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CALCULATING CENTRE OF PRESSURE FROM MULTIPLE FORCE PLATES FOR KINETIC ANALYSES OF SPRINT RUNNING

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Force plates are relatively small compared to athletes' step lengths during sprint running. A large number of trials are subsequently rejected when collecting force plate data, which could be reduced by using multiple force plates. The aim of this study was to determine the suitability of foot contacts occurring across the boundaries of two force plates for use in inverse dynamics analyses. Centre of pressure data for a loaded wheel rolling across two force plates were compared to known positions of the wheel measured using an automated motion analysis system. A mean difference of 0.0027 [±0.0024] m was found between centre of pressure location and the measured wheel position as the wheel crossed the boundary between plates. The centre of pressure error resulted in joint power errors ranging from 0.27% to 1.47% for the ankle, knee and hip.

KEYWORDS: inverse dynamics analysis, accuracy, verification.

INTRODUCTION: The use of force plates to collect kinetic data during sprint running has been common for many years (Mann, 1981; Mann & Sprague, 1980). For accurate kinetic data to be collected, contact with the force plate must occur within the boundaries of the plate, so that the measured force is not affected by force being applied to the surrounding surface. The need for contact within the plate boundaries can lead to rejected trials if foot contacts overlap the boundaries of the plate (Johnson & Buckley, 2001), which increases the number of trials required to allow collection of sufficient data for analysis.

One problem associated with the use of force plates to collect sprint data is the size of the force plate surface relative to athletes' step length. A typical force plate measuring 0.90 m x 0.60 m covers less than half of a 2 m step. Abendroth-Smith (1996) noted the detrimental effects on the kinetic data when athletes target the force plates to increase frequency of acceptable contacts. The detrimental effects of force plate targeting combined with the small size of force plates relative to athletes' step lengths means that often only one foot contact can be analysed from a sprint run, which has limited the understanding of the interaction between consecutive foot contacts.

A possible solution to increase the successful attainment of useable foot contacts from sprint trials and to increase the area of force data collection is to utilise numerous force plates mounted end to end. The addition of a second force plate of equal size would double force data collection area and could also allow the possibility of collecting steps that overlap between plates. Contacts occurring across two plates would result in all of the force being applied to the plates and not the surrounding track surface. However, errors could occur with the calculation of centre of pressure (COP), which is a required input when performing an inverse dynamics analysis (IDA). As COP is calculated relative to each force plate, a method was required to treat the data so that a global COP location could be calculated from the data recorded by each force plate. Bobbert and Schamhardt (1990) reported that the accuracy of COP calculation for piezoelectric force plates was greatest at the centre of the plate, with the largest errors being present in the area outside of the plate's sensors. Foot contacts that occur across two plates may therefore inherently include a greater amount of error in COP calculation than contacts occurring in the middle of the plate. The aim of this study was to determine whether COP could be determined sufficiently accurately for contacts occurring across two force plates. The determination of accurate COP data was necessary to allow appropriate IDA to be conducted, and to consequently allow an extended insight into the mechanics of sprint running.

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METHODS: Ground reaction force data were collected at the National Indoor Athletics Centre in Cardiff using two force plates (Kistler, 9287BA), each measuring 0.90 m x 0.60 m. The force plates were mounted in customised housings sunk into the floor of the athletics track (Figure 1). The plates were covered with Mondo track surface (Mondo, USA), which was flush with the surrounding track surface. The trolley position was calculated using an automated motion analysis system (CODA) to provide known positions for comparison with COP data. Two CODA scanners (cx1) were positioned either side of the force plates, at a separation distance of 8.40 m. The x (medio-lateral), y (antero-posterior) and z (vertical) axes of the CODA system were positioned so that they were parallel to the corresponding axes of the force plates. Three active CODA markers were attached to the top of a loaded fixed-axle rigid trolley, which was rolled over both plates at a near constant velocity. The CODA software collected kinetic data from the force plates at 1000 Hz and synchronised marker positional data at 800 Hz. The use of the trolley allowed a smooth transition from one plate to the other, in an antero-posterior motion, similar to the COP pathway created by an athlete during a sprint running trial. The trolley was loaded with a mass of 500 kg positioned above one wheel so that the force applied to the track surface by the loaded wheel was approximately 2000 N, which represented the peak vertical force that an athlete would exert on the plate during a sprint trial (Mero & Komi, 1994).

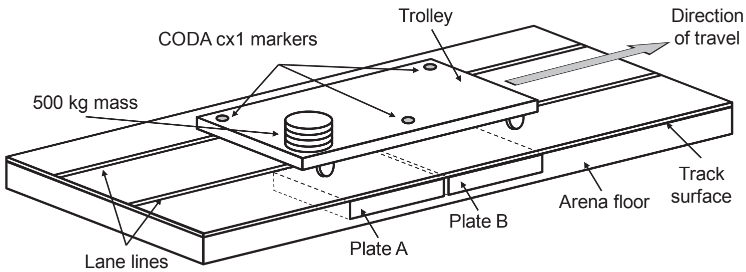

Figure 1: Cross section of data collection area demonstrating the location of the multiple force plates and trolley used for force plate verification study.

In total 15 test trials were collected, by rolling the wheel across the plates in three different pathways. The pathways followed the mid line of the plates, where accuracy is reported as highest (Bobbert & Schamhardt, 1990), and the two outer edges (medial and lateral) of the plates, where accuracy is lower. The force plates were reset following each trial to reduce any effects of hysteresis and to cancel amplifier drift.
CODA force and positional data were filtered using a digital low-pass Butterworth filter with optimal cutoff frequencies determined using the autocorrelation method of Challis (1999). COP location was calculated in the sagittal plane for each separate plate using the equations supplied by the force plate manufacturer (Kistler). Global COP location in the y direction was then calculated by combining the values calculated from each plate with weighting values calculated based on the proportion of overall force being applied to each plate:

$$ay = \left(ay_a \times \left(Fz_a / Fz\right)\right) + \left(ay_b \times \left(Fz_b / Fz\right)\right)$$

where ay = global y location of COP, $ay_{a/b}$ = y location of COP measured by Plate A/B, $Fz_{a/b}$ = vertical force measured by Plate A/B, Fz = total vertical force measured by both plates. Marker locations were combined to allow determination of the location of the triangle's centre, referred to as the 'control point'. The global COP location and position of the control point were adjusted to accommodate any lateral motion of the trolley by altering the vectors connecting each point to the global origin so that they lay on the y axis (Figure 2). The mean distance between the adjusted control point and COP location was calculated whilst the trolley was stationary and resting on one plate; this static value was used as a reference value with which to compare the dynamic trials.

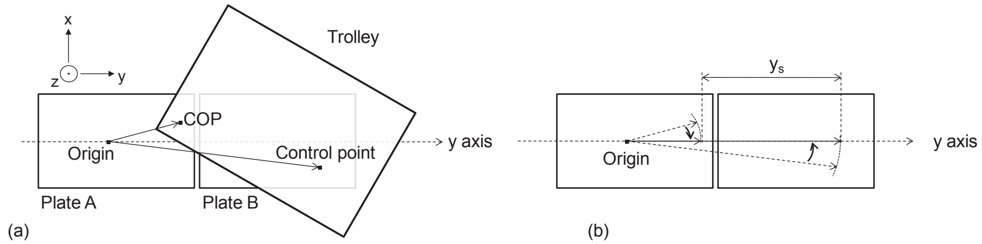

Figure 2: Location of control point and COP before adjustment (a) and after adjustment (b) and the separation between adjusted COP and control point (y_s).

To determine the effect of COP error on subsequent IDA calculations, joint power data from a maximal sprint run were additionally calculated using the measured COP via two-dimensional IDA. The calculation was then repeated having altered the COP values by the mean and maximum differences for all trials between the reference y_s value and the mean y_s value as the trolley crossed the plate boundaries. Percentage root mean squared difference (%RMSD) values were calculated between the results calculated with the measured and adjusted COP values.

RESULTS: Mean [±SD] differences between adjusted COP and control points were 0.0006 [±0.0040] m, 0.0054 [±0.0009] m and 0.0014 [±0.0055] m for the left, middle and right sides of the force plates, respectively. The mean error for all trials was 0.0027 [±0.0024] m, whilst the largest error (0.0076 m) occurred in a trial on the right side of the plate. An example comparison between the COP and control point locations throughout one trial is shown in Figure 3.

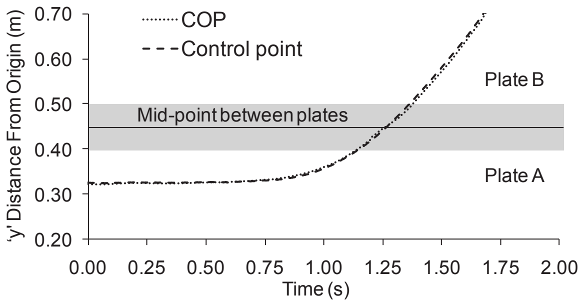

Figure 3: Example comparison between COP and control point as trolley is rolled across force plates for one trial, on left side of plate.

Table 1 contains sensitivity results for the joint power calculations based on the mean and maximum errors for all trials, caused by calculating COP across two force plates. The largest effect was seen at the knee joint (1.47% and 4.02%) whilst the smallest effect was for the ankle joint (0.27% and 0.73%).

Table 1
Effect of COP error on the calculation of joint power for the ankle, knee and hip joints.

COP Error	Change in Joint Power (%RMSD)		
	Ankle	Knee	Hip
Mean (0.0027 m)	0.27	1.47	0.36
Max (0.0076 m)	0.73	4.02	1.06

DISCUSSION: The aim of this study was to determine whether COP could be determined sufficiently accurately for contacts occurring across two force plates to be used in subsequent IDA. The largest mean difference between COP and the measured trolley position was observed when the trolley was rolled along the middle of the force plates; however the SD was lowest for this position indicating low variability between trials. The greater consistency of the results for the middle position was expected as force plate accuracy for COP calculation decreases towards the extremities of the plate (Bobbert & Schamhardt, 1990).
Figure 2 demonstrates the similarity in COP and control point positions throughout a trial. The positional difference between COP and the control point was similar during the highlighted crossover region (±0.05 m from the plate boundaries) to the rest of the trial when the wheel was located on one force plate.
Mean error in COP location across the boundary between two force plates was 0.0027 [±0.0024] m. COP calculation displayed greater consistency for contacts occurring towards the middle of the plates' x axis than those towards the edge. Results of the joint power sensitivity analysis indicated that the mean error of 0.0027 m would lead to a change in joint power ranging from 0.27% for the ankle to 1.47% for the knee.
The sensitivity in the joint power calculations were similar in magnitude to those reported for other inverse dynamic sensitivity analyses, such as that of Bezodis et al. (2008), who reported possible joint power error values ranging from 2.9% (knee) to 8.4% (hip) caused by error introduced in the digitising process. As COP error is a position error, it may be considered comparable to positional error introduced by the digitising process.

CONCLUSION: Foot contacts of sprint running that occur in the centre of a single force plate, where the COP error is reduced are favourable when compared to contacts occurring at the outer edge. However, COP data obtained for foot contacts occurring across two force plates were shown to be realistic and caused less error in joint power calculations than that previously reported due to digitising error. Utilising multiple force plates to collect sprint running data may facilitate the collection of successive ground contacts, while simultaneously allowing realistic COP data to be obtained for IDA. The use of accurate COP data in IDA is fundamental to allow an extended insight into the mechanics of sprint running.

REFERENCES:

Abendroth-Smith, J. (1996). Stride adjustments during a running approach toward a force plate. *Research Quarterly for Exercise and Sport*, 67(1), 97-101.

Bezodis, I.N., Kerwin, D.G. and 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(4), 707-15.

Bobbert, M.F. and Schamhardt, H.C. (1990). Accuracy of determining the point of force application with piezoelectric force plates. *Journal of Biomechanics*, 23(7), 705-10.

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(3), 303-17.

Johnson, M.D. and Buckley, J.G. (2001). Muscle power patterns in the mid-acceleration phase of sprinting. *Journal of Sports Sciences,* 19(4), 263-72.

Mann, R.V. (1981). A kinetic analysis of sprinting. *Medicine and Science in Sports and Exercise,* 13(5), 325-8.

Mann, R.V. and Sprague, P. (1980). A kinetic analysis of the ground leg during sprint running. *Research Quarterly for Exercise and Sport,* 51(2), 334-348.

Mero, A. and Komi, P.V. (1994). Emg, force, and power analysis of sprint-specific strength exercises. *Journal of Applied Biomechanics,* 10(1), 1-13.

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