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Movement characteristics of international and elite domestic netball players during match-play

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ABSTRACT

This study quantified and compared the movement characteristics of elite domestic and international netball match-play, including fifteen individual players who compete at both levels. Microtechnology data were collected across 75 matches in a league-wide study from players ($n = 113$) competing in the Netball Superleague (elite domestic) and from international players ($n = 23$) in 22 international matches. Players were categorised according to the seven playing positions. Accelerometer-derived variables were analysed per whole-match and per quarter, for both absolute (i.e. volume) and relative to duration (i.e. intensity [per minute]) values. The median playing duration ranged across positions from 23.6 to 42.4 minutes at international and 31.6 to 48.1 minutes at domestic level. International matches were greater than elite domestic competition for relative variables across all positions. *Moderate* to *large* effect sizes (1.00–1.50) were found between playing levels for PlayerLoad™ per minute (AU·min^{-1}). Significant decreases in both absolute and relative variables were observed across quarters for both competition levels. The movement characteristics are position dependent, with greater absolute characteristics at domestic level across whole-match analysis, but greater relative characteristics at international level. These findings provide practitioners with information to guide training prescription, return-to-play protocols, and transitioning athletes between levels of competition.

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KEYWORDS
Netball; movement characteristics; microtechnology; inertial measurement units; international; match demands

1. Introduction

Netball is an intermittent court-based sport in which high-intensity multidirectional movements are performed, interspersed with short periods of lower-intensity activity (Fox et al.,

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2013; Mackay et al., 2023). A netball team consists of seven players, each with an individual playing position. Each position is restricted to specific court areas resulting in each position requiring a different combination of physical and technical capabilities (Sweeting et al., 2017). Quantifying the movement characteristics of matches is common in many team sports and is required to ensure training prepares players for the demands of the sport (Bourdon et al., 2017; Theodoropoulos et al., 2020). For players to perform optimally they must be prepared for the demands of their playing position(s), and their level of competition. Players can also be involved at different levels of competition (e.g. club and international) or be progressing to higher levels of competition. Therefore, it is necessary to understand the movement characteristics of the sport at varying levels to support player development and inform training prescription (Bourdon et al., 2017; Noor et al., 2019).

There is currently no data regarding netball match-play movement characteristics using microtechnology at the international level. Other sports, such as rugby league (Whitehead et al., 2019), rugby union (Beard et al., 2019), and soccer (Andersson et al., 2010; Scott et al., 2020) have identified differences in movement demands between domestic and international standards. With a practitioner's aim of optimising athlete performance to progress to higher standards of competition, or to physically prepare athletes to transition between different levels of competition, understanding if the match demands required at each level (for each playing position) differ, and to what extent, can assist in practice (Whitehead et al., 2019).

Microtechnology units are widely used in research and applied settings to quantify the movement characteristics of team sports (Cummins et al., 2013). Indoor court-based team sports can utilise local positioning systems (LPS) and inertial movement units (IMU) that comprise tri-axial accelerometers, gyroscopes, and magnetometers. Accelerometer-derived PlayerLoad™ (Catapult Innovations, Melbourne, Australia) is a reliable arbitrary unit (AU) metric used widely in team sports to establish the total volume of activity completed (Barrett et al., 2014; Nicolella et al., 2018). PlayerLoad™ has been used in netball to investigate the differences between training and matches at the elite domestic level in Australia (Brooks et al., 2021; Simpson et al., 2020), between different playing positions (Graham et al., 2020; van Gogh et al., 2020; Young et al., 2016) and levels (amateur domestic *vs*. representative (King et al., 2020); state *vs*. recreational (Cormack et al., 2014)).

Whilst PlayerLoad™ can be used in a practical setting (e.g. as a monitoring tool to evaluate the overall demand a player has been exposed to over time), the specific application of PlayerLoad™ may be limited due to the various aspects that contribute to the accumulation of total PlayerLoad™ (e.g. type of movement). The IMU can however detect and quantify specific movements completed frequently in netball (i.e. accelerations, decelerations, jumps, and changes of direction [COD]). These metrics can be used to quantify and understand the specific demands relevant to the multidirectional movements and repeated efforts performed in netball (Brooks et al., 2020; Fox et al., 2013; Simpson et al., 2020, 2020). Studies quantifying specific movements of different playing positions at the elite level identified that Goal Keeper and Goal Shooter perform the highest number and frequency of jumps, alongside Goal Attack (Brooks et al., 2020; Simpson et al., 2020). The playing positions with fewer court restrictions (Goal Attack, Wing Attack, Centre, Wing Defence, Goal Defence) were found to complete a higher number of lower-intensity movements (i.e. accelerations, decelerations, COD and jumps between 1.0 and 1.9 $m.s^{-1}$) (Simpson et al., 2020). The differences in jump frequency between the defensive Goal Defence and Goal Keeper positions (0.78 *vs*. 1.03 n·min^{-1}) suggest that playing positions are required to be further investigated individually rather than as positional groups (e.g. defence, midcourt, shooters) (Simpson et al., 2020). However, current research is limited to the investigation of one club per study cohort.

Research studies quantifying netball movement characteristics of match-play have focused on investigating players from one club, limiting the generalisability of the findings as the movement characteristics may be impacted by a team's playing style, tactics and/or individual personnel (Austin & Kelly, 2014; Sweeting et al., 2017). Therefore, more research involving multiple teams is required for a more heterogenous sample to further understand the match-play movement characteristics of the sport, positional differences, and the variability between matches (Whitehead et al., 2021). Additionally, research at the elite level is currently limited to one competition (i.e. Suncorp Super Netball, Australia) with no current research available in other elite competitions in their present format. Further research is required to establish the league-wide match-play movement characteristics of different elite domestic competitions across the world such as the Netball Superleague (NSL), the highest level in the United Kingdom (UK). This is important to quantify the movement characteristics of different domestic competitions and compare to international level competition at an individual player level.

The aim of this study was therefore to quantify and compare the whole-match and quarter movement characteristics for the team and individual positions in elite domestic and international level match-play. A secondary aim was to explore the movement characteristics of players competing in both elite domestic and international netball. Knowledge of the characteristics for different playing positions, at different playing levels will provide practitioners with information to assist in training prescription and planning to physically prepare athletes for competition.

2. Methods

2.1. Experimental design

A prospective observational design was used to quantify the movement characteristics of elite domestic club and international netball match play. Microtechnology data were collected from 75 matches across the 2022 domestic NSL season and 22 matches across two international seasons from 2021 to 2022. Match observations per player were 5.3 ± 5.2 (range: 1–21) and 10.5 ± 6.0 (range: 2–20) respectively, resulting in 843 player match observations. Movement characteristics for each playing position were quantified at the two levels, with differences between, and variability within the levels compared.

2.2. Participants

All eleven elite domestic clubs (n = 132 players) competing in the NSL were invited to participate in the study. One hundred and thirteen female netball players from ten elite domestic clubs competing in the NSL (mean ± SD, age = 25.7 ± 4.4 years) and twenty three international netball players (mean ± SD, age = 28.1 ± 5.5 years) from one international team participated in the study. Fifteen players were in both the elite domestic and international groups which was accounted for when analysing data. The study was approved by Leeds Beckett University ethics committee, and written informed consent was obtained from all participants.

2.3. Procedures

All players wore a Catapult Vector S7 microtechnology device (Catapult Innovations, Melbourne, Australia) comprising a 100 Hz tri-axial accelerometer, gyroscope, and magnetometer. The validity and reliability of Catapult devices for measuring accelerometer-derived PlayerLoad^{TM}, count of inertial movement analysis (IMA) metrics (Luteberget et al., 2018), and jumps (Spangler et al., 2018) have been established. All players were familiarised with wearing the microtechnology devices prior to study commencement. The devices were positioned between the scapulae, worn in tightly fitted sports vests at elite domestic level and worn within custom-made pouches on the netball match kit at the international level. At the international level, and where possible at the domestic level, players were assigned the same device for each match they participated in to minimise inter-device error (Buchheit & Simpson, 2017). All matches were played indoors on wooden sprung courts for 60 minutes over four 15-minute quarters.

Given the unique demands of each position (Sweeting et al., 2017; van Gogh et al., 2020), players were categorised according to their playing position for each quarter of each match. As it is common in netball for players to play multiple positions within a match (e.g. Goal Shooter and Goal Attack, or Centre and Wing Defence) positional observations are given per number of quarter observations – Goal Shooter international $n = 93$, domestic $n = 250$; Goal Attack international $n = 93$, domestic $n = 344$; Wing Attack international $n = 92$, domestic $n = 240$; Centre international $n = 96$, domestic $n = 262$; Wing Defence international $n = 103$, domestic $n = 300$; Goal Defence international $n = 94$, domestic $n = 314$; Goal Keeper international $n = 96$, domestic $n = 248$. For whole-match analysis, players' on-court playing position was still considered (i.e. if a player plays 30 minutes at Goal Shooter and 30 minutes at Goal Attack, two separate match observations were recorded). Match observations were only excluded if a players' total match time at any playing position was less than five minutes (Sampaio et al., 2006) (i.e. players did not have to complete a full quarter to be included).

2.4. Data analysis

After each match, the microtechnology data were extracted and downloaded using the accompanying propriety software (Openfield v3.4.0, Catapult Innovations, Melbourne, Australia). The raw data traces were aligned with the match footage to ensure accurate start and end times for each quarter within the match. The data were cut to include only the four playing quarters for each match, and all breaks between quarters were excluded (Brooks et al., 2020). Players were only included in a quarter if they took to the court during this time. If a player was substituted during a quarter, only the time on-court was included to quantify the movement characteristics of match-play. The aligned video footage was used to ensure this was accurate. Players were assigned their playing position for each quarter. If a team change was made, and a player switched position during a quarter this was reflected in the dataset (e.g. a player plays 8 minutes at Goal Attack then 7 minutes at Goal Shooter during one quarter). If an injury occurred and the umpire extended the standard allocated injury time, this duration was excluded from analysis. Data were analysed in this way to accurately reflect the movement characteristics of live match-play.

Accelerometer-derived PlayerLoad^{TM} (AU) and PlayerLoad$^{TM}{}_{2D}$ (AU) metrics were analysed as per previous research (Brooks et al., 2020). Additionally, IMU derived jumps (*n*), accelerations (*n*), decelerations (*n*) and CODs (*n*) were analysed as per previous studies (Simpson et al., 2020). Jumps have been analysed and reported as an individual metric; however, acceleration and deceleration counts have been combined with COD counts (acc-dec-COD) based on the reliability findings of total IMA from Luteberget et al. (2018) and preliminary findings investigating the validity of discrete movements detected by IMU in netball. These variables were analysed as absolute (volume demands) values. Variables were also analysed relative to duration in minutes (intensity demands): PlayerLoad^{TM} per minute (AU·min^{-1}), acc-dec-COD per minute (n·min^{-1}) and jumps per minute (n·min^{-1}). All metrics included are defined in supplementary table S1. Metrics were analysed for the whole-match, and per quarter at an individual player level (i.e. for the duration of time on-court).

2.5. Statistical analysis

General and generalised linear mixed models were used to quantify and compare the whole-match and quarter movement demands for the team and individual positions in elite domestic and international level match-play. Continuous variables (e.g. PlayerLoad^{TM}) were analysed using general linear mixed models, and count variables (e.g. jumps) were analysed using generalised linear mixed models assuming a negative binomial distribution (Gardner et al., 1995; Weaving et al., 2019). To compare at the whole-match level, playing level, playing position and the interaction between playing level and playing position, were specified as fixed effects (Whitehead et al., 2019). To compare at the quarter level, playing level, playing position, quarter, and the fully factorial interaction between the three variables were included as fixed effects. In all models, player, match, and player nested within playing level were set as random effects to account for variability (Delaney et al., 2016; Whitehead et al., 2019). In all models, pairwise differences between playing levels and among playing positions were obtained and differences between quarters were also established in quarter models.

To establish players' movement characteristics at different levels of competition, the predicted movement demands of the 15 players that played in both elite domestic and international matches were extracted from each model. These values were calculated by adding each player's individual intercept (taken from the player random effect) and competition (taken from the player nested within playing level random effect) adjustments to the fixed effects model. No statistical analysis was performed on these differences as this is already provided within the main effects analysis described above.

The coefficient of variation (CV) was used to assess between match variability within each of the playing levels. CV was calculated using mean and standard deviation for continuous variables and using the standardised median absolute deviation (MAD) and median for count data (Crang et al., 2022). CV was classified as *low* (≤5%), *moderate* (<10%), or *high* (≥10%) (Crang et al., 2022; Dalton-Barron et al., 2021). Due to its unconventional distribution, duration data are presented as median and interquartile range (IQR) and were modelled using kernel density instead of linear mixed models. Density plots are provided for each position in each competition using the same bandwidth for each plot following the methodology of a previous study (Sawczuk et al., 2022). These provide an understanding of the differences in playing duration between playing positions and playing level.

All modelled variables are presented as estimated means (95% confidence interval [CI]). Cohen's *d* effect size (ES) statistic was used to provide a standardised measure of differences for all continuous variables and classified as *trivial* (<0.2), *small* (0.2–0.59), *moderate* (0.6–1.19), *large* (1.2–1.99), *very large* (2.0–4.0), or *extremely large* (>4.0) (Hopkins et al., 2009). Rate ratios (RR) were used to determine differences between all modelled count, and relative count, data. The RR was classified as *trivial* (0.90–1.11), *small* (0.7–0.9 or 1.11–1.43), *moderate* (0.50–0.70 or 1.43–2.00) and *large* (<0.50 or > 2.00) (Rennie et al., 2021). All statistical analysis was computed using R (R. 4.2.2, R Foundation for Statistical Computing, Vienna, Austria).

3. Results

Whole match playing duration descriptive data and density plots for both domestic and international levels, per playing position, are presented in Figure 1.

Estimated means and 95% CI for absolute and relative metrics per playing position for domestic and international level match-play are presented in Tables 1 and 2. All absolute and relative variables per playing position for each quarter are provided in supplementary tables S2–5. Differences between playing levels and playing positions exist across all absolute and relative variables ($p < 0.05$).

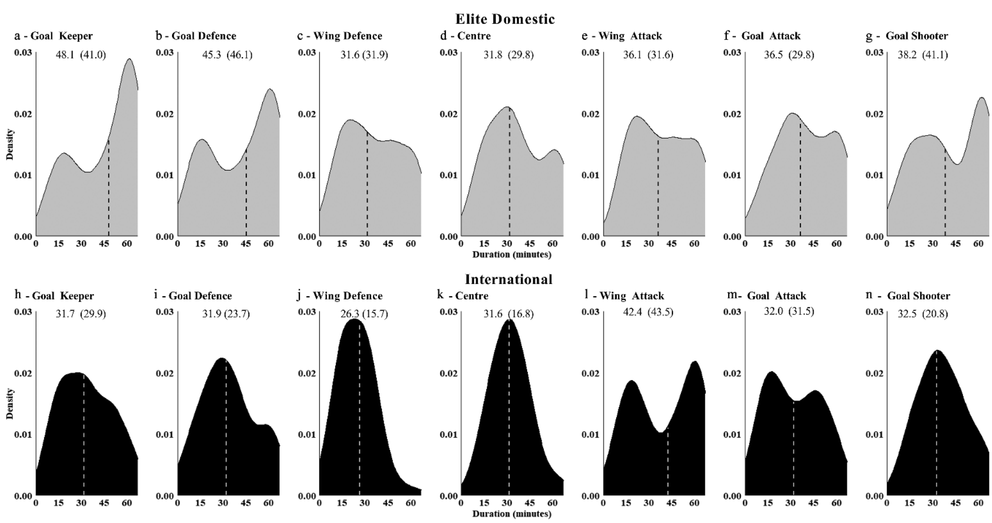

Figure 1. Density plots with median highlighted as dashed line and median (IQR) displayed above each plot, for total match duration played (in minutes), for each position, at elite domestic (grey [a – g]) and international (black [h – n]) level – Goal Keeper (a&h), Goal Defence (b&i), Wing Defence (c&j), Centre (d&k), Wing Attack (e&l), Goal Attack (f&m), Goal Shooter (g&n).

Table 1. Estimated means, 95% CI, %CV and ES or RR (indicated in the table) between levels of competition for whole-match absolute variables across each playing position, for international (INT) and elite domestic (DOM) competitions.

		Playing Position																				
		Goal Keeper			Goal Defence			Wing Defence			Centre			Wing Attack			Goal Attack			Goal Shooter		
Variable	Level	*Mean (95% CI)*	*% CV*	*ES*	*Mean (95% CI)*	*% CV*	*ES*	*Mean (95% CI)*	*% CV*	*ES*	*Mean (95% CI)*	*% CV*	*ES*	*Mean (95% CI)*	*% CV*	*ES*	*Mean (95% CI)*	*% CV*	*ES*	*Mean (95% CI)*	*% CV*	*ES*
PlayerLoad™ (au)	DOM	257[g] (204–311)	42.3	0.37	362[d e] (318–406)	48.6	0.70	375* (333–418)	51.6	1.15	386[d e] (343–430)	53.8	0.15	357 (310–404)	49.0	0.25	375[d e] (331–419)	47.1	0.12	234[f g] (185–283)	49.9	0.58
	INT	208 (120–269)	48.5		268 (180–356)	50.8		221 (147–295)	43.7		366[g] (283–448)	39.0		324 (234–414)	55.2		358 (269–448)	54.7		312 (220–403)	48.3	
PlayerLoad™$_{2D}$ (au)	DOM	165[g] (131–198)	42.2	0.27	225[d e] (197–253)	49.0	0.57	232* (205–259)	52.7	1.02	235[d e] (208–263)	54.1	0.04	220 (190–249)	49.0	0.11	229[d e] (201–257)	47.3	0.05	148[f g] (117–179)	50.0	0.69
	INT	142 (86–197)	49.0		177 (121–232)	50.9		146 (99–193)	44.0		239[g] (187–291)	40.0		210 (154–267)	55.5		233 (178–290)	55.5		206 (148–263)	47.9	
		Mean (95% CI)	*% CV*	*RR*	*Mean (95% CI)*	*% CV*	*RR*	*Mean (95% CI)*	*% CV*	*RR*	*Mean (95% CI)*	*% CV*	*RR*	*Mean (95% CI)*	*% CV*	*RR*	*Mean (95% CI)*	*% CV*	*RR*	*Mean (95% CI)*	*% CV*	*RR*
Acc-dec-COD (n)	DOM	423 (353–508)	39.7	0.79	488 (420–567)	38.5	0.80	523* (454–602)	70.5	0.68	497[e] (431–574)	59.9	1.11	515 (441–602)	64.9	0.81	541[e] (468–625)	54.1	0.89	361[f g] (307–425)	71.8	1.25
	INT	335 (235–444)	75.9		392 (294–523)	56.9		357 (284–448)	53.5		554[g] (427–719)	43.6		415 (310–557)	77.8		483 (361–646)	67.9		449 (336–600)	51.5	
Jumps (n)	DOM	27.1 (21.7–34.0)	54.4	0.75	22.1 (18.6–26.2)	86.5	0.75	21.7* (18.2–25.9)	78.0	0.63	22.2[b f] (18.6–26.5)	56.0	1.11	31.6 (26.2–38.1)	62.7	0.82	33.2[g] (27.9–39.6)	54.2	0.92	32.7 (26.7–39.9)	78.9	1.27
	INT	20.3 (14.3–28.7)	64.5		14.0[e] (10.6–18.5)	53.9		13.7 (10.3–18.1)	71.9		24.7[g] (18.1–33.8)	71.4		25.8[g] (18.6–35.7)	54.4		30.7[g] (21.6–43.5)	98.0		41.5[g] (29.1–59.2)	59.9	

Abbreviations: DOM, Domestic; ES, effect size; CI, confidence interval; CV, coefficient of variation; INT, International; RR, rate ratios.

*Significantly ($p < 0.05$) different from the equivalent international playing position.
[a]Significantly ($p < 0.05$) different from all positions. [b]Significantly ($p < 0.05$) different from Goal Attack. [c]Significantly ($p < 0.05$) different from Goal Defence. [d]Significantly ($p < 0.05$) different from Goal Keeper. [e]Significantly ($p < 0.05$) different from Goal Shooter. [f]Significantly ($p < 0.05$) different from Wing Attack. [g]Significantly ($p < 0.05$) different from Wing Defence.

Table 2. Estimated means, 95% CI, %CV and ES or RR (indicated in the table) between levels of competition for whole-match relative variables across each playing position, for international (INT) and elite domestic (DOM) competitions.

		Playing Position																				
		Goal Keeper			Goal Defence			Wing Defence			Centre			Wing Attack			Goal Attack			Goal Shooter		
Variable	Level	*Mean (95% CI)*	*% CV*	*ES*	*Mean (95% CI)*	*% CV*	*ES*	*Mean (95% CI)*	*% CV*	*ES*	*Mean (95% CI)*	*% CV*	*ES*	*Mean (95% CI)*	*% CV*	*ES*	*Mean (95% CI)*	*% CV*	*ES*	*Mean (95% CI)*	*% CV*	*ES*
PlayerLoad™ per minute (au·min^{-1})	DOM	6.9*[e f g] (6.5–7.2)	15.1	1.42	9.8*[d e f] (9.5–10.1)	10.1	1.00	9.4* (9.1–9.7)	11.4	1.15	10.7*[a] (10.4–11.0)	10.3	1.40	9.2* (8.9–9.5)	13.0	1.01	9.3[d e] (9.0–9.6)	13.3	1.03	6.0*[f g] (5.6–6.3)	13.0	1.50
	INT	7.7[f g] (7.1–8.3)	11.8		10.4[d e] (9.9–11.0)	9.9		10.1 (9.6–10.6)	12.8		11.6[a] (11.1–12.1)	9.5		9.9 (9.3–10.4)	8.7		9.9[d e] (9.3–10.5)	18.8		6.9[f g] (6.2–7.5)	13.0	
		Mean (95% CI)	*% CV*	*RR*	*Mean (95% CI)*	*% CV*	*RR*	*Mean (95% CI)*	*% CV*	*RR*	*Mean (95% CI)*	*% CV*	*RR*	*Mean (95% CI)*	*% CV*	*RR*	*Mean (95% CI)*	*% CV*	*RR*	*Mean (95% CI)*	*% CV*	*RR*
Acc-dec-COD per minute (n·min^{-1})	DOM	10.9[f g] (10.3–11.6)	15.0	1.01	14.1[d e] (13.4–14.8)	16.7	1.07	13.8* (13.1–14.4)	15.6	1.11	14.9*[b d e g] (14.2–15.6)	17.0	1.16	13.8 (13.2–14.6)	13.0	1.07	13.0[d e] (12.3–13.6)	25.9	0.98	9.8[f g] (9.2–10.3)	13.1	0.96
	INT	11.1[e f g] (10.2–12.0)	19.9		15.0[d e] (14.0–16.1)	26.9		15.3 (14.4–16.2)	12.3		17.2[a] (16.1–18.4)	19.1		14.7 (13.8–15.8)	8.1		12.7[c e f g] (11.8–13.7)	13.1		9.3[f g] (8.7–10.1)	9.5	
Jumps per minute (n·min^{-1})	DOM	0.7 (0.6–0.8)	39.5	0.94	0.8[g] (0.7–0.8)	54.5	0.96	0.6 (0.5–0.7)	45.3	1.05	0.7[e f g] (0.6–0.8)	51.2	1.10	0.9[g] (0.8–1.0)	35.2	1.02	0.8[g] (0.7–0.8)	34.2	1.03	0.9[g] (0.8–1.0)	36.1	1.04
	INT	0.7 (0.6–0.8)	35.6		0.7 (0.6–0.8)	30.0		0.6 (0.5–0.7)	56.9		0.7 (0.6–0.9)	49.9		0.9[g] (0.8–1.0)	33.3		0.8 (0.7–0.9)	46.9		0.9[g] (0.8–1.1)	34.0	

Abbreviations: DOM, Domestic; ES, effect size; CI, confidence interval; CV, coefficient of variation; INT, International; RR, rate ratios.

*Significantly ($p < 0.05$) different from the equivalent international playing position.
[a]Significantly ($p < 0.05$) different from all positions. [b]Significantly ($p < 0.05$) different from Goal Attack. [c]Significantly ($p < 0.05$) different from Goal Defence. [d]Significantly ($p < 0.05$) different from Goal Keeper. [e]Significantly ($p < 0.05$) different from Goal Shooter. [f]Significantly ($p < 0.05$) different from Wing Attack. [g]Significantly ($p < 0.05$) different from Wing Defence.

PlayerLoad™ was higher at the domestic level for six of the seven playing positions (Goal Keeper [ES = 0.37, $p = 0.32$]; Goal Defence [ES = 0.70, $p = 0.06$]; Wing Defence [ES = 1.15, $p < 0.01$]; Centre [ES = 0.15, $p = 0.66$]; Wing Attack [ES = 0.25, $p = 0.52$] and Goal Attack [ES = 0.12, $p = 0.75$]). Whilst PlayerLoad™ per minute ($AU{\cdot}min^{-1}$) was higher at the international level across all playing positions with *moderate* differences for Goal Defence ($p = 0.047$), Wing Defence ($p < 0.01$), Wing Attack ($p = 0.045$) and Goal Attack ($p = 0.06$), and *large* differences for Goal Keeper ($p = 0.01$), Centre ($p < 0.01$) and Goal Shooter ($p < 0.01$). *Large* (≥10% CV) within-level between match variability was found across whole-match variables, particularly jump count (CV = 54.2% to 98.0%), with the exception of PlayerLoad™ per minute in which *moderate* to *large* variability was established (CV = 8.7% to 18.8%).

The absolute PlayerLoad™, PlayerLoad™ per minute, jump count and acc-dec-COD count per quarter are displayed in Figure 2. A significant decrease in PlayerLoad™ per minute and jump count ($p < 0.01$) from quarter one to all other quarters was found at the domestic level, with a significant decrease from quarter one to all other quarters in absolute PlayerLoad™ and acc-dec-COD count ($p < 0.01$) found at both levels of

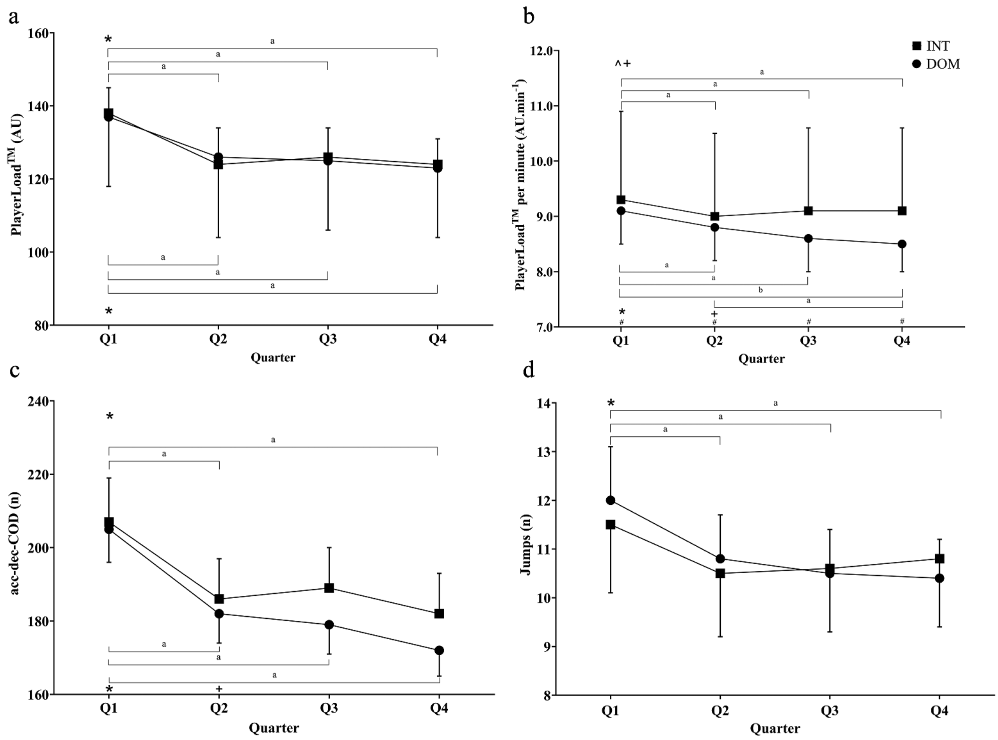

Figure 2. Estimated means and 95% CI across all playing positions for PlayerLoad™ (a), PlayerLoad™ per minute (b), acc-dec-COD count (c) and jump count (d) per quarter at elite domestic (DOM) and international (INT) level.
*Significantly ($p < 0.05$) different from all other quarters; ^Significantly ($p < 0.05$) different from quarter 2; +Significantly ($p < 0.05$) different from quarter 4 (within the same level of competition). Effect sizes (Figures a & b) and rate ratios (Figures c & d) between quarters: a, small; b, moderate. Effect sizes between levels of competition: #, small.

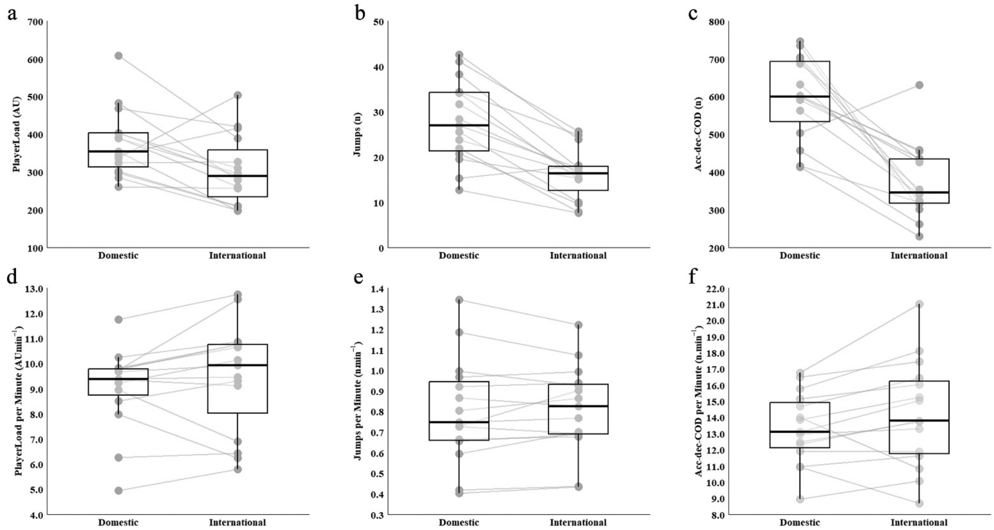

Figure 3. Differences in absolute PlayerLoad^{TM} (a), jump count (b), acc-dec-COD count (c), relative PlayerLoad^{TM} per minute (d), acc-dec-COD per minute (e) and jumps per minute (f) between domestic and international level for players in both levels of competition ($n = 15$). Boxplots show the median and interquartile range with lines identifying individual cases (participant and level).

competition. PlayerLoad^{TM} per minute deceased by 0.6 AU·min^{-1} (9.1 AU·min^{-1} to 8.5 AU·min^{-1}, ES = 0.64, $p < 0.01$) between quarter one and quarter four at the domestic level, and by 0.3 AU·min^{-1} (9.5 AU·min^{-1} to 9.2 AU·min^{-1}, ES = 0.30, $p = 0.04$) at the international level (Figure 2b).

The whole-match differences between positions at both levels of competition are shown in supplementary figure S1 (continuous variables) and supplementary figure S2 (count variables). *Very large* to *extremely large* ESs (DOM, 3.85 to 7.64; INT, 3.51 to 7.49) were found between the Goal Shooter and Goal Keeper, compared to all other positions for PlayerLoad^{TM} per minute (supplementary figure S1C & S1F). PlayerLoad^{TM} per minute, at both levels of competition, presented the largest differences between playing positions across all analysed metrics. For absolute PlayerLoad^{TM} *trivial* to *moderate* differences were found at the domestic (ES = 0.04 to 1.14) level and international (ES = 0.05 to 1.17) levels (supplementary figure S1A & S1D).

Differences in absolute and relative metrics between domestic and international levels for the fifteen players that participated at both levels are displayed in Figure 3. An overall lower volume in absolute metrics (Figures 3a–c) occurred at international level compared to domestic. When duration was considered, an increase at the international level was identified compared to domestic for relative values (Figures 3d–f). Individual variability was observed particularly for both PlayerLoad^{TM} variables (Figures 3a & 3d).

4. Discussion

This study primarily aimed to quantify and compare the whole-match and quarter movement characteristics for the team and individual positions in elite domestic and international level match-play. Secondly, it aimed to assess the movement characteristics of players competing in both elite domestic and international level netball. It is the first study to establish the movement characteristics of both international and UK elite domestic netball match-play, and investigate individual player movement characteristics between levels of competition. Additionally, it is the first movement characteristics study in netball literature that involves multiple teams within the same level of competition. Results found greater relative (intensity) characteristics across all playing positions during international matches compared to domestic matches. In contrast, greater absolute (volume) characteristics were found at the domestic level across whole-matches. Significant decreases in absolute and relative characteristics were observed across quarters for both elite domestic and international competition. Quantification of, and differences between, the movement characteristics for playing positions and levels of competition can assist practitioners in physically preparing athletes for competition and during the return to play process.

Differences between international and domestic levels were identified across the whole-match, and per quarter, for relative movement characteristics. *Moderate* and *large* differences in whole-match PlayerLoad™ per minute were found across all playing positions (Table 2), with the international level recording higher PlayerLoad™ per minute values across all positions. Significantly higher acc-dec-COD per minute characteristics were found for the midcourt Centre and Wing Defence positions at the international level compared to domestic, with all playing positions excluding the two goal shooting positions (Goal Attack and Goal Shooter) producing greater acc-dec-COD per minute characteristics at the international level. This may be due to the style of play undertaken by the international team analysed. The higher relative characteristics found at the international level (Table 2 & Figure 2b) could be attributed to the differences in playing duration identified, with six of the playing positions recording more total minutes on-court at the domestic level compared to the international level (Figure 1). Specifically, the Goal Keeper had the greatest difference (INT, 48.1 minutes *vs*. DOM, 31.7 minutes) in median duration with 16.4 minutes more on-court during a whole-match at the domestic level, constituting more than one quarter of a match. Therefore, more substitutions and/or team changes (Mackay et al., 2023) take place at international level, which may contribute to the higher intensities established. Differences in intensity could also be attributed to the higher standard of opposition, differences in playing style, and the technical-tactical characteristics of international and domestic level matches. However, further research is required in this area to quantify these differences and their relationship with movement characteristics. The differences in intensity indicate that as players transition from the domestic season to international competition, the training prescription should prioritise intensity to prepare for the increase in match intensity experienced at the international level.

In contrast to the findings on PlayerLoad™ per minute, absolute volume metrics revealed only *trivial* to *moderate* differences for PlayerLoad™ between international and domestic levels for all positions. Greater PlayerLoad™ was accumulated at the domestic level for all positions, excluding the Goal Shooter, in the whole-match analysis compared to international. The greatest and smallest average accumulated PlayerLoad™ were Centre (366 [283–448] AU) and Goal Keeper (208 [120–269] AU) at the international level and Centre (386 [343–430] AU) and Goal Shooter (234 [185–283] AU) at the domestic level, respectively. The domestic level findings are consistent with previous literature in Australian domestic netball from Brooks et al. (2020) in which Centre (744.4 ± 59.4 AU) and Goal Shooter (393.4 ± 20.4 AU) had the greatest and smallest accumulated PlayerLoad™. As PlayerLoad™ is strongly correlated with distance covered (Cardinale & Varley, 2017; Scott et al., 2013), the higher PlayerLoad™ observed for Centre could be due to their lack of positional court restrictions compared to other positions and therefore accumulates greater movement characteristics. Additionally, a higher number of acc-dec-COD movements and jumps were completed on average across a match at the domestic level for Goal Attack, Goal Defence, Goal Keeper, Wing Attack and Wing Defence compared to international level; with the Wing Defence recording significantly larger differences for both acc-dec-COD (DOM, 523 [454–602] *vs*. INT, 357 [284–448]; RR = 0.68) and jumps (DOM, 21.7 [18.2–25.9] *vs*. INT, 13.7 [10.3–18.1]; RR = 0.63). The larger volume of movements completed across a whole-match at the domestic level is likely due to the longer duration of time on-court compared to the international level (Figure 1). However, it could also be due to differences in technical-tactical abilities. For example, at the domestic level more errors, and therefore turnovers, may occur which could result in players moving throughout the court for longer durations, though further research is required. Similar to match intensities, the total volume of PlayerLoad™ and discrete movement patterns specific to each position and level of play (e.g. jumps) can be used to prescribe training, particularly during the return to play process.

When considering the fifteen players competing at both the international and domestic level, similar trends in the absolute volume and relative per minute variables were identified. At the international level, the absolute volume characteristics were lower. However when duration is considered, the demands increase at the international level with a higher median observed across the fifteen players for all relative variables. Individual variability exists, particularly for the PlayerLoad™ variables. The shorter median duration spent on-court at the international level could have an impact as a higher PlayerLoad™ per minute may be produced for shorter durations and maintained by the rotation of players through substitutions and/or team changes. Coaches may therefore wish to consider the impact of player substitutions throughout the match; however further research is required to establish the contributing factors to the fluctation in relative intensity between levels of competition. Individual variability may be influenced by players' dominant playing position within their international and domestic team. However, this highlights practitioners need to consider player movement demands on an individual basis given the variability, as well as prepare players for greater intensity and density of movement at the international level rather than overall match volume.

Differences in movement characteristics were identified between quarters, however these were specific to playing level. A significantly larger average PlayerLoad™, acc-dec-COD and jump volume were established in quarter one compared to all other quarters at the domestic level of competition, with a significantly larger acc-dec-COD volume showing in quarter two compared to quarter four also (Figures 2a, 2c & 2d). This decrease in movement demand could be influenced by the game management style in which substitutions and team changes are commonly made after quarter one leading to less movement completed for substitute players in latter quarters when less time is spent on-court. As players continue to complete fewer acc-dec-COD movements throughout the quarters at the domestic level, it is possible fatigue may also contribute, however other aspects such as team and opposition playing style may impact the findings. At both the domestic and international levels, there were *small* and *moderate* differences in PlayerLoad™ per minute between quarters when considering all players (Figure 2b). However, PlayerLoad™ per minute was significantly higher in quarter one compared to all other quarters at the domestic level, but at the international level quarter one was only significantly higher than quarters two and four, showing a slight increase in PlayerLoad™ per minute following the half time break at international level in comparison to the continuous decline seen at the domestic level (Figure 2b). The volume as well as the intensity metrics therefore vary throughout the quarters of a match at both levels of competition. Similar findings have been established in other sports (Coutts et al., 2010; Luteberget & Spencer, 2017). In handball, higher PlayerLoad™ per minute values were found at the start of matches with gradual declines observed throughout halves (Luteberget & Spencer, 2017) and in Australian football total distance, high-intensity running and average speed significantly declined from quarter one to all other quarters (Coutts et al., 2010). Contributing factors to this could be the playing style of the team or opposition and the personnel on-court however, as multiple teams were involved in the study this was therefore the general trend apparent across the league. The decrease in intensity following quarter one could be due to players adjusting to the opposition playing style, fatigue, pacing and/or substitutions/team-changes. For example, if players produce a higher intensity in quarter one that is not maintained throughout the other quarters of the match, then fatigue may have impacted the players. However, the significant drop from quarter one to quarter two does not continue as the quarters progress at the international level, therefore pacing may be present to maintain a sustainable intensity for the remainder of the match (Edwards & Noakes, 2009). Further research is required in netball to investigate this further to support the preperation of players.

The whole-match data predominantly show *large* (≥10% CV) between match variability within each playing level for all absolute and relative variables. Between match variability of PlayerLoad™ per minute revealed the least variability of all metrics analysed, ranging from *moderate* (<10% CV) to *large* (≥10% CV) and ranging between playing position at each level (CV = DOM, 10.1% [Goal Defence] – 15.1% [Goal Keeper]; INT, 8.7% [Wing Attack] – 18.8% [Goal Attack]). Similar between match PlayerLoad™ per minute variability was found in elite female soccer which ranged from 9.1% for a fullback player to 20.0% for a forward player (Trewin et al., 2018). The lower variability found for PlayerLoad™ per minute suggests it is the most consistent metric between matches and therefore practitioners could use the PlayerLoad™ per minute metric to track match intensity for players between games (Trewin et al., 2018). However, it should be considered that movements contributing to the accumulation of PlayerLoad™ do vary, as shown by the larger variability in the movement count metrics (Table 1). *Large* variability (≥10% CV) was established for all absolute metrics, across a whole match, for all positions. The high variability established could be limited by the smaller match sample size in comparison to other sports such as rugby league (Dalton-Barron et al., 2021) and soccer (Dellal et al., 2011); however, this is the largest domestic and international sample within netball literature to date. Considering the large variability, practitioners could monitor movement count metrics and PlayerLoad™ simultaneously to provide context on the composition of PlayerLoad™. However, the reliability and validity of the movement count metrics in netball is yet to be understood, therefore practitioners should consider this in the interpretation and use. Future research should investigate the impact other factors, such as opposition and team playing style, have on between match variability to provide further insight.

This paper considered the movement characteristics of netball at a position specific level however due to the structure of netball teams having small team sizes and seven individual positions, the position specific sample sizes are smaller compared to other league wide studies in team sport (Dalton-Barron et al., 2021; Dellal et al., 2011; Rennie et al., 2021). The lower number of international matches played per season also impacts the sample size, and the generalisability of the international findings is limited by the inclusion of only one international team. Further research should consider the movement characteristics of league-wide domestic and international matches over a longer period. Additionally, the different garments holding the microtechnology devices between the international and elite domestic groups may impact the data and therefore future research should consider a consistent tight-fitting garment across all participants (Malone et al., 2017).

In conclusion, this is the first study to establish the movement characteristics of both international and UK elite domestic netball match-play and investigate players competing in both levels of competition. The findings demonstrate that the median duration of time on-court is greater at the domestic level. When considering the whole-match movement characteristics there is greater volume at the domestic level, but greater intensity during international match-play. Significant decreases in absolute and relative metrics across quarters were found at both levels of competition, particularly between quarter one and all other quarters. Further research is needed to provide more detail on the contributing factors causing differences in intensity across the levels of competition. Additionally, to provide more context to the movement characteristic findings the technical and tactical characteristics of the different levels of competition need to be determined and combined with the physical aspects on a league-wide scale, as well as providing further insight into the cause of the quarter-to-quarter fluctuations. Practitioners should consider the greater intensity characteristics found in international match-play when transitioning athletes from the domestic season to international competition. Both the volume and intensity metrics can be used in training for position-specific training prescription.

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Data sharing

All data relevant to the study are included in the article or uploaded as supplementary information.

Ethical approval

This project was approved by Leeds Beckett University, Local Ethics Committee (77292693).

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