DEVELOPMENT AND RECOMMENDATION OF KINEMATIC EVENT DETECTION METHODS FOR USE DURING BEND SPRINT RUNNING

Jonathan White[1], Joseph Moore[1] Cassie Wilson[2], Gareth Irwin[3] Hans Von Liers und WIlkau[3] and Timothy Exell[1]

School of Sport, Health and Exercise Science, University of Portsmouth, Portsmouth, England[1] Department of Health, University of Bath, Bath, England[2] School of Sport and Health Sciences, Cardiff Metropolitan University, Cardiff, Wales[3]

This study aimed to validate different kinematic event detection methods for use during maximal velocity bend sprint running. Eight sprinters completed nine 60 m bend sprints each around an athletic track with a 36.5 m bend radius. Three kinematic event detection methods were adapted and compared to instances of touchdown and toe-off as determined by force plates. Using peak and maximum vertical acceleration of the toe marker yielded mean errors of less than 1 frame (0.004 s) for touchdown, whilst peak acceleration was the most accurate for determining toe off (mean error = 0.85 frame).The findings suggest that, when carefully applied with additional controls, kinematic-based event detection methods offer an accurate alternative to force-plate detection methods for use during biomechanical analyses of bend sprint running when ground reaction force data are not available.

KEY WORDS: touchdown, toe-off, validation.

INTRODUCTION: In sprint running, the primary performance descriptors require knowledge of the time of subsequent foot touchdown and toe-off events. The gold-standard method for detecting these events involves the use of force plates and utilising a threshold of vertical force to detect them. For example, the mean plus two standard deviations of the vertical ground reaction force (with zero load on the force plate) implemented as a threshold (Bezodis et al., 2007). Obtaining force plate data for multiple steps becomes increasingly difficult during bend sprint running, where the path of the athlete is curvilinear wheras force plates are commonly positioned along a linear path. Therefore, alternative methods for accurately detecting touchdown and toe-off events using kinematic data are necessary. Whilst research has validated a kinematic-based event detection method during linear acceleratative sprint running (Nagahara & Zushi, 2013), previous literature highlights several kinematic differences, between linear and bend sprint running.
In Alt et al's., (2015) study of lower extremity kinematics during bend sprint running, touchdown and take-off events were identified using the foot contact algorithm (FCA) developed by (Maiwald et al., 2009). However, this algorithm was produced using steady-state treadmill running at 3.5 m/s. More recently, Judson et al., (2020) utilised methods described by Bezodis et al. (2007) where the mean plus two standard deviations of the fifth metatarsal head vertical coordinates in the static trial were used as a threshold to detect touchdown and take-off. Nevertheless, no comparison to force plate events are reported. Thus, there appears to be no validated method for detecting gait events using kinematic data during maximal velocity bend sprint running. Therefore, the aim of this study was to determine the accuracy of adapted kinematic event detection methods to validate for use during maximal bend sprint running.

METHODS: Following institutional ethical approval, eight competitive sprinters (one female and seven males), aged 22 ± 5 years with a height of 178.28 ± 4.45 cm and a mass of 74.07 ± 4.62 kg, were recruited using convenience sampling for the study. Their 200 m personal best time was 22.63 ± 0.82 seconds for males and 24.89 seconds for the female participant.
Participants undertook nine 60 m sprints around a 36.5 m bend radius. Forty metres from the starting position, twelve optoelectronic cameras (Vantage V8, Vicon, Oxford Metrics, UK, 250 Hz) were mounted onto tripods creating a capture volume that enabled a minimum of one full stride (two complete steps) to be captured. Four force plates (Kistler 9281CA, Kistler Instruments AG, Switzerland) were placed within the testing area and sampled at 2000 hz to

collect two consecutive ground contacts (Figure 1). Participants were prepared by attaching retro-reflective markers to the lower limb and trunk in accordance with Judson et al. (2018).

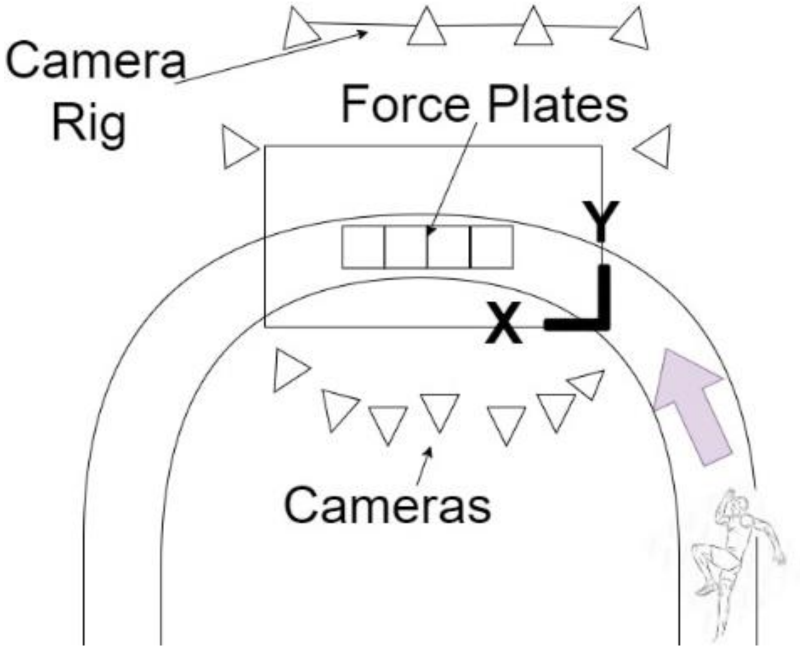

Figure 1. Experimental set up (not to scale)

Ground reaction force data from the four force plates and marker trajectories for the toe and fifth metatarsal head were exported to MATLAB (2021b). Touchdown and toe-off events were identified using the mean plus two standard deviations of vertical ground reaction force data where there was zero load on the force plate as a threshold (Bezodis et al., 2007). All data were filtered with a a fourth-order Butterworth-filter at cut-off frequencies using the autocorrelation method (Challis, 1999) The first tested kinematic method, described by Bezodis et al., (2007) and used in Judson et al., (2020), involved calculating the mean vertical position of the fifth metatarsal head marker during the static trial and adding two standard deviations. This mean vertical position plus two standard deviations of the mean vertical position was calculated and used as a threshold for ground contact for each participant (first frame below threshold defined as touchdown and first frame when exceeds threshold defined as toe-off), hereafter termed the threshold method. The second method is described by Nagahara & Zushi (2013) where touchdown was identified using the peak vertical acceleration of the toe marker, hereafter termed the Nagahara Peak Acceleration method. The Nagahara Peak Acceleration method determined toe-off as one frame before the subsequent peak vertical toe acceleration. Within the same validation study, Nagahara & Zushi (2013) found the most accurate way to detect toe-off was using the first frame after the minimum vertical toe position. The difference between the two methods was 0.13 frames (0.00052 s), thus both methods were included in the present study and hereafter termed the Nagahara Peak acceleration method (touchdown and toe-off) and the Nagahara position method (toe-off only). The final method called the foot contact algorithm (FCA) (Maiwald et al., 2009) was used to calculate events durning bend sprint running by Alt et al. (2015). The FCA uses a characteristic maximum in the vertical acceleration curve of the target marker (in this case the toe and not the heel) in a given window around the minimum vertical position. For take-off, a local maximum in the vertical acceleration of the toe marker is detected and compared to the minimal vertical position of the toe. A logical operation selects the event that occurs earlier in time, which is then used to estimate take off.

Limits of Agreement (LoA) were used calculate the systematic and random bias between the force plate and kinematic gait events, as per (Altman & Bland, 1983). Further accuracy criteria included a mean absolute error of within ± one frame for detecting touchdown (TD) and toe-off (TO). Additionally, the mean absolute error was calculated to highlight the accuracy of methods in the context of key bend sprinting variables (ground contact time, ankle eversion at touchdown and touchdown distance).

RESULTS: Limits of Agreements (LoA) and mean error can be seen in Table 1. The Nagahara and FCA methods performed similarly for detecting touchdown with mean error < ±1 frame compared to the force plate method with key variables calculated at touchdown almost identical (Table 2). Mean ground contact time calculated using the force plate was 0.113 ± 0.015 s. For TO, the Nagahara peak acceleration method displayed the lowest LoA and mean error (Table 1). mean error values for GCT highlight that the Nagahara Peak Acceleration method performs best due to its greater accuracy for detecting TO compared to the FCA method. The methods utilising the vertical position (Nagahara Position and Threshold) perfomed poorly when detecting TO.

Table 1. Limits of Agreements and Mean Absolute error for all kinematic event detection methods compared to that of the force plate.

Variable	LoA	Lower LoA	Upper LoA	Mean Error
Touchdown				
Nagahara Peak Acceleration	1.9	-2.7	1.2	-0.72
Threshold	2.0	-3.1	1.0	-1.0
FCA	1.8	-2.5	1.1	-0.68
Toe-Off				
Nagahara Peak Acceleration	3.9	-3.1	4.8	0.85
Nagahara Position	7.4	-10	4.8	-2.7
Threshold	18	-25.2	10	-7.6
FCA	5.6	-7.1	4.2	-1.4

Table 2. Mean absolute error of kinematic methods compared to force plate for key vairables

Variable	Eversion at Touchdown (°)	Touchdown Distance (m)	GCT (s)
Nagahara Peak Acceleration	1.79	0.0297	0.0069
Nagahara Position	N/A	N/A	0.0108
Threshold	2.40	0.0357	0.0278
FCA	1.79	0.0288	0.0071

DISCUSSION: For detecting touchdown, the adapted FCA method produced the lowest mean error value. However, there was minimal difference between the three methods, with all three methods equal to or below the threshold of ± 1 frame, thus, all were deemed acceptable for detecting touchdown during maximal velocity bend sprint running. Previous research has reported mean errors of 1.24 ms for detecting touchdown using the Peak acceleration method (Nagahara & Zushi, 2013). The present study sampled at 250 Hz, thus 1 frame equates to 4 ms, therefore the current study found mean errors of 2.7 – 4 ms highlighting similar accuracy across the tested methods during linear accelerative and maximal bend sprinting.

Greater variability in accuracy was observed for detecting toe-off, with the peak acceleration method being the most accurate for detecting toe-off. Only the Nagahara peak acceleration method achieved the accuracy criteria of ± 1 frame compared to the force plate. Nagahara & Zushi, (2013) report mean errors of 1.88 ms for detecting toe-off, whilst in the present study the Nagahara Peak acceleration method yielded 3.4 ms. The methods solely using vertical position (Nagahara Position method), using the frame after minimum toe position and the threshold method utilising vertical position of the fifth metatarsal head and were found to be less effective for detecting toe-off (Nagahara Position: = -2.7 frames; Threshold: = -7.6 frames). One potential reason for these high values of error is due to the large eversion angles during commonly observed during bend sprint running, (~ 12 degrees (Alt et al., 2015) and 22 degrees of pronation (Hamill et al., 1987). This high eversion angle potentially leads to the vertical position of the target marker exceeding the vertical position threshold during early-mid-stance. Therefore, these methods picked up frames during the early-mid-stance and not the toe-off, thus should not be recommended for use during bend sprint running analyses.

When considering TD and TO to calculate GCT, the Nagahara Peak acceleration method produced the lowest mean error values (0.0103 s) compared to the FCA (0.0117 s), nonetheless only the Nagahara peak acceleration method achieved the threshold of < ± 1 frame of mean error for both touchdown and toe-off and thus is recommended for use. The mean GCT in the present study was 0.113 s, meaning that a mean error of 0.0069 s equates to a potential error in the calculation of GCT of 6.11 %. World-class sprinters produce GCT as short as 0.086s (Čoh et al., 2018), thus, it is important to acknowledge that an error of 0.0069 s is a potential error of 8.02 % in GCT for world-class sprint athletes. Nonetheless where force plate data is not available, the Nagahara peak acceleration method enables calculation of touchdown and toe-off events during maximal bend sprint running.

CONCLUSION: The study's findings recommend the Nagahara Peak acceleration method for detecting touchdown and toe-off events during maximal bend sprint running where ground reaction force data is not available. In summary, this study contributes to the validation and improvement of kinematic-based event detection methods for maximal bend sprint running. These methods, when carefully applied with the proposed additional controls, offer an accurate alternative to force-plate detection methods for use during biomechanical analyses of bend sprint running.

REFERENCES

Alt, T., Heinrich, K., Funken, J., & Potthast, W. (2015). Lower extremity kinematics of athletics curve sprinting. Journal of Sports Sciences, 33(6), 552–560. https://doi.org/10.1080/02640414.2014.960881

Altman, D. G., & Bland, J. M. (1983). Measurement in Medicine: The Analysis of Method Comparison Studies. The Statistician, 32(3), 307. https://doi.org/10.2307/2987937

Bezodis, I., Thomson, A., Gittoes, M., & Kerwin, D. (2007). Identification Of Instants Of Touchdown And Take-Off In Sprint Running Using An Automatic Motion Analysis System. Paper presented at: ISBS-Conference Proceedings Archive 2007.

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), 303–317. https://doi.org/10.1123/jab.15.3.303

Čoh, M., Hébert-Losier, K., Štuhec, S., Babić, V., & Supej, M. (2018). Kinematics of Usain Bolt's maximal sprint velocity. Kinesiology, 50(2), 172–180. https://doi.org/10.26582/k.50.2.10

Hamill, J., Murphy, M., & Sussman, D. (1987). The Effects of Track Turns on Lower Extremity Function. International Journal of Sport Biomechanics, 3(3), 276–286. https://doi.org/10.1123/ijsb.3.3.276

Judson, L. J., Churchill, S. M., Barnes, A., Stone, J. A., Brookes, I. G. A., & Wheat, J. (2018). Measurement of bend sprinting kinematics with three-dimensional motion capture: A test–retest reliability study. Sports Biomechanics, 19(6), 761–777. https://doi.org/10.1080/14763141.2018.1515979

Judson, L. J., Churchill, S. M., Barnes, A., Stone, J. A., Brookes, I. G. A., & Wheat, J. (2020). Kinematic modifications of the lower limb during the acceleration phase of bend sprinting. Journal of Sports Sciences, 38(3), 336–342. https://doi.org/10.1080/02640414.2019.1699006

Maiwald, C., Sterzing, T., Mayer, T. A., & Milani, T. L. (2009). Detecting foot-to-ground contact from kinematic data in running. Footwear Science, 1(2), 111–118. https://doi.org/10.1080/19424280903133938

Nagahara, R., & Zushi, K. (2013). Determination of Foot Strike and Toe-off Event Timing during Maximal Sprint Using Kinematic Data. International Journal of Sport and Health Science, 11, 96–100. https://doi.org/10.5432/ijshs.201318