SURFACE MARKERS VERSUS CLUSTERS FOR DETERMINING LOWER LIMB JOINT KINEMATICS IN SPRINT RUNNING

Timothy Exell, David Kerwin, Gareth Irwin & Marianne Gittoes

Cardiff School of Sport, University of Wales Institute, Cardiff, United Kingdom

The purpose of this study was to compare lower limb joint angle time histories using surface markers and segmental clusters. An athlete completed three single leg standing trials whilst moving the joints of the free leg from maximum flexion to maximum extension followed by seven maximal sprint runs. Trials were tracked by a three-dimensional CODA system. For standing trials, mean timing differences were greatest in maximum extension at the ankle and hip (0.01 s). Angle differences ranged from 2° (knee flexion) to 11° (ankle extension). Timing differences in sprinting were greatest in extension (hip 0.03 s) with joint angle differences in maximum flexion and extension 7 & 9° (ankle), 3 & 6° (knee) and 23 & 4° (hip) respectively. When comparing results from surface markers and clusters, a good level of agreement was found in the continuous knee flexion-extension profile, and the discrete timings for all joints.

KEY WORDS: flexion-extension, range of motion, precision.

INTRODUCTION: Calculation of key kinematic data is an important part of most biomechanical analyses of sprint running. Kinematic data offer a quantitative description of athletes' movements and are a required input for the calculation of many kinetic variables, for example, when using an inverse dynamic approach. It is important that kinematic values are calculated accurately and that they truly represent the movement being analysed (Challis & Kerwin, 1996). Joint angles at specific event times (i.e. maximum flexion/extension, touchdown) are commonly reported values associated with successful sprint performance (Mann & Herman, 1985).

Many previous studies have analysed sprinting using digitised markers on joint centres (Mann & Herman, 1985; Bezodis *et al*., 2008). Gait research studies often utilise three-dimensional (3D) kinematics and kinetics using segmental clusters (Cappozzo & Cappello, 1997; McClay & Manal, 1999), giving more information on the orientation of segments. This allows internal segmental rotations to be calculated. Whilst the calculation of 3D kinematic data is beneficial, there are inevitably situations, such as in competition, when collection of the required data is not possible and kinematic data calculated from joint centre locations is the norm. To enable direct comparisons between results calculated from clusters and surface markers, differences between the two methods should be quantified.

The aim of this study was to compare surface anatomical markers located on joint centres with segmental clusters for the calculation of temporal and angular characteristics of lower limb joints. Findings will be of use when comparing results calculated using more contemporary cluster methods with those collected using traditional or field based methods.

METHOD: Data Collection: Data collection took place on the 110 m straight of the National Indoor Athletics Centre, Cardiff. One male athlete participated in the study (age 24.1 years, body mass 70.5 kg, height 1.84 m). A CODA Motion Analysis System (Charnwood Dynamics, UK) was set up operating four scanners (CX1) at a sampling rate of 200 Hz (capture time: 8 s). Scanners were positioned at a height of 1.3 m above the track surface, in pairs 6 m from the centre of the lane and at a separation of 5 m along the lane. This gave a bilateral field of view of 10 m, between 30 and 40 m from the start line. The system was aligned according to manufacturer's guidelines. Active CODA markers (21) were attached to the athlete (Figure 1) as surface markers located on joint centres or as part of four-marker clusters (Charnwood Dynamics, UK). Prior to testing, four additional markers were attached to the athlete whilst a static calibration trial was captured, allowing orientations of clusters to be determined relative to joint centres. The foot cluster and individual markers were attached using double-sided adhesive tape, reinforced with PVC tape. Shank and thigh clusters were attached by means of silicon friction pads and Coban Self-Adherent Wrap (3M, USA).

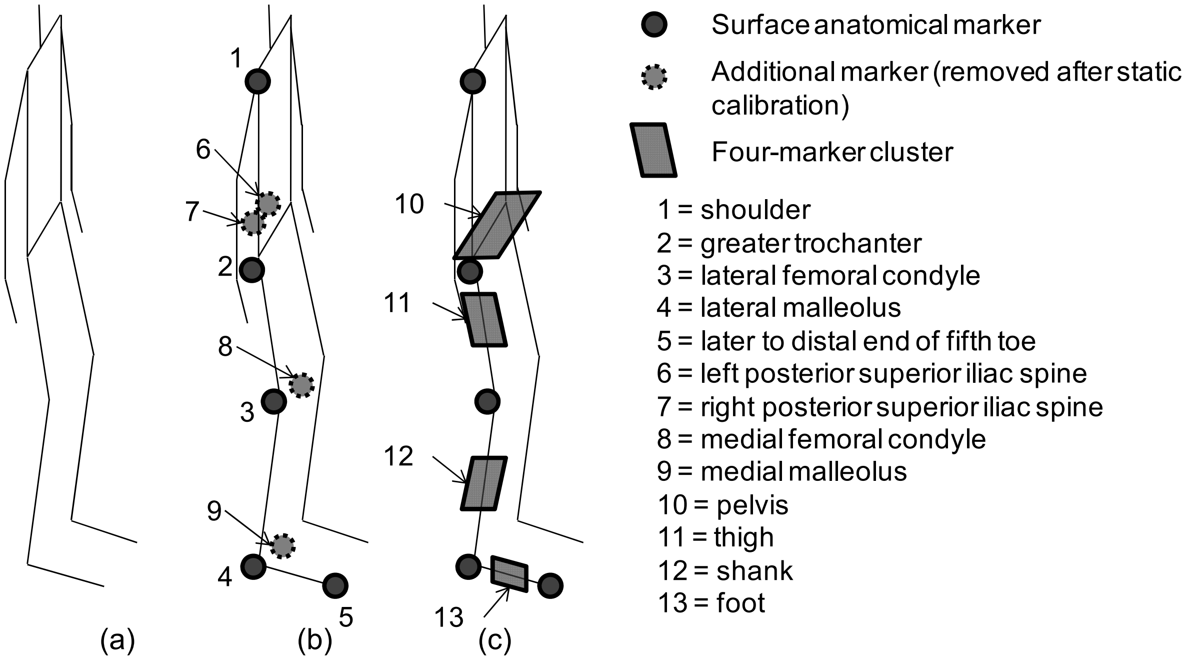

Figure 1: Stick figure representation of athlete (a) showing locations of surface anatomical markers (b) and four-marker clusters (c)

Data collection occurred in two phases; standing trials where the athlete stood on his left leg and moved the joints of his right leg through a full range of motion in the sagittal plane. Ten cycles of maximum flexion to extension were collected for each joint. In the second phase data were collected during seven maximal sprint runs. The athlete accelerated maximally from the start line through the data collection volume to a finish line 10 m beyond.

Data Analysis: Coordinate data were filtered via a low-pass Butterworth digital filter with a 17 Hz cut off frequency determined from Challis' (1999) autocorrelation method. Joint angles were calculated in two ways: for surface markers, three-point vector angles were calculated; for clusters, angles between adjacent segments' Cartesian locations were calculated. During sprint trials, right foot touchdown was calculated using the vertical acceleration method of Bezodis *et al.* (2007). Root mean squared differences (RMSD) between angles and event times calculated from clusters and surface markers were calculated for maximum flexion and extension. For sprint trials angular data were compared across one complete stride (right foot touchdown to subsequent right foot touchdown) and at instants of touchdown.

RESULTS: Mean RMSDs between joint angles calculated using the two methods are presented in Table 1. Discrepancies in event times were consistently low throughout all trials. A range of values were seen for mean differences between maximum flexion and extension angles, the lowest being for maximum knee flexion (<2°) and the largest being maximum ankle extension (~11°). During sprint trials, the least difference was at the knee with a RMSD of ~4° across all strides. The difference in hip flexion angle was surprisingly large (23°), however this magnitude did not occur throughout the range, shown by the difference in extension angle (~4°). Figure 2a shows time profiles for one standing trial. These show similarity of knee results, consistent differences at the ankle and inconsistency between methods for the hip. Figure 2b illustrates mean results for one stride from all sprint trials. Results are similar to standing trials, with consistency between angle differences for the ankle and knee, but not for the hip. Ankle differences were similar throughout the stride (~10°); increasing at approximately 70% of the stride cycle (~15°). Differences at the knee were small throughout the stride, with the largest differences occurring around maximum flexion. There was less consistency in differences at the hip joint with the largest occurring between 70 and 80% of the stride (>30°).

Table 1 Group mean [± SD] RMSD between lower-limb joint kinematic measures obtained using cluster and surface marker protocols during standing and sprint trials

Standing	**Flexion**		**Extension**		**RMSD**	
Trials	**Time (s)**	**Angle (°)**	**Time (s)**	**Angle (°)**	**Angle (°)**	
Ankle	0.01 [0.01]	9.5 [0.4]	0.01 [0.02]	10.7 [1.4]	10.2	
Knee	0.00 [0.00]	1.5 [0.4]	0.00 [0.00]	6.2 [0.6]	3.9	
Hip	0.01 [0.01]	6.0 [2.6]	0.01 [0.01]	8.2 [8.5]	12.0	
Sprint	**Flexion**		**Extension**		**RMSD**	**Mean TD**
Trials	**Time (s)**	**Angle (°)**	**Time (s)**	**Angle (°)**	**Angle (°)**	**Angle (°)**
Ankle	0.00 [0.00]	7.1 [1.4]	0.02 [0.02]	9.1 [1.4]	9.8	8.2 [0.9]
Knee	0.00 [0.01]	2.5 [2.2]	0.00 [0.00]	5.7 [0.7]	3.8	4.7 [0.9]
Hip	0.02 [0.01]	23.0 [7.4]	0.03 [0.02]	4.2 [3.9]	12.9	22.7 [20.6]

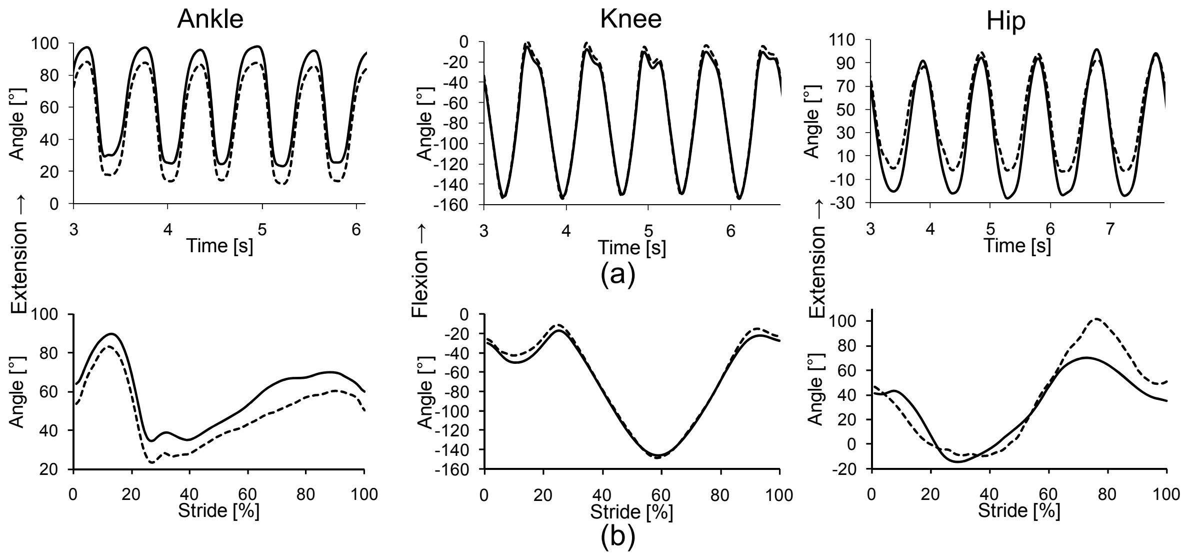

Figure 2: Joint profiles calculated using surface anatomical markers (solid lines) and segmental clusters (dashed lines) for (a) sample standing trial and (b) mean sprint trials (n=7)

DISCUSSION: This study's aim was to compare surface markers with segmental clusters for the calculation of temporal and angular characteristics relating to lower limb joint angles, as these are key variables that have been related to successful performance (Mann & Herman, 1985). Results showed that event times calculated using both methods are similar. Event timings at the knee were least different (0.00 s); ankle and hip values were higher at 0.01 and 0.02 s respectively. These were within precision levels possible for comparable data obtained from 50 Hz video (0.02 s). For standing trials, knee angle differences (~4°) were smaller than for the other joints. Ankle angles calculated from surface markers were consistently larger (~10°) than those from clusters, however there were smaller differences in ranges of movement between maximum flexion and extension (~2°). The largest differences were at the hip (RMSD = 12°), however, unlike ankle results, the magnitude and polarity of the differences varied throughout trials. Results for sprint trials followed a similar trend to standing trials with the knee showing the least differences in event times (0.00 s) and angles (~4°). Ankle differences were consistently ~10° throughout the stride. Hip results were least comparable with differences ranging from ~4° at maximum extension to ~23° for maximum flexion and touchdown angle (Figure 2b). One source of inconsistency in hip angle differences could be angle definition when using clusters and surface markers. Cluster hip angles were calculated relative to the pelvis, discounting upper body movement. However, for surface markers, the shoulder marker is typically included, therefore, upper body movements affect hip angle. The consistent difference at the ankle may be due to cluster angle definition from the static calibration trial. This introduces a systematic offset, relating to the athlete's stance in the static calibration, which may be correctable using offset normalisation (Mullineaux, 2004).

Care should be taken when comparing ankle angles calculated with the two methods; however, the range of movement and temporal characteristics were similar for both methods indicating that direct comparisons are possible for those variables. Knee angles were similar for both methods of calculation. Discrepancies were evident between hip angles, which may be due to shoulder motion affecting hip angle when calculated from surface markers.

The study has highlighted key performance related variables that can be compared across methods, allowing comparison between data collected using newer methods with previous data and data from competition. Further work could investigate effects of upper body movement on hip angle and whether this could be isolated when comparing results calculated using surface marker methods, as hip angle was highlighted by Mann and Herman (1985) as one of the most consistent success factors. Future work will benefit from a larger sample size and the comparison of cluster data with video based surface marker data.

CONCLUSION: Initial findings, based on single subject trials, indicate that surface markers and segmental clusters can be used to detect similar key event times of maximum flexion and extension of the ankle, knee and hip angles during maximal sprint running. When comparing kinematic measures derived from surface markers and clusters, a good level of agreement was found in the continuous knee flexion-extension profile, and discrete timings for all joints. The level of agreement in the hip joint angle range was lower than achieved for the ankle and knee.

REFERENCES:

Bezodis, I. N., Thomson, A., Gittoes, M. J. R. & Kerwin, D. G. (2007). Identification of instants of touchdown and take-off in sprint running using an automated motion analysis system. In H. J. Menzel & M. H. Chargas (Eds). *Proceedings of the XXVth Symposium of the International Society of Biomechanics in Sports* (pp 501-4). Ouro Preto, Brazil.

Bezodis, I. N., Kerwin, D. G. & Salo, A. I. T. (2008). Lower limb mechanics during the support phase of maximum-velocity sprint running. *Medicine and Science in Sports and Exercise*. 40, 707-15.

Cappozzo, A. & Cappello, A. (1997). Surface-marker cluster design criteria for 3-D bone movement reconstruction. *Transactions on Biomedical Engineering*. 44, 1165-74.

Challis, J. H. (1999). A procedure for the automatic determination of filter cutoff frequency for the processing of biomechanical data. *Journal of Applied Biomechanics*. 15, 303-17.

Challis, J. H. & Kerwin, D. G. (1996). Quantification of the uncertainties in resultant joint moments computed in a dynamic activity. *Journal of Sports Sciences*. 14, 219-31.

Mann, R. V. & Herman, J. (1985). Kinematic analysis of Olympic sprint performance: Men's 200 meters. *International Journal of Sport Biomechanics*. 1, 151-62.

McClay, I. & Manal, K. (1999). Three-dimensional kinetic analysis of running: significance of secondary planes of motion. *Medicine and Science in Sports and Exercise*. 31, 1629-37.

Mullineaux, D. R. (2007). Sample size and variability effects on statistical power. In C. J. Payton and R. M. Bartlett (Eds) *Biomechanical Analysis of Movement in Sport and Exercise: Biomechanics Testing Guidelines* (pp162). London: Routledge.

Acknowledgement

This work was funded by EPSRC grant number EP/D076943.