INTERPRETATION OF VECTOR CODING VARIABILITY MEASURES: WITHIN-DAY REPEATABILITY AND BETWEEN-SUBJECT VARIATION IN TREADMILL RUNNING

Holly Stock[1], Cassie Wilson[1], Chris McLeod[2], Richard van Emmerik[3], Ezio Preatoni[1]
[1]University of Bath, Bath, UK; [2]English Institute of Sport, Manchester, UK; [3]University of Massachusetts, Amherst, USA

This study investigated the within-day repeatability and between-subject variation of vector coding variability during treadmill running. The lower-limb kinematics of eight male triathletes running at 12 km/h were captured twice on the same day. Mean coupling angle variability across the stride cycle was computed for 20 couplings using the modified vector coding technique. Between-subject variation was calculated from the first data collection and data from both sessions were used to calculate systematic and typical error. Between-subject variation ranged from 1.4° to 3.7°. Systematic errors between sessions were observed for two couplings and typical errors were between 0.6° and 1.9°. The between-subject variation and within-day repeatability of the measures reported will aid the interpretation of vector coding variability in cross-sectional and intervention studies.

KEYWORDS: reliability, gait, coordination variability

INTRODUCTION: The modified vector coding technique is a measure which combines the kinematics from two segment or joint angles to understand how those two variables interact with one another (Van Emmerik et al., 2014). Some studies using modified vector coding have interpreted the direct result, a coupling angle (e.g. Silvernail et al., 2013). The coupling angle is a measure of how two movements interact with one another, a quality that is particularly relevant in human movement. This is because movement at one segment or joint will frequently impact on neighbouring segments and joints, thus the body must coordinate all its components in unison to achieve a given task. More frequently, however, the variability of this coupling angle is the focus of the investigation (e.g. Cunningham et al., 2014). Variability is thought to have relevance in exploratory learning, expert performance and injury prevention (Preatoni et al., 2013). A range of different tasks have been analysed using the modified vector coding technique, but it has been applied most frequently in walking (e.g. Chang et al., 2008) and running (e.g. Hafer et al., 2016) analyses.

The repeatability of a measure is vital for the interpretation of that measure. It allows us to understand if an observed difference is meaningful, whether that is a difference between population groups or intra-individual changes that may occur over time or as a result of an intervention (Hopkins, 2000). Knowledge of measure repeatability is also important when calculating sample sizes for future research studies (Hopkins, 2000). Whilst many studies have investigated the repeatability of kinematics measures (e.g. Horst et al., 2016), vector coding coupling angles represent the change in one variable with respect to another between two data points. Therefore coupling angles rely on properties of kinematic data, for which the repeatability has not previously been assessed. There is a lack of published research into the repeatability of vector coding measures themselves, and also in the variability of these measures. Treadmill gait provides a controllable set-up, where task and environmental conditions do not change. This helps isolate the variability of an individual's movement and is therefore a good setting in which to measure the repeatability of variability.

The purpose of this paper is to investigate the between-subject variation and within-day repeatability of vector coding coupling angle variability in treadmill running gait. It was assumed that there would be no systematic within day changes due to their temporal proximity.

METHODS: Eight male triathletes (22 ± 3 yrs, 1.81 ± 0.05 m, 72 ± 5 kg) provided informed consent to take part in this study. Participants were required to be training without restriction due to injury for a month prior to the first data collection session.

Each participant visited the lab twice in one day to repeat the same data collection protocol. A minimum of two and maximum of six hours separated the end of the first session and start of the second. The lab was set up with 15 infrared cameras (13 Oqus 400, 1 Oqus 300, 1 Oqus 210c, Qualisys AB, Sweden) around a treadmill (Powerjog J200, Expert Fitness UK ltd, South Wales). Markers were applied to lower-limb anatomical landmarks by the same expert tester according to marker placement guidelines (van Sint Jan et al., 2007) and the lower limb model used by Vanrenterghem et al. (2010) to define foot, shank, thigh and pelvis segments. The same tester attached rigid clusters to the thighs and shanks, a heel marker and two additional tracking markers to the rear lateral aspect of the shoe. In order to minimise errors in repeat marker placement, a visual check was made in the second session using an image overlay application (Overlay Camera, Add Quick) and standardised participant and camera positioning. Participants completed a five minute warm up consisting of 1 minute at speeds, which incremented by 1 km/h, starting at 8 km/h. Following this, a further 5 minute block was completed on the treadmill at 12 km/h. Marker position data were captured in the last 60 seconds of the 5 minute block.

Data processing and analysis: Markers of the right lower limb were tracked and labelled in QTM and their positions exported to Visual 3D (V5, C-Motion Inc, Germantown, MD, USA). A static trial was used to create a hybrid model consisting of a: Visual 3D composite pelvis, right thigh, right shank and right kinematic foot segment. Tracking markers were filtered with an 8 Hz cut-off, low pass, 2nd order, bi-directional Butterworth filter and used to calculate joint angles. These data were then exported to MATLAB (v2015b, The MathWorks Inc., Natick, MA) where a custom script separated data into temporally registered stride cycles (101 data points) by identification of foot strike using the algorithm validated by Maiwald et al. (2009). Vector coding coupling angles (CA) for 20 stride cycles and the coupling angle variability (CAV) across those 20 stride cycles was calculated for each time-point using the same method as Heiderscheit et al. (2002). CAV was then averaged across the stride cycle (CAV_{mean}). Twenty couplings were included: HxKx, HxKy, HxKz, HyKx, HyKy, HyKz, HzAy, HzKx, HzKy, HzKz, KxAx, KxAy, KyAx, KyAy, KzAx, KzAy, HyHz, KxKy, KxKz, KyKz (where H, K and A represent the hip, knee and ankle joints respectively, and x, y, and z represent flexion-extension, ab/ad-duction and in/ex-ternal rotation for the hip and knee, and dorsi-plantar flexion, in/e-version and ab/adduction for the ankle). For example, HxKx represents the hip flex/ext – knee flex/ext coordination coupling. The above couplings were chosen on the basis of their previous use in the literature.

To indicate the average magnitude of CAV_{mean} and the between-subject variation, the mean and sample standard deviation of CAV_{mean} across participants was calculated or each coupling using data from the first session. The difference in CAV_{mean} between sessions, $\delta_{session,}$ was also calculated for each participant and coupling. Systematic error was estimated as the average change in $\delta_{session}$ and the typical error as the sample standard deviation of $\delta_{session}$ divided by $\sqrt{2}$ across participants for a given coupling (Hopkins et al., 2000).

RESULTS: The couplings with the lowest typical error were HzKz (typical error: 0.6°), followed by HyKz (0.9°) (Figure 1). Those couplings with the highest typical error were: KyKz (1.9°), HzKy (1.9°), KyAy (1.8°) and HzKy (1.8°) (Figure 1). The typical error bars for HzKz and HyKz did not overlap the zero line (Figure 1), indicating possible systematic increases in the mean from session 1 to session 2. The smallest between-subject variations in CAV_{mean}

were observed for the KxAx (1.4°) and HxKx (1.6°) in addition to HzAy (1.6°) and KyAy (1.7°) coupling. The between-subject standard deviation was highest for the HxKz (3.7°), HxKy

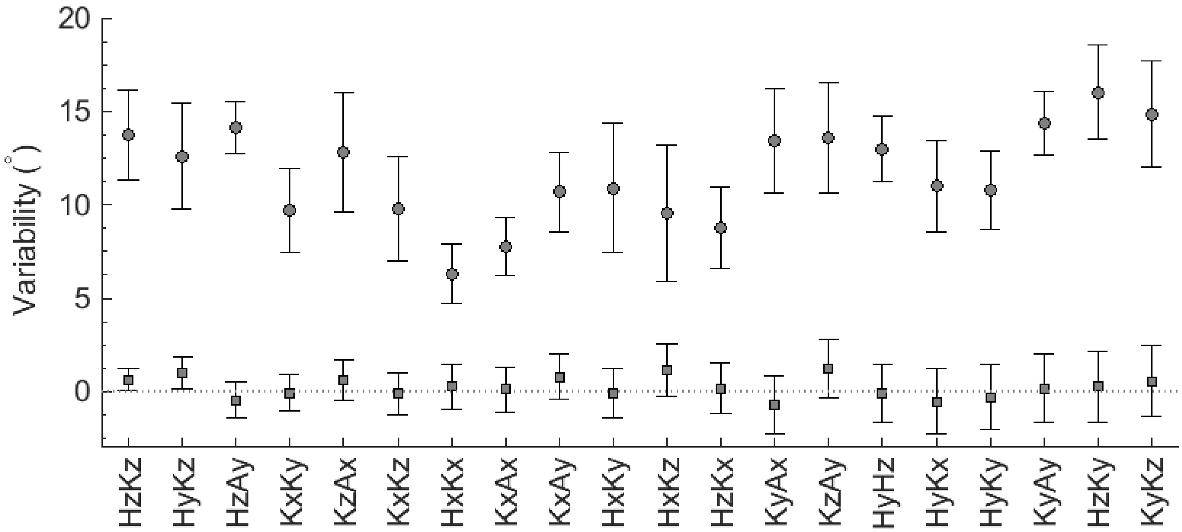

Figure 1. The between-subject mean (circles) and sample standard deviation (bars) in CAV_{mean} for each coupling in addition to the systematic error (squares) and typical error (bars). The couplings are displayed in order of the magnitude of their typical error.

(3.4°) and KzAx (3.2°) couplings (Figure 1).

DISCUSSION: This study aimed to investigate 1) the within day repeatability and 2) the between-subject variation of vector coding variability measures. As hypothesised, most couplings showed no systematic within-day changes, but two couplings suggested there had been a systematic increase from the first to the second session.

As both sessions occurred less than 6 hours apart we expected to see no systematic change in the mean, based upon the assumptions that gait does not change and the measure is fully repeatable. In line with this prediction, 18 of the 20 couplings did not appear to change between sessions, however systematic increases in CAV_{mean} were observed for HzKz and HyKz (Figure 1). Both couplings contained Kz as a component and transverse plane knee rotation measurements are known for their low reliability in gait analyses (McGinley et al., 2009). This may be connected to why HzKz and KyKz couplings unexpectedly showed systematic changes between sessions. An alternative explanation of why systematic errors were observed is familiarisation, but participants had spent 4 minutes running prior to data capture in addition to the 5 minute warm up in the first session, therefore this is unlikely to be a moderating factor.

Typical error in the CAV_{mean} can indicate the magnitude of difference needed to detect meaningful intra-individual differences. For the couplings investigated in this study, typical error ranged from ± 0.6 to 1.9°. Using the typical errors of the most and least repeatable couplings (HzKz and KyKz respectively), within subject differences of less than ± 0.6° are not likely indicative of a real change for any of the above investigated couplings but are more likely to represent fluctuations in the measurement. In contrast, a difference which exceeded ± 1.9° would be of likely interest for all couplings investigated in this study.

One fifth of the between-subject standard deviation of a given variable has been suggested as the minimal magnitude of difference that should be observed for a difference between populations to be meaningful (Hopkins et al., 2009). The lowest between-subject standard deviation observed in this study was seen for the KxAx coupling (1.4°) and the highest for HxKy (3.7°). Therefore for between group comparisons, these data suggest that differences

should be at least 0.3° but may need to exceed 0.7° for certain couplings to indicate differences which are not simply due to sampling error.
Further work should look to understand the repeatability of this measure at each point across the gait cycle. By averaging CAV over the whole stride cycle, the measure may exaggerate or underestimate the repeatability seen at any given time or phase of the stride as has been the focus of many studies using vector coding measures.

CONCLUSION: This abstract has detailed the between-subject variation and within-day repeatability of vector coding variability averaged across the stride cycle in treadmill running gait. The values identified here form the basis to identify meaningful changes or differences in the variability of coordinative patterns for clinical and lab based investigations. Couplings that contain transverse knee rotations should however be interpreted with caution as they may be susceptible to systematic errors.

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Acknowledgements

This research was match funded by the English Institute of Sport, Manchester, UK.