MARKERLESS MOTION CAPTURE WITHIN SPORT: AN EXPLORATORY CASE STUDY

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The purpose of this case study was to compare centre of mass (CoM) recorded by a markerless motion capture system (60 Hz) to a criterion marker based system (120 Hz). Gait kinematics of one healthy male participant was recorded five times by both capture systems simultaneously. CoM position was assessed using a full body six degrees of freedom model, normalised to the stance phase based on a 20 N vertical force threshold recorded with force plates. T-tests on RMSE indicated frontal (0.002 m) and sagittal (0.066 m) CoM coordinates were not significantly different between systems, transverse CoM (0.020 m) was significantly different. Statistical parametric mapping showed significant difference in sagittal CoM during the last 20% of stance. Markerless systems show promise in accurately assessing CoM. Future work should focus on sport actions with larger cohorts.

KEY WORDS: Markerless, Motion Capture, PlayStation Eye^{TM}, Gait, Centre of Mass

INTRODUCTION: Three dimensional (3D) motion capture within sport is commonly undertaken using active or passive marker-based systems allowing for kinematic data to be acquired. Such information can be utilised by scientists and coaches to provide feedback to athletes with a view to enhancing performance or reducing the risk of injury (Bishop, Fiolkowski, Conrad, Brunt, & Horodyski, 2006). However, such systems do present with disadvantages. These include expensive hardware and software, limited portability and time and labour intensive set-ups (Bonnechere et al., 2014). Additionally, the presence of markers may affect the ecological validity of the movement being captured (Peters, Galne, Sangeux, Morris, & Baker, 2010). In an effort to decrease the difficulties associated with marker based (MB) motion capture, considerable advancements have been made in markerless (ML) motion capture technologies. Recently developed comparably low cost portable sensors such as the Microsoft Kinect^{TM} camera that use infrared depth sensors have the ability to track real-time human movement without the need for markers attached to the body (Boas, 2013).

Whilst initially created for machine vision applications within the animation industry, companies such as iPiSoft (www.iPiSoft.com) have recently developed specialist software and algorithms to be used with ML systems, opening up the possibility for their use within the field of clinical and sports biomechanics. Previously a Microsoft Kinect^{TM} depth sensor has been utilised to demonstrate high centre of mass (CoM) tracking accuracy over a badminton court (Choppin & Wheat, 2013); although CoM_Z position was subject to large variations and segment coordinate tracking was low. Additionally depth sensors have been shown to provide accurate measurements in CoM position during balance training (Lim, Kim, Jung, Jung, & Chun, 2015), however the system was limited in its ability to record medial-lateral and vertical movements. A similar camera system that is compatible with iPiSoft software but has received no attention in the literature is the PlayStation Eye^{TM} (PSE). Much like the Microsoft Kinect^{TM} the PSE camera records at the same resolution to track movement, however rather than using depth sensors the PSE employs sophisticated computer vision and gesture recognition methods (Schild, Seele, & Masuch, 2011). In addition the PSE is able to record at 60 frames per second (fps) compared to only 30 fps with depth sensors. Motion capture technologies are a popular tool within sport science research (Polak, Kulasa, Vencesbrito, Castro, & Fernandes, 2016). With the higher cost and lower fps achievable with the Microsoft Kinect^{TM} depth sensor, if the PSE incorporated ML motion capture system could be found to demonstrate accuracy comparable to that of MB motion capture systems, this could open up the possibility of more dynamic sporting movements able to be assessed in-situ then is currently possible. The aim of this case study was to compare the accuracy of

CoM position during gait recorded from ML motion capture via PSE cameras to that of a criterion MB system.

METHODS: With ethical approval and informed consent, one healthy male participant free from injury was recruited from the University population. An 11 camera Vicon Vantage Motion capture system with two Vicon Vue cameras (Vantage V8, Vicon Motion Systems Ltd, Oxford) were used to collect kinematic data; additionally two force plates (Kistler Type 9287CA, Kistler Instrumente AG, Winterthur, Switzerland) were used to collect kinetics whilst the participant walked bare-footed at a self-selected pace along a 10 m walkway. Forty-two 14 mm diameter retro-reflective markers were positioned on the participant's head, thorax, upper limbs, pelvis and lower limbs; four clusters of three markers were positioned on the left and right upper and lower arms segments with four clusters of four markers positioned on the left and right thigh and calf segments. Motion capture and force plate data was synchronised at 120 Hz and 960 Hz respectively, Vue video cameras were recorded at 60 Hz. Simultaneously a six camera Sony PSE video capture system (Sony, California) captured trials at 60 Hz using specialist software (iPiRecorder v3.2.5., iPiSoft, Russia). MB CoM coordinates (x: mediolateral, y: anteroposterior, z: vertical) were time-normalised to 100 % of the stance phase based on a vertical threshold of 20 N identifying foot strike and toe-off to create waveforms of 101 data points (Visual 3D V6, C-Motion, USA). IPiSoft trials were normalised to stance phase by synchronising the PSE video with the Vicon Vue video at the frame where the vertical force thresholds occurred, as identified in Vicon Nexus 2.5. From this, stance phase CoM position was obtained in the iPiSoft software using the iPi Biomech-add on (iPi Mocap Studio v3.416) (Figure 1).

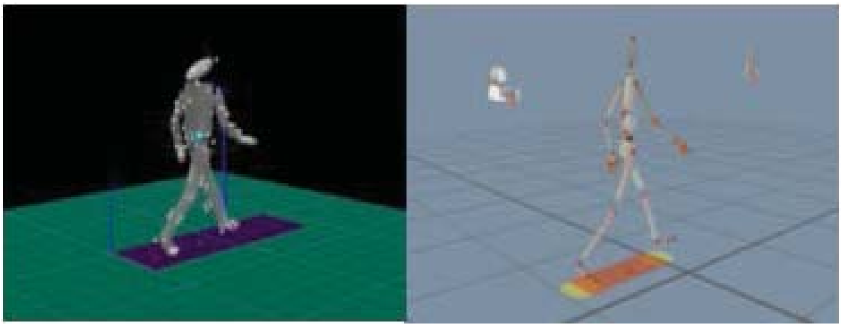

Figure 1. Synchronised mid-stance phase during gait in Visual 3D (left) and iPiSoft (right)

Data analysis of CoM coordinates for ML and MB systems were conducted using Matlab (TheMathWorksInc, Natick, MA, USA). Marker trajectories were filtered using a 4th order zero lag Butterworth filter. Cut-off frequencies (Hz) for each data point were determined using an auto correlation algorithm (Challis, 1999). Root mean squared error (RMSE) of CoM position between motion capture systems was used to determine differences between CoM trajectories. Data were tested for normality and equality of variance using Kolmogorov-Smirnov and Levene's test. For CoM_X, CoM_Y and CoM_Z position, independent samples t-tests were used to evaluate statistical differences in RMSE. Alternatively, the non-parametric Mann-Whitney U test was employed. In addition for CoM positions, two-tailed statistical parametric mapping (SPM) and where data was non-parametric, two-tailed statistical non-parametric mapping (SnPM) was used to identify where phase specific statistical differences occurred between systems. Significance was set at $P < 0.05$.

RESULTS: RMSE between motion capture systems is shown in Table 1. During the stance phase, error of 2 mm and 60 mm for the CoM_X and CoM_Y coordinates were not found to be significant. There was however a significant error of 20 mm in the CoM_Z coordinate between systems ($P<0.05$). Figure 2a shows SPM of the CoM_Y coordinate with SnPM of the CoM_X and CoM_Z coordinates, as they were found to be non-parametric. SnPM indicated that for the duration of the stance phase, CoM_X and CoM_Z position was not statistically different between systems. For CoM_Y position, SPM indicated that the last 20% of the stance phase was statistically different (P<0.05) between motion capture systems. Variances in the CoM_X and CoM_Y coordinates during trials can be seen in figure 1b.

Table 1: Root mean squared error of CoM position between marker-based and markerless motion capture during stance phase of gait

CoM	RMSE (m)	*P*
X	0.002	0.065
Y	0.066	0.669
Z	0.020	<0.001

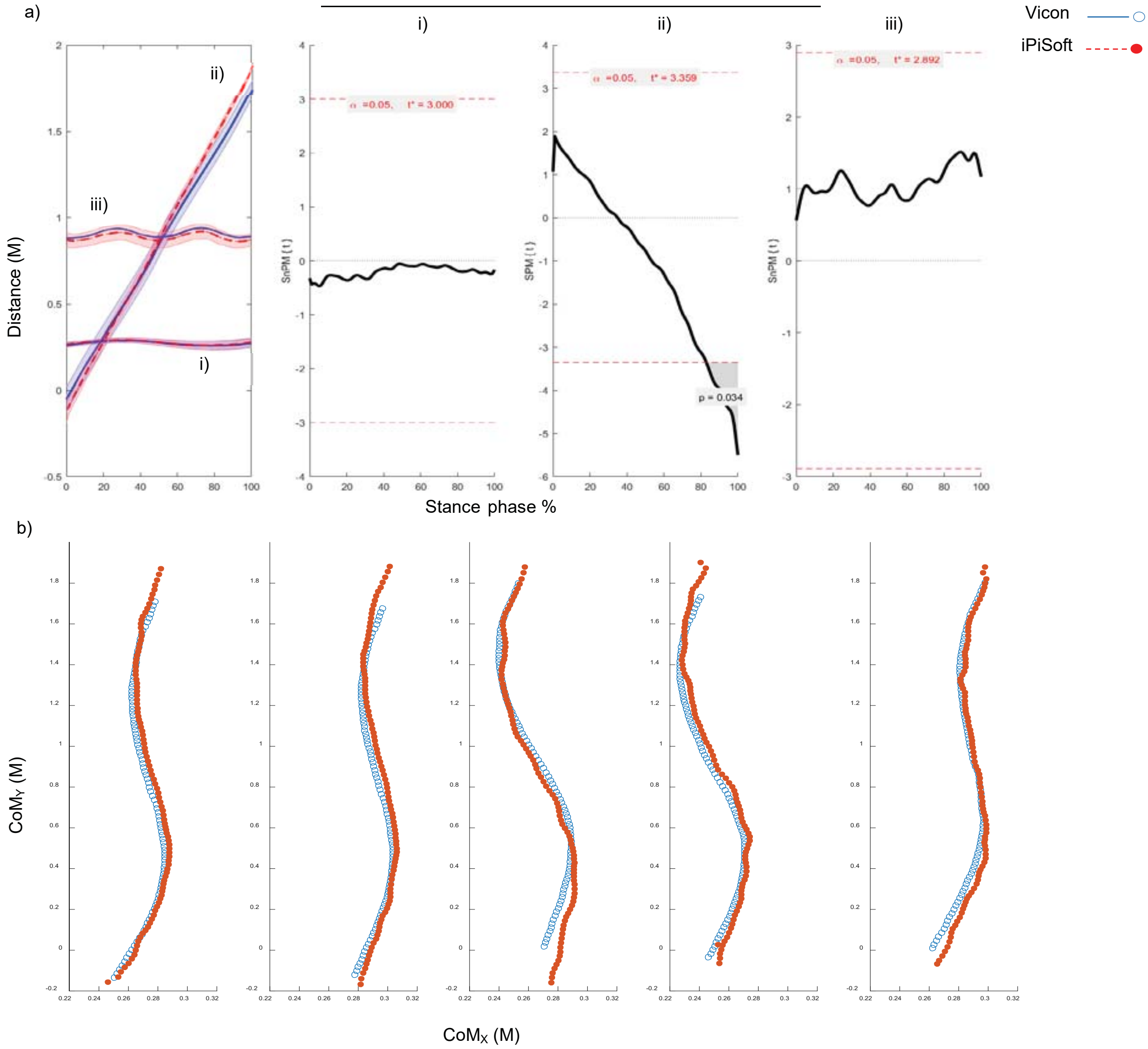

Figure 2: a) Mean (SD) for CoM_X (i) CoM_Y (ii) and CoM_Z (iii) position with corresponding SPM and SnPM; b) normalised CoM_X and CoM_Y for all gait trials

DISCUSSION: Within sport MB motion capture systems are traditionally used to obtain kinematic data, however their ability to capture skills in-situ still present with challenges. The recent development in ML capture technologies which use computer and gesture recognition have the potential to overcome such challenges, allowing for athletes and coaches to gain a greater understanding of in-situ performance. The purpose of this study therefore was to investigate the accuracy of gait CoM position recorded by a PSE ML motion capture system compared with that of the gold standard MB system. For CoM_X and CoM_Y locations no significant difference in RMSE were found between capture systems. There was however a significant difference between CoM_Z coordinates. This difference in CoM_Z position could have been an effect of systematic error whilst recording with iPiSoft software due to calibration or camera placement issues. Incorrect identification of the ground plane due to factors such as environmental reflections and occlusion during calibration may have led to incorrect estimates of segmental masses and positions during trials; thus contributing to the variances in CoM_Z position processed by the iPiSoft software. These differences seen in CoM_Z position between motion capture systems agree with a previous study by Choppin and Wheat (2013) who found that CoM_Z position was subject to large systematic bias of 405 mm. Whilst CoM_X and CoM_Y position showed good accuracy between systems, the last 20 % of the stance phase was seen to be statistically different between CoM_Y positions. Similar to CoM_Z position, it is therefore possible that this variation could not only be due to equipment setup limitations, but as a result of reduced system accuracy, due to the end of the stance phase occurring towards the edge of the ML motion capture system's volume; an issue which is also occurs in MB motion capture volumes

Findings in CoM position reflect the recent body of research that have demonstrated how ML systems can provide an accurate inexpensive method for recording kinematics (Lim et al., 2015) In light of the ML system having recorded CoM_Z position proximal compared to the MB system throughout the whole stance phase and that this was found to be statistical different, investigation is also required to understand how experimental setup may influence iPiSoft results. Further to this, comparison of CoM position, lower-limb and trunk angles between systems will be compared during more dynamic sporting actions such as running, counter movement jumps and cutting manoeuvres.

CONCLUSION: This exploratory case study explored whether markerless motion capture could accurately identify CoM position during gait with that of a criterion marker-based system. To the authors' knowledge this is the first study to indicate that the PSE cameras used in conjunction with iPiSoft software has the potential to provide accurate measurements of CoM position. By assessing the accuracy of such ML systems, it is anticipated that future studies could highlight how these relatively cheap motion capture solutions could be used in-situ during sporting actions; helping to provide coaches and athletes with an effective biomechanical feedback tool to assess movement patterns during sport.

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