement error was observed for the X-COG than for the Y-COG coordinate values.

APPLICATION

The practice of using center-of-gravity values for describing human performance is routinely accepted in biomechanical research studies. Although the calculated COG values are considered to be most representative of the movement being analyzed, the question of the reliability, and ultimately the validity, of these data is rarely addressed. If the COG data are not reliable, then subsequent calculations e.g. displacement, velocity, and acceleration values, are also not dependable.

On the basis of the signal/noise ratios determined in the present study, the following two conclusions are warranted with respect to the reliability of COG data computed by the segmental method:

1. Total body COG values calculated using the most common digitizing scheme may be more imprecise than is now recognized
2. COG displacement through the vertical and horizontal planes may affect the precision of the estimated universe score.

Without question, the digitizing procedure is a tedious and time-consuming process. For cinematographical analyses, the data collected through this procedure serve as the basic information for all subsequent steps in the data reduction process. Measurement error is an inherent feature of the digitizing procedure but little attention has been paid to quantifying and reducing the magnitude of this error. Sport researchers must recognize measurement error in the data collection process and seek digitizing procedures that will minimize error and increase the reliability of their film data.

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