THE SPANNING SET AS A MEASURE OF MOVEMENT VARIABILITY

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The variability of an individual's movement pattern is an increasingly important focus of research in sport and exercise biomechanics. Inter-trial variability of a single variable is typically assessed using mean deviation or coefficient of variation, however, recent alternatives to these have been proposed such as the spanning set technique. This paper presents an investigation into the validity of the spanning set measure. Variability scores using the spanning set were compared against more traditional measures of variability (mean deviation, coefficient of variation and variance ratio). Results indicate that the spanning set is biased towards early-phase variability and may inaccurately describe the overall level of movement variability.

KEY WORDS: spanning set, mean deviation, variability, variance ratio.

INTRODUCTION: The interpretation of human movement variability has evolved from the historical standpoint, which viewed variability as noise or error in movement patterns, to the more recent viewpoint which considers the functional role of inter-trial variability and suggests both positive and negative relationships between variability and performance or health (Button et al. 2003; Crowther et al. 2008; James et al. 2000). While research does suggest direct links between performance and variability, the specific directional effects (beneficial or detrimental) of these links appear to be determined by complex interactions between skill type, performance variable and the level of performer (Button et al. 2003). Research which attempts to elucidate on these complex performance-variability interactions clearly requires valid and informative measures with which to quantify variability. The spanning set (SS) is one measure of inter-trial variability that has been recently recommended in the literature. Kurz et al. (2003) proposed the SS as an alternative and more sensitive measure than traditional variability measures such as mean deviation (MD) and coefficient of variation (CV). Subsequently, the SS technique has been used to quantify variability in running kinematics between different footwear types (Kurz & Stergiou, 2003) and in walking kinematics between control subjects and patients with peripheral arterial disease (Crowther et al. 2008). The mechanics of the SS approach for variability assessment are based on work by Lay (2000) and described in detail by Kurz and Stergiou (2004). In brief, the technique first involves fitting high-order polynomials to the standard deviation (SD) curves of a mean ensemble curve. The coefficients of each polynomial are then used to define the vectors of a spanning set between the two SD curves. The greater the difference between the two spanning set vectors (calculated as the root sum of squared differences between coefficient pairs) the greater the variability that is indicated in the mean ensemble curve.

Despite findings in favour of the SS technique (Kurz et al. 2003), no research work has strategically assessed its functionality in order to determine its validity as a measure of inter-trial variability. In reviewing the SS technique, there are indications that the mathematical procedures which underpin it are overly biased towards variability at the beginning of the movement cycle and far less sensitive to any variability occurring later in the movement cycle. Therefore, the purpose of this study was to assess the validity of the SS measure in a controlled manner using movement patterns with incidences of discrete phase-specific variability.

METHODS: Technique validation: Any measure of inter-trial variability should be equally sensitive to increases in variability at all phases of the movement cycle. Due to concerns about the phase-related sensitivity of the SS technique, it was assessed using four alternative phase-variability models, each involving variability at a different phase of the movement cycle (see Table 1). These variability models were applied to datasets from two diverse movement patterns: the sagittal plane knee angle in gait and the sagittal plane elbow angle during a basketball free throw. The mean movement patterns for each skill were based on actual data, with simulated variability added according to each variability model. These patterns were time-normalised to 101 data points (0-100% of cycle). Figure 1 illustrates the four phase variability models as applied to the knee angle during a complete gait cycle. The SS technique was conducted in accordance with the guidelines provided by Kurz and Stergiou (2004). Polynomial curve fitting was carried out using the least squares procedure in LabVIEW 8.2.

Table 1 Datasets used to assess phase-related sensitivity of SS technique.

Phase variability model	Knee angle (Gait)	Elbow Angle (Basketball)
1. Control	SD = 2^0 over complete cycle	SD = 5^0 over complete cycle
2. Variability Start	SD is 80% > than control during 0-30% phase of cycle	SD is 60% > than control during 0-30% phase of cycle
3. Variability Middle	SD is 80% > than control during 35-65% phase of cycle	SD is 60% > than control during 35-65% phase of cycle
4. Variability End	SD is 80% > than control during 70-100% phase of cycle	SD is 60% > than control during 70-100% phase of cycle

NOTE: The variability in the unaltered 70% of models 2-4 was equal to that of the control model.

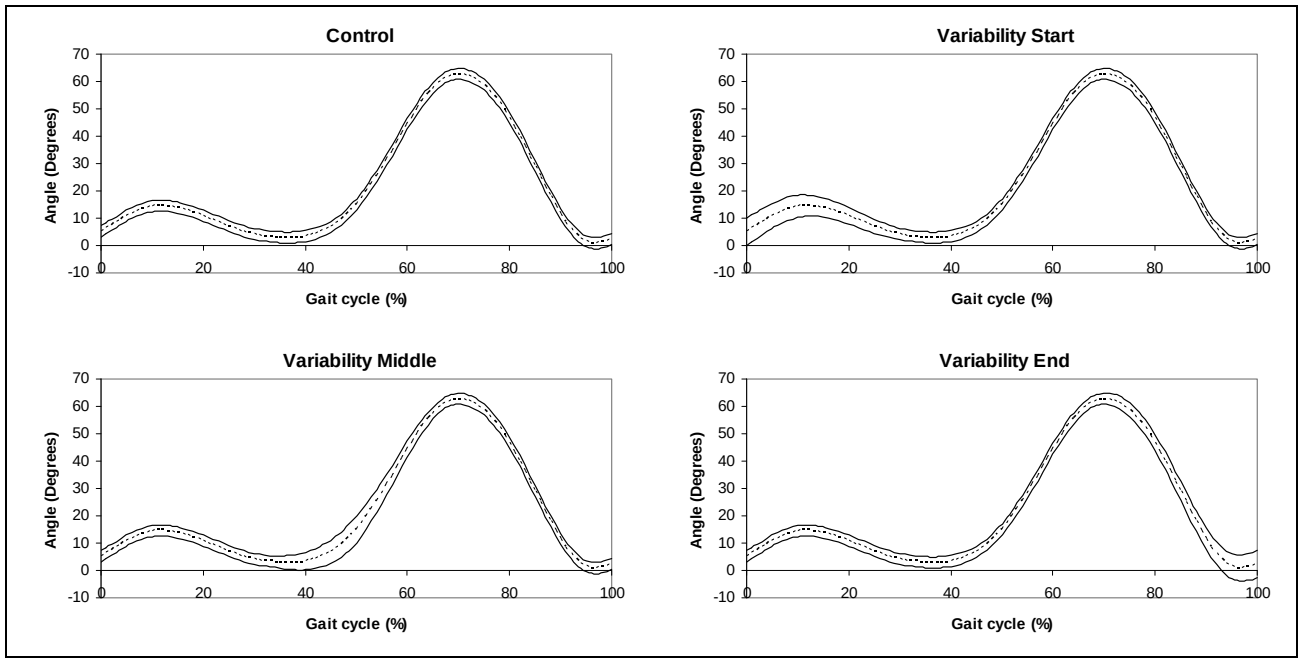

Figure 1: Phase-variability models used to assess validity of SS technique (applied to knee angle dataset)

Data Analysis: The SS scores were compared against three other recommended techniques for inter-trial variability: MD, variance ratio (VR) and CV (Hershler & Milner 1978; Kurz & Stergiou 2004).

RESULTS: Table 2 displays the variability scores (SS, MD, CV, and VR) for each dataset. As the relationship between variability models was identical for MD, CV and VR, only the MD results are plotted against the SS results in Figure 2. As the results trend was also identical between knee angle data and elbow angle data, only the knee angle results are illustrated in Figure 2. The addition of variability at the start of the movement resulted in an average increase in the SS score of 122% (knee +148%, elbow +96%), versus average decreases of 21% (knee -24%, elbow -18%) and 3% (knee -3%, elbow -2%) when variability was added at the middle and the end of the movement respectively. Conversely, the addition of variability resulted in changes in MD, CV and VR that were identical, regardless of the phase during which variability was added.

Table 2 Variability scores for SS and traditional variability measures in each dataset. Units for SS and MD are degrees, while CV is a % (VR is a unitless ratio).

	Knee angle (Gait)				Elbow angle (Basketball)			
	SS	MD	CV	VR	SS	MD	CV	VR
1. Control	4.00	2.00	9.27	0.010	10.00	5.00	6.14	0.051
2. Variability Start	9.91	2.48	11.48	0.017	19.55	5.89	7.23	0.074
3. Variability Middle	3.02	2.48	11.48	0.017	8.18	5.89	7.23	0.074
4. Variability End	3.89	2.48	11.48	0.017	9.76	5.89	7.23	0.074

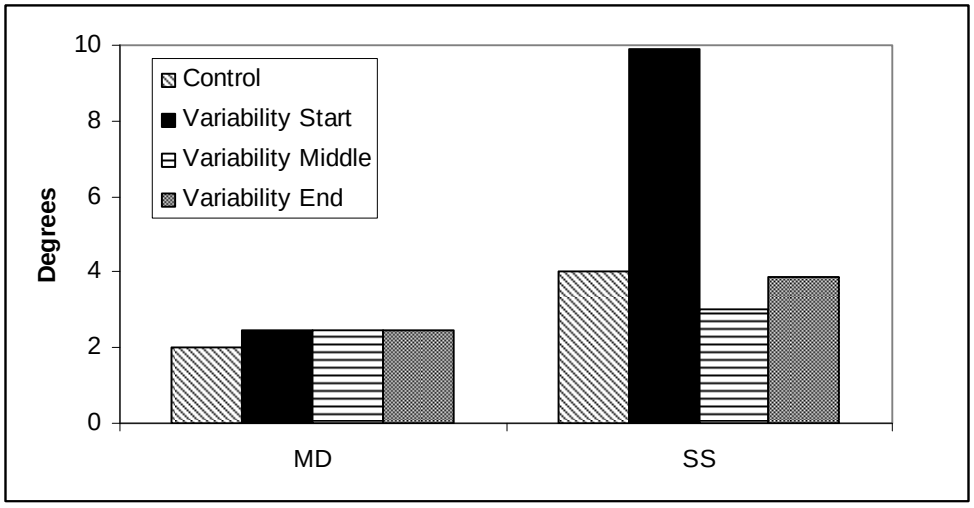

Figure 2: MD and SS scores for each variability model applied to the knee angle dataset.

DISCUSSION: This study assessed the phase-related sensitivity of the SS variability score in an effort to gauge its validity as a measure of inter-trial variability. It is evident from the results that the SS measure is heavily biased towards variability at the start of the movement (122% increase in scores) while being relatively insensitive to variability occurring at the middle and end of movement patterns (reductions of 21% and 3% respectively). This is in contrast to traditional measures of variability which show equal increases in their scores regardless of the phase during which variability is added. The fact that the SS is unequally weighted towards early-phase variability means that it is unsuitable for comparisons between subjects or between conditions (where variability could occur during any movement phase). Also, the erroneous finding of decreased variability by SS scores after mid-phase variability has been added to the movement is also a strong finding against the SS technique.

The combination of these results with a functional analysis of the SS technique indicates possible causes of the phase-related bias in variability scores. The SS score uses the calculated differences between coefficient pairs from polynomials mapping the upper and lower SD curves (Kurz and Stergiou 2004). As the largest coefficient value is typically the first coefficient, this has the greatest influence on the overall score. However, this first

coefficient is also an indicator of the intercept value of the SD curve (i.e. the SD value at the start of the movement cycle), hence the bias towards early-phase variability.
These results prompt reinterpretation of the findings of previous studies using the SS technique. For example, the claim by Kurz et al. (2003) that the SS offered a more sensitive measure of movement variability between shod and barefoot running would appear to be solely the result of increased variability at the start of the movement cycle in barefoot versus shod conditions, rather than increased variability throughout the complete gait cycle. The suggested sensitivity of the SS technique is, therefore, an artefact of the calculation which only relates to early-phase variability. If the aim of a research study is to assess variability changes at specific phases of the movement cycle, then comparing the SD at these specific phases (rather than calculating the MD over the complete cycle) should allow the sensitivity of measurement required.
In considering alternatives to the spanning set, a strong note of caution should be issued in relation to the use of the CV. This quantity is seen as a useful way of normalising the SD so that variability can be compared between different conditions, individuals and variables. However, as pointed out by Mullineaux et al. (2001), the inclusion of the mean as the denominator can lead to imbalances between CV values and absolute SD values (e.g. when the mean is close to zero). This is further evidenced by the results of this study which show higher CV values for the knee angle data than the elbow angle data, despite the opposite trend being shown in MD values. The VR technique appears to offer a useful alternative to the CV value. This technique normalises the variation in curves to the average deviation from the overall single mean value, therefore accounting for the higher variability expected in more dynamic movements. This is supported by the findings in this study which show similar relationships between knee angle and elbow angle data for both the MD and VR techniques.

CONCLUSION: The present study shows that the SS method for assessing inter-trial movement variability is biased towards variability occurring at the start of a movement pattern and cannot be recommended as a valid measure. Researchers and practitioners seeking to understand the links between variability and performance should use the MD and VR measures instead of the spanning set, as these appear to offer greater accuracy in quantifying variability.

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