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Short communication

Impact of sensor/reference position on player tracking variables: Center of scapulae vs center of pelvis



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ABSTRACT

Electronic performance and tracking systems (EPTS) traditionally rely on one of two body positions as the ultimate representative for the entire body in space: the upper torso between the scapulae (GPS- and radar-based systems) or the body's estimated center (optical and some radar-based systems). The aim of this study was to quantify the impact of the respective reference point upon the resulting kinematic tracking variables. We present a marker-based method comparing center of pelvis (COP) derived tracking variables with center of scapulae (COS) derived tracking variables in a 30×30 m (900 m^2) VICON measurement area. Fourteen male soccer players completed a running circuit with prescribed team-sport specific movements. Results showed that differences between COP and COS heavily depend on the underlying movement characteristic. Low-speed running showed the lowest deviations whereas accelerated movements and movements with sharp changes in direction lead to a significant increase in the observed differences. Results further showed that COS sprinting distance was on average -44.65% ($p < 0.001$) lower in comparison to COP. Similarly, maximum speed obtained from COS was -2.94% ($p = 0.001$) lower in comparison to COP. On the contrary, maximum acceleration values of COS were on average 16.15% ($p = 0.02$) higher compared to COP. Our work illustrates that the anatomical reference point used to represent the entire body in space needs to be carefully considered in the interpretation of tracking variables delivered by different EPTS.

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1. Introduction

Monitoring players' locomotor demands during both training and competition is a common practice in professional team sports (Buchheit et al., 2014; Carling, 2013; Stevens et al., 2014). As a matter of fact, it is not uncommon for some players to be tracked by two or three different electronic performance and tracking systems (EPTS) during a regular week (Buchheit and Simpson, 2017). Consequently, interchangeability and agreement between different EPTS are of key importance to allow for a substantiated assessment of a player's external load and to integrate the data of different EPTS in a meaningful way. As a result, scientific literature provides various validation studies that aim at quantifying the difference or agreement between different EPTS (Linke et al., 2018; Buchheit et al., 2014; Johnston et al., 2014; Randers et al., 2010; Siegle et al., 2013). The key finding of these studies is that a between-systems agreement in terms of locomotor activity (e.g. distance

covered, number of sprints and accelerations) proved problematic. Causes for these inconsistencies between different EPTS can primarily be traced to fundamental differences in the underlying technology (global positioning systems (GPS), radar-based local positioning systems (LPS), or semiautomatic camera systems) and data processing procedures, which are often chosen at the discretion of the manufacturer (Malone et al., 2017).

Apart from this, less attention was given to the aspect of the chosen anatomical reference point on the human body. Whereas wearable sensor systems (GPS and LPS units) are either attached to the upper thoracic spine between the scapulae (center of scapulae COS) or, in some cases, to the lumbosacral region of the spine, semiautomatic camera systems typically identify a pixel-based bounding box to estimate the body's center, hereinafter referred to as center of pelvis (COP) (Manaffard et al., 2017). Obviously, using different anatomical reference positions provides additional potential for inconsistencies to occur when comparing metrics provided by different EPTS. Therefore, the aim of this study was to quantify the differences between COP and COS derived tracking variables. The results could contribute to an improved understanding of performance parameters provided by EPTS.

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2. Methods

2.1. Participants

Fourteen male elite youth soccer players (age: 17.4 ± 0.4 years, height: 178.6 ± 4.2 cm, body mass: 70.2 ± 6.2 kg) playing for the German Bundesliga team FC Augsburg participated in the study. Voluntarily signed informed consent to participate in the study was provided by both the players and their parents. Institutional board approval for the study was obtained from the Ethics Commission of the Technical University of Munich.

2.2. Protocol

Five adhesive marker mounts were glued on each participant's skin (acromio-clavicular joint of the right (RSHO) and left (LSHO) shoulder, left anterior superior iliac spine (LASI), right anterior superior iliac spine (RASI), and first sacrum vertebra (SACR)) (Fig. 1). The reflective markers were then fixed to the mounts through a tight-fitting compression shirt. COP was estimated by means of the reconstructed pelvis method (Saini et al., 1998), defined as the spatial center of RASI, LASI, and SACR. COS was defined as the spatial center of RSHO and LSHO.

A circuit with seven different exercises was used to analyze elementary movements of the kind typically encountered in field-based team sports: (1) 15 m sprint followed by 5 m deceleration, (2) 20 m sprint, (3) 10 m backward running followed by 10 m forward sprinting, (4) 505 agility test (maximum 180° turning ability), (5) 90° turns, (6) curved runs, and (7) low-speed recovery runs between exercises (<6 km·h⁻¹).

2.3. Data acquisition and processing

A 33-camera motion capture system (VICON, Oxford, UK) was utilized to determine marker positions at a frequency of 100 Hz. Retro-reflective 38.0 mm markers were used to assure stable recognition of the markers within the measurement area (30.0×30.0 m, 900.0 m²). Raw displacement data was low pass filtered (4th order Butterworth) with a cut-off frequency of 10 Hz. Speed (scalar magnitude of velocity, as per rate of change

in position) and acceleration (as per rate of change in speed) were derived from the filtered displacement data. Vertical (Z) displacement was neglected since EPTS typically report an athlete's motion in the horizontal plane (XY-coordinates). Kinematic deviations between COP and COS (momentary position, speed, and acceleration) were calculated both from an entire circuit (pooled) as well as for each of the seven exercises individually. Key performance indicators (KPI) were additionally calculated from the displacement data of an entire circuit (i.e. maximum speed, maximum acceleration, and distance traveled while running with different ranges of speed (low-speed (<6 km·h⁻¹), moderate-speed (6 – 15 km·h⁻¹), elevated-speed (15 – 20 km·h⁻¹), high-speed (20 – 25 km·h⁻¹), and sprinting (>25 km·h⁻¹)). Data were analyzed with MATLAB (Release 2017b, The MathWorks, Inc., Natick, MA) based on marker trajectories processed with Vicon Nexus (Version 2.3).

2.4. Statistical analysis

Deviations between COP and COS are presented as root mean square error (RMSE): dRMSE (m): distance RMSE (horizontal distance between COP and COS); vRMSE (m·s⁻¹): instant speed RMSE, and aRMSE (m·s⁻²): instant acceleration RMSE. Each participant completed the circuit twice. Final analysis includes the mean of the resulting values. Non-parametric test procedures were used because the data was not normally distributed. Wilcoxon signed-ranks tests were used to test if the RMSEs between COP and COS differ from zero. Non-parametric Friedman tests were used to test whether the RMSEs differ between exercises. Dunn's test was used to for post-hoc comparisons of Friedman's results. Cohen's d and Kendall's W coefficient of concordance were calculated to measure the size of effects (Cohen, 1992). Descriptive statistics are presented as mean and standard deviation (SD). Statistical significance was set at $p < 0.05$.

3. Results

3.1. Position, speed and acceleration deviation

Wilcoxon Signed-Ranks tests showed that dRMSE ($Z = 3.29$, $p < 0.001$, $d = 0.88$), vRMSE ($Z = 3.33$, $p < 0.001$, $d = 0.89$) and

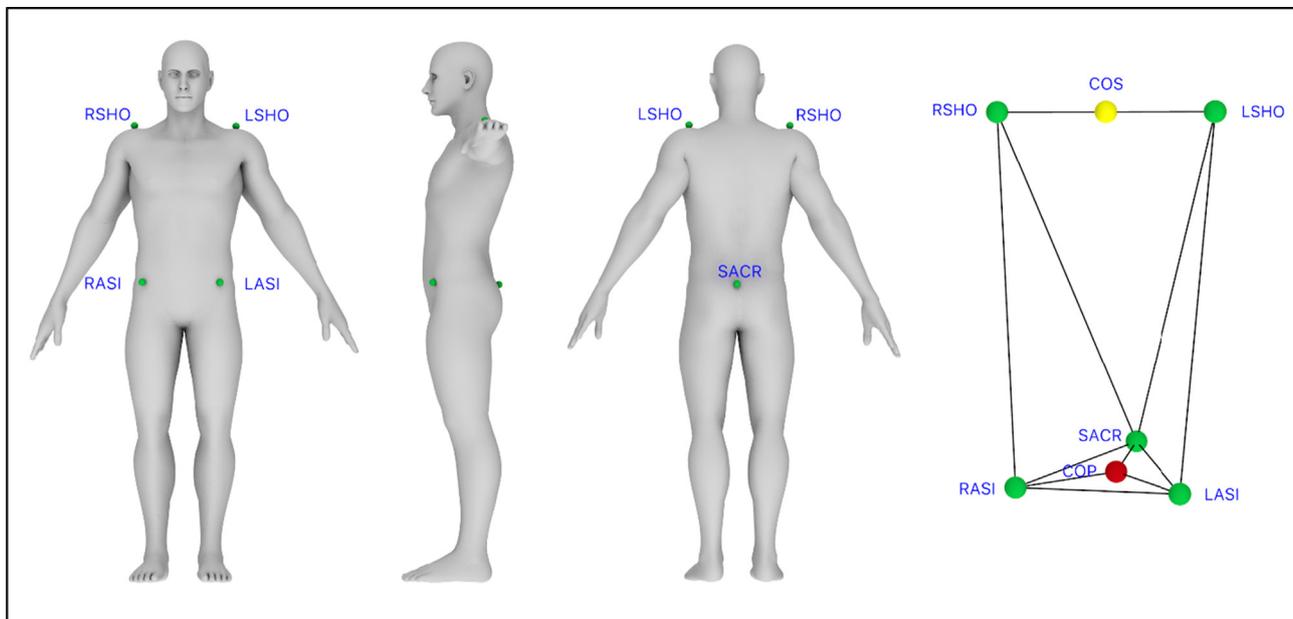


Fig. 1. Marker positions on the human body. Center of pelvis (COP) in red, center of scapulae (COS) in yellow. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1

Mean deviation (root mean square error RMSE) between COP and COS based on all data points of each subject ($n = 14$). One-sample Wilcoxon Signed Rank Tests were used to test if the deviations between COP and COS were significantly different from zero. Standardized (Z) test statistic and resulting effect sizes (Cohen's d) are also displayed. CI = 95% confidence intervals. dRMSE = distance root mean square error (spatial horizontal distance between COP and COS); vRMSE = instant speed root mean square error; aRMSE = instant acceleration root mean square error.

	Mean \pm SD	5–95% CI	Z	p	d
dRMSE (cm)	11.32 \pm 1.61	[11.00, 12.32]	3.29	< 0.001	0.88
vRMSE ($m \cdot s^{-1}$)	0.24 \pm 0.02	[0.24, 0.27]	3.33	< 0.001	0.89
aRMSE ($m \cdot s^{-2}$)	4.68 \pm 0.50	[4.47, 5.03]	3.29	< 0.001	0.88

aRMSE ($Z = 3.29$, $p < 0.001$, $d = 0.88$) were significantly different from zero (Table 1). Non-parametric Friedman tests of RMSE differences among exercises rendered Chi-square values of 68.48 (dRMSE, $p < 0.001$, $W = 0.82$), 67.69 (vRMSE, $p < 0.001$, $W = 0.81$), and 61.96 (aRMSE, $p < 0.001$, $W = 0.74$). dRMSEs were smallest during recovery runs (7.31 ± 1.75 cm) and highest during 20 m sprints (22.65 ± 2.56 cm) and 505 agility tests (dRMSE = 24.75 ± 1.73 cm). Deviations in instantaneous speed and acceleration were also smallest during recovery runs (vRMSE = 0.16 ± 0.02 $m \cdot s^{-1}$; aRMSE = 2.79 ± 0.32 $m \cdot s^{-2}$) but highest during 90° turns (vRMSE = 0.52 ± 0.05 $m \cdot s^{-1}$; aRMSE = 9.91 ± 1.25 $m \cdot s^{-2}$) (Fig. 2). vRMSE was significantly higher during exercises with multidirectional movements (90° turns, curved runs, and 505 agility tests) compared to straight line movements (Fig. 2).

3.2. Key performance indicators KPI

Percentage deviations between KPIs derived by either COP or COS ranged from -0.32% (total distance) to -44.65% (sprinting distance), indicating that the magnitude of deviations increases with increasing speed of motion, which is also supported by large effect sizes ($d > 0.80$) in the elevated, high-speed, and very high-speed categories (Table 2).

4. Discussion

This study examined the impact of two anatomical reference points that are commonly used to represent the human body in

space on kinematic tracking variables. Results show that the applied reference point has a significant influence on the athlete's momentary position, speed, and acceleration. Consequently, resultant KPIs also differ between COP and COS, sometimes considerably. Highest percentage deviations were found in the sprinting distance and maximum acceleration category. Since these KPIs are amongst the most important variables to be tracked in sports practice (Buchheit and Simpson, 2017), it is advised that coaches and practitioners consider the component of the technology-related anatomical reference point in their interpretation of EPTS derived tracking variables.

4.1. Spatial deviation dRMSE

Highest deviations in the horizontal plane were observed during movements with high accelerations/decelerations and sharp changes in direction (e.g. 505 agility tests, see Fig. 2), which is most probably an effect of the upper body's inclination angle. During the initial stage of sprinting, athletes tilt their upper body forward to direct ground reaction forces in the horizontal direction. As they approach their maximum speed, the torso is lifted gradually into an upright position (Mero et al., 1992). Accordingly, COS is positioned in front or behind COP, depending on the upper body's tilt. Similarly, sharp turns are associated with a lateral inclination of the upper torso (to counteract the occurring centrifugal forces) and COS is shifted laterally in relation to COP. Collectively, these circumstances indicate that the spatial deviation between COP and COS heavily depends on the underlying movement characteristic, resulting in an average dRMSE of 11.6 ± 1.6 cm (Fig. 2).

4.2. Momentary speed and acceleration deviation vRMSE & aRMSE

Momentary speed and acceleration deviation between COP and COS increased with speed and change in direction, which could be explained by the fact that the coupling strength between thorax and pelvis is inversely related to the movement frequency (Lamoth et al., 2002; Beek et al., 1995). Accordingly, the in-phase coordination present at low walking speeds gradually evolves towards antiphase coordination as the speed increases (Lamoth et al., 2002), resulting in an average deviation of 0.26 ± 0.03 $m \cdot s^{-1}$ in speed, and 4.78 ± 0.65 $m \cdot s^{-2}$ in acceleration, respectively (Fig. 2).

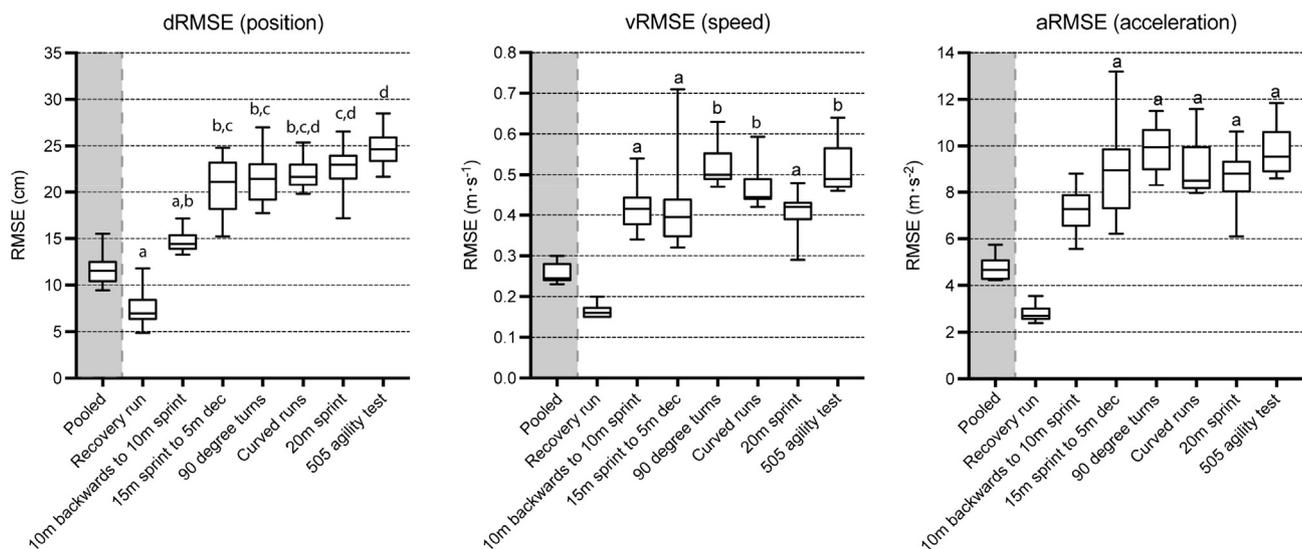


Fig. 2. Spatial deviation (dRMSE), instant speed (vRMSE) and instant acceleration (aRMSE) deviation depending on the exercise. Dunn's post hoc analyses were used to identify homogeneous exercise subsets (a, b, c, d: groups with the same letter designation are not significantly different. All other groups differ significantly from each other).

Table 2
Results of non-parametric Wilcoxon signed-ranks tests of KPI differences between COP and COS (n = 14). The percentage difference (% Diff) is presented from the COS perspective, i.e. a negative %Diff means that COS underestimates the respective KPI in comparison to COP. d = Cohen's d effect sizes. Z = standardized test statistic.

Metric	COP		COS		Z	p	d	% Diff
	Mean	±SD	Mean	±SD				
Total distance (m)	327.00	±15.25	326.42	±14.96	2.98	0.003	0.80	−0.32%
Low-speed distance (m)	89.46	±22.30	91.30	±22.45	2.35	0.018	0.63	2.01%
Moderate-speed distance (m)	114.02	±22.64	114.86	±21.82	1.29	0.119	0.30	0.73%
Elevated-speed distance (m)	48.46	±2.91	53.85	±4.12	3.29	0.001	0.88	10.00%
High-speed distance (m)	55.36	±4.76	52.45	±5.32	2.98	0.003	0.80	−5.56%
Very high-speed distance (m)	19.27	±1.80	13.32	±3.01	3.29	0.001	0.88	−44.65%
Maximum speed (m·s ^{−1})	8.01	±0.15	7.78	±0.20	3.30	0.001	0.88	−2.94%
Maximum acceleration (m·s ^{−2})	24.93	±4.07	29.73	±2.71	3.11	0.019	0.83	16.15%
Maximum deceleration (m·s ^{−2})	−23.30	±2.27	−22.36	±2.55	1.01	0.265	0.29	−4.23%

4.3. Key performance indicators KPI

Maximum speed derived by COP was on average 3% higher than maximum speed derived by COS, possibly caused by the torso's tilting behavior during the transition from accelerated to decelerated running. Due to the relatively short sprint distance in this study (20 m), subjects reached maximum speed during the phase transition from acceleration to deceleration. At the same time, the torso's forward lean present in the acceleration phase transitions into a posterior lean during deceleration (Hewit et al., 2011), shifting COS posterior in relation to COP, which results in an earlier deceleration of COS compared to COP. Our results, therefore, suggest that COS underestimates maximum speed values during acceleration phases.

It was further shown that maximum accelerations derived by COS were on average 16% higher than those derived by COP, most probably due to the fact that, during acceleration, the flexion and extension of the trunk results in an increased range of motion of the upper torso compared to the pelvis (Schache et al., 1999). Contrastingly, maximum decelerations derived by COS were on average 4% lower than those derived by COP. Since the upper body plays an important role in damping gait-related oscillations during locomotion (Kavanagh et al., 2004), higher ground contact-induced decelerations in the pelvis region are well comprehensible.

The difference in the total distance covered category was statistically significant but rather trivial with respect to the percentage deviation (<1%). Similar results were found in low-speed (2%) and moderate-speed categories (<1%). However, deviations tended to increase as speed increased. COS derived distances in the elevated speed category were on average 10% higher than those derived by COP. On the contrary, COS derived distances in the highest speed categories (high speed & sprinting) were on average significantly smaller (−6% & −45%). A possible explanation for the significant underestimation of high-speed distances derived by COS could be grounded in COS's underestimation of maximum speed. As COP generally spent more time in high-speed categories, it is not surprising that the aggregated distances covered with high-speed differ considerably. Since high-speed distances account for only a small proportion of the total distance, small differences in this category can ultimately lead to high percentage deviations between COP and COS.

It should be mentioned that the raw data characteristics and data processing steps used in this study may not necessarily be comparable to data processing steps commonly applied in the field to EPTS. Whereas we decided to use a measurement device with the best possible spatiotemporal accuracy to investigate the original research question, there are no generally accepted definitions of required signal properties, optimal sampling rate or algorithmic specifications in the field of EPTS. As a result, tracking data obtained from different EPTS may vary, sometimes considerably,

and thus transferability of results inevitably depends on the particular data processing procedures of the respective EPTS.

5. Conclusions

This study quantified the impact of two anatomical reference points (COP and COS) on resultant kinematic parameters. While only trivial deviations (<1%) were observed in total distance measures, high deviations were found in high-speed running distance (45%), maximum speed (3%), maximum acceleration (16%) and deceleration (4%) categories. Our results illustrate that the anatomical reference point used to represent the entire body in space needs to be carefully considered in the interpretation of tracking variables delivered by different EPTS.

Conflicts of interest

The authors declare no financial or personal relationships with other persons or organizations that might inappropriately influence our work presented herein.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jbiomech.2018.11.046>.

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