METHODS FOR QUANTIFYING THE VARIABILITY IN DATA

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Variability in movement affects statistical significance and is important for interpreting data. The aim of this study was to compare methods for quantifying variability, and to use these in assessing the effect of 'pain' in the right leg on the running technique of one male English First Division footballer. The player's sagittal plane movements were filmed while running on a treadmill at 3.58 $m.s^{-1}$. The variability in 3 strides was quantified using standard deviation, confidence intervals (95%CI) and root mean square difference (RMSD). The kinematics of the left and right legs of the player were different, but did not contain different amounts of variability (e.g. RMSD of both knees at heel strike = 1.2°). To estimate variability the preferred techniques are: 95%CI for n = 1 as the only available; RMSD for small n; normalised techniques only when means are similar. The variability of the player's movements in other planes and at faster speeds should be explored in future.

KEY WORDS: coefficient of variation, confidence intervals, root mean square, trial size

INTRODUCTION: When conducting technique analyses it is common that one trial is selected with the implicit assumption that it is representative of the performer's 'normal' technique. The importance of using more than one trial can be highlighted from philosophical, research design, statistical and interpretation perspectives. For example, Bates *et al*. (1992) judge that a singular response strategy should be considered with caution, and Shultz and Sands (1995) consider that reducing variance is the most efficient method of increasing statistical power. Many of these methods consider controlling variability for statistical purposes, but it can be meaningful to discuss variability in light of its importance in the successful control and outcomes of movement.

Variability can be assessed qualitatively and quantitatively, often for the whole movement or at key times such as at toe off in running. Qualitatively, inspecting plots of repeat trials provides information on the patterns of movement. Quantitatively, techniques occasionally used in the literature (see Table 1) can provide more objective assessments of the variability over trials in the values (variable-time graphs) or ratios of the variables (variable-variable plots: e.g. angle-angle plots; phase-plane portraits).

Table 1 Statistics Employed in the Literature for Quantifying Variability of Repeat Trials

Statistic	Equation	Excel formula*
S	$\sqrt{\sum_{i=1}^{n}(\bar{x} - x_i)^2 / (n-1)}$	=STDEV(A1:C1)
RMSD	$\sqrt{\sum_{i=1}^{n}(x_C - x_i)^2 / n}$	=STDEVP(A1:C1)
95%CI	$1.96\, s/\sqrt{n}$	=1.96*STDEV(A1:C1)/COUNT(A1:C1)^0.5
%CV	$100 s/\bar{x}$	=100*STDEV(A1:C1)/AVERAGE(A1:C1)
%RMSD	$100\, RMSD / \sqrt{\sum_{i=1}^{n}(x_C)^2 / n}$	=100*STDEVP(A1:C1)/AVERAGE(A1:C1)

Statistic: sample standard deviation (*s*); root mean square difference (RMSD); 95% confidence intervals (95%CI); percentage coefficient of variation (%CV); percentage RMSD (%RMSD).

Equation: mean ($\bar{x}$); variable (x_i); sample or trial size (n); criterion value (x_C).

Excel: *s* (STDEV); population standard deviation, σ (STDEVP); $\bar{x}$ (AVERAGE); *n* (COUNT).

***** Where no criterion exists the mean value of the data is appropriate and the equations

simplify to combinations of *s*, σ, $\bar{x}$ and *n*. The formulas provided for Excel 97 (Microsoft Corporation, Redmond, WA, USA) assume three trials with the data contained in cells A1, B1 and C1.

The variability in a performer's movement can be important to identify 'boundaries' which may, for example, be useful in making comparisons between limbs or assessing the effectiveness of a rehabilitation programme over time. If after a rehabilitation programme a performer's movements were beyond these boundaries then it could be more positively implied that the programme has had an effect, assuming that confounding effects are not responsible. The aim of this study was to compare methods for quantifying variability in data, and to use these in assessing the effect of an injury on the running technique of one subject.

METHODS: One male English First Division footballer (mass = 72.4 kg; height = 1.70 m; age = 19 years), suffering from 'pain' in the right hamstrings on the day after exercise, was referred for a biomechanical assessment as any 'problems' were difficult to detect qualitatively. As the hamstrings are principally involved with hip and knee movements in the sagittal plane, and from discussion with the footballer's physiotherapist, details on the co-ordination of the hip and knee angles of the right leg were selected. In addition, comparison of kinematics in the left to right legs was desired.
The sagittal plane movements of the player running on a Pulsar treadmill (H-P-Cosmos Sports & Medial, Nussdorf-Traunstein, Germany) at 3.58 $m.s^{-1}$, similar to the player's chosen training speed, were filmed in two-dimensions (2D) from the left side in accordance with the BASES guidelines (Challis *et al*., 1997) using a Panasonic AG455 camcorder (Matsushita Electric Industrial Company, Osaka, Japan). Three consecutive strides were selected and the hip, knee and ankle joints' centres of rotations (Plagenhoef, 1971) of the left and right sides were manually digitised at 50 Hz from five frames before right heel strike to five frames after right toe off by one experienced operator. The digitising system comprised of the Apex Imager hardware (Millipede Electronic Graphics, Bury St Edmunds, Suffolk, UK) and Target software (Loughborough University of Technology, Loughborough, Leics, UK) and the position data obtained were converted to real life measurements using a 2D Direct Linear Transformation. Kinematic data were obtained using the Coda Motion Analysis software (Charnwood Dynamics, Rothley, Leics, UK) and smoothed using a simple running-average low-pass filter with a 10 Hz cut-off selected from visual inspection of the fit. Angles for the knee (positive flexion values – full extension is 180°) and hip (thigh angle to the vertical: positive flexion values; negative hyperextension values) and respective knee-hip angle-angle plot were obtained. The variability of each leg was quantified at the key instants of heel strike and toe off, identified visually as the first frame after the event, in Excel 97 using the five techniques described in Table 1.

RESULTS: The co-ordination of the knee and hip are illustrated in Figure 1, along with the variability in the kinematics over three consecutive strides. The descriptive statistics and quantification of variability of the left and right legs at the key times that distinguish between the swing and support phases are described in Table 2.
Qualitatively, the left and right legs are quite similar, although there are small differences that may be of note (see Figure 1). The left leg appears to be less variable during the swing phase and more variable during the support phase than the right leg. The mean values in Table 2 indicate that there are mostly differences between the kinematics of the left and right legs at heel strike and toe off. The exception is that at heel strike there is only a small difference between the angles of the left and right knee.

DISCUSSION: The data supports the observation that there are slight differences in the kinematics of the left and right legs. The injured leg has slightly greater ranges of movement. Qualitatively, the right leg is more variable during the swing phase and less variable during the support phase than the left leg. The results for the statistical methods in Table 2 provide different implications for the variability of the left versus right leg kinematics.

a) б)

Table 2 Descriptive Statistics and Quantification of Variability for the Hip and Knee Angles and Hip to Knee Ratio at Heel Strike and Toe Off for the Left and Right Legs

	Heel strike						Toe off					
	Hip		Knee		Hip:Knee		Hip		Knee		Hip:Knee	
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Non-normalised (degrees - except ratios that have no units)												
$\bar{x}$	20.1	16.2	170.0	171.2	0.118	0.095	-14.6	-18.7	153.8	158.0	-0.095	-0.118
s	1.5	1.5	1.3	3.2	0.009	0.010	2.0	1.2	3.4	4.1	0.011	0.006
RMSD	1.2	1.2	1.1	2.6	0.007	0.008	1.7	1.0	2.8	3.3	0.009	0.005
95%CI	1.6	1.6	1.5	3.6	0.010	0.012	2.3	1.4	3.8	4.6	0.013	0.006
Normalised (percentages)												
%CV	7.2	9.0	0.8	1.9	7.7	10.8	-13.9	-6.4	2.2	2.6	-11.7	-4.8
%RMSD	5.9	7.3	0.6	1.5	6.3	8.8	-11.4	-5.2	1.8	2.1	-9.6	-3.9

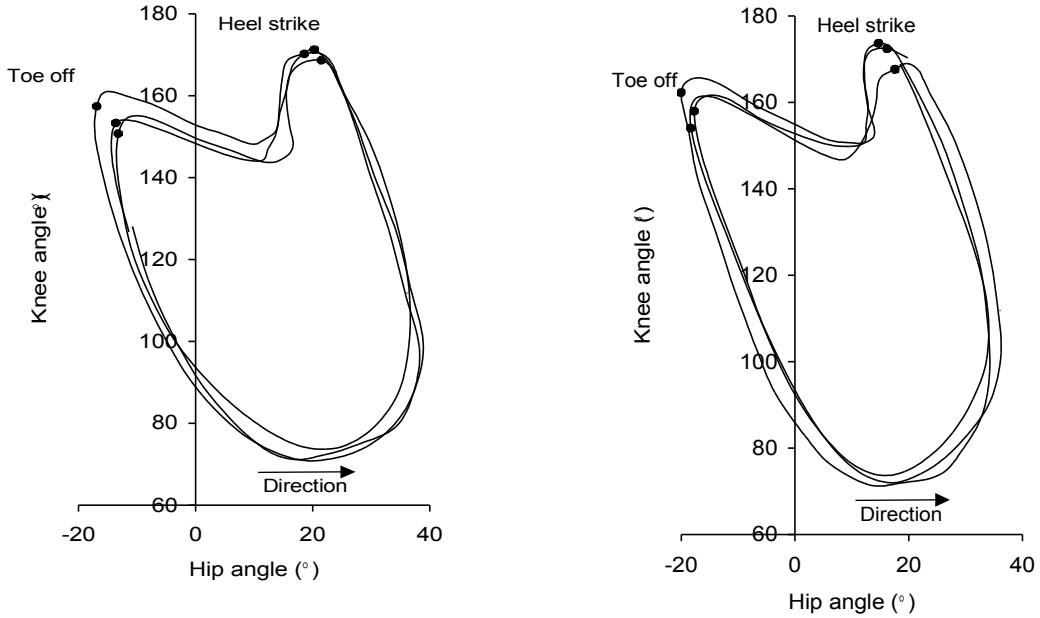

Figure 1 - Knee-hip plot for three strides for (a) left and (b) right legs. Heel strike, toe off and direction of motion are illustrated.

At heel strike, the variability in hip angle is the same between left and right legs when using non-normalised methods. Using the mean of the trials as the criterion, the RMSD provided the smallest value, followed by *s* and then the 95%CI. For *n* equals 3, this size order for these techniques will always be the same. For different trial sizes the size order of different tests is summarised in Table 3. The normalised techniques, often used to account for different magnitudes between data sets, provide different results in that the right leg is more variable. As the mean is the denominator in %CV and %RMSD equations, these values are larger for the right leg as the mean is smaller. Normalising data to the mean can be useful when the means are similar in size, otherwise it can be misleading and should not be used as in this instance.

As the variability equations contain different degrees of freedom in the denominator (e.g. *n*-1), then they will be affected predictably by changes in trial size (*n*). For small *n* these changes will be large, and the changes when increasing *n* from *n*-1 are described in Table 4. For instance, increasing *n* from 2 to 3 results in an 18.4% reduction in variability when

calculated using σ or 95%CI. It is important that the test and trial size used are standardised between studies as changing these alters the variability obtained and makes comparisons difficult.

Table 3 Comparison of the Size of Variability Calculated with Different Statistics

Output	*n*	Size - smallest to largest		
Non-normalised (units of measurement)	≤ 3	RMSD	*s*	95%CI
	4	RMSD	95%CI	*s*
	≥ 5	95%CI	RMSD	*s*
Normalised (percentages)	All	%RMSD	%CV	

Table 4 Percent Reduction in σ When Used Instead of *s*, and Percent Reduction in σ, 95%CI and *s* When *n* in the Denominator Has Been Increased from *n* –1

n	1	2	3	4	5	6	7	8	9	10
σ % smaller than *s*	N/A	29.3	18.4	13.4	10.6	8.7	7.4	6.5	5.7	5.1
Decrease in σ & 95%CI	N/A	29.3	18.4	13.4	10.6	8.7	7.4	6.5	5.7	5.1
Decrease in *s*	N/A	N/A	29.3	18.4	13.4	10.6	8.7	7.4	6.5	5.7

All these techniques for quantifying variability are underpinned by assumptions of parametric data. Trials that are considered outliers or unrepresentative of technique should be omitted from the variability analysis as they will have a large affect on the results, particularly for small *n*. Greater variability is likely with lower sampling frequencies as the errors in identifying key instances increases. As the variability is small in this study, a higher sampling frequency will unlikely change the findings reported.

As the left and right legs are similar, separating out different sources of variability may be useful for a more precise assessment. Variability in the data can be derived from two primary sources - the player and the methods. Although the player's source is of primary interest, not separating variability from the methods source provides for simplicity. Techniques for quantifying variability from the methods are described by Challis (1997, p. 109) including for accuracy (e.g. RMSD of predicted to actual control point locations) or precision (e.g. reliability or objectivity assessment of repeated digitisation effects on variables). If the variables of interest require several levels of computation, partitioning out variability is useful in calculating the error propagation or when the variability between comparisons is small as in this instance. It may be appropriate to partition out variability in future analyses, and to explore the existence of variability of movement in other planes and at faster speeds.

CONCLUSION: The kinematics of the left and right legs of the footballer are different, and show variability. However, the legs do not contain different amounts of variability in the sagittal plane. To quantify variability the preferred techniques are: 95%CI for $n = 1$ as it is the only technique available; RMSD for small *n*; normalised techniques only when means are similar. Future analyses of this player may require partitioning out sources of variability, as the variability is similar, and analysing the movement in another plane and at faster speeds.

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