UNIVERSITY OF TECHNOLOGY SYDNEY

Integrating Training Load Metrics with Player Development Pathways in High-Performance Youth Basketball

by Jonathon R Lever

Thesis submitted in fulfilment of the requirements for the degree of

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under the supervision of Professor Hugh H.K. Fullagar, Professor Rob Duffield, Dr Andrew Murray and Dr Jonathan D. Bartlett

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Certificate of Original Authorship

I, Jonathon Lever, declare that this thesis is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the Faculty of Health, School of Sport, Exercise and Rehabilitation at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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Abbreviations and Symbols

Abbreviation/Symbol/Unit	Word/Phrase
AAU	Amateur Athletic Union
ACWR	Acute:Chronic Workload Ratio
AIC	Akaike Information Criterion
AIS	Australian Institute of Sport
ANOVA	Analysis of Variance
AU	Arbitrary Units
BA	Basketball Australia
BMI	Body Mass Index
CI	Confidence Intervals
CoD	Change of Direction
CR-10	Category-Ratio 10 Scale
CSV	Comma-separated values
DSL	Dynamic Stress Load
DXA	Dual-energy X-Ray Absorptiometry
FIBA	Federation of International Basketball Association
GPS	Global Positioning System
$h \cdot wk^{-1}$	Hours per week
HR	Heart Rate
HR_{max}	Heart Rate Maximum
HSD	Tukey's Honestly Significant Difference
Hz	Hertz
IDG(s)	Individual Development Goal(s)
IMU(s)	Inertial Measurement Unit(s)
km/h	Kilometres per hour
LPS	Local Positioning System
$m \cdot min^{-1}$	Metres per minute
m/s^2	Metres per second squared
NBA	National Basketball Association
NBPA	National Basketball Players Association
NCAA	National Collegiate Athletic Association
OR	Odds Ratio
PL	PlayerLoad
Q1-Q4	Quarter 1-4
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RPE	Rating of Perceived Exertion
sRPE	Session Rating of Perceived Exertion
SD	Standard Deviation
SGT(s)	Specific Goal Type(s)
SSG(s)	Small Sided Game(s)
TL	Training Load
TRIMP	Training Impulse
UWB	Ultra-Wideband
Uxx	Under-xx
VIF	Variance Inflation Factor
VO_2max	Maximal Oxygen Uptake

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Metoyer, C. J., **Lever, J. R.,** McGinty, M., Landow, L., Hunt, R., Hauenstein, J. D., ... & Wagle, J. P. (2025). The impact of localized muscle mass on sprint mechanics during the swing and stance phases of division I collegiate American football players. *The Journal of Strength & Conditioning Research, 10-1519*. https://doi.org/10.1519/JSC.0000000000005163

Huebner, A., **Lever, J. R.,** Clark, T. W., Suchomel, T. J., Metoyer, C. J., Hauenstein, J. D., & Wagle, J. P. (2025). Novel use of Generalizability Theory to optimize countermovement jump data collection. *Sports, 13(3), 85*, https://doi.org/10.3390/sports13030085

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Abstract

High-performance youth basketball academies operate within formal athlete-development pathways that bridge secondary education and senior professional or collegiate competition. Within these environments, players undertake intensive, multi-term schedules combining on-court training, strength and conditioning, and academic demands, comprising holistic athlete development models. Managing these loads requires systematic monitoring of both internal and external training loads (TLs) to ensure appropriate progression, manage fatigue, and align practice design with developmental aims. This thesis investigates how TL monitoring can be integrated within player-development pathways and coaching practice in a male high-performance basketball academy through four linked studies examining internal and external TL, coaching perspectives, and training intent–outcome fidelity.

Study 1 quantified longitudinal patterns of internal TL (ratings of perceived exertion; RPE, session rating of perceived exertion; sRPE) and training exposure (duration and session counts) across years in the program, academic terms, and playing positions. Mixed-effects modelling revealed significant increases in session count, session duration, and session RPE (sRPE) load in Year 2 compared with Year 1 ($p<0.001$), and in Year 3 versus Year 1 for weekly sRPE ($p=0.007$). Within-year comparisons showed higher TLs in Terms 3–4 than Terms 1–2 ($p<0.001$), with no positional differences evident ($p>0.05$). These data indicate an increase in internal load after Year 1, with increased training loads observed in the latter academic terms within each respective year.

Study 2 described season-long external TLs using inertial measurement units (IMUs). Mixed effects models showed no year-on-year differences were evident ($p>0.05$), but term effects existed, whereby total distance was greater in Terms 3–4 than Terms 1–2 ($p<0.03$), distance·min^{-1} in T2–T4 was higher than T1 ($p<0.01$), and PlayerLoad·min^{-1} was higher in T4 than T1 and T2 ($p<0.01$). Backcourt players recorded higher distance·min^{-1} and PlayerLoad·min^{-1} (both $p=0.011$) and more Band 1–3 decelerations ($p=0.023$; $p<0.001$; $p<0.001$) than Frontcourt players. These results show seasonal and positional differences in external TLs within a calendar year.

Study 3 explored coaches' philosophies and perspectives on athlete development and TL monitoring. Semi-structured interviews ($n = 9$) and reflexive thematic analysis revealed that coaches emphasised holistic preparation integrating technical–tactical, psychological, and physical elements. They prioritised behavioural qualities such as effort, discipline, and coachability alongside, yet ahead of, physical traits including lateral quickness and explosiveness and described performance as the interaction of mindset and movement quality. Monitoring was valued when it supported communication, recovery management, or load planning, but coaches resisted prescriptive thresholds and complex composite metrics they perceived as detached from practice. Adoption of TL information was improved when reporting used shared definitions, consistent time windows, and visualisations tailored to coaching language.

Study 4 evaluated the alignment between coach-prescribed Individual Development Goals (IDGs) and measured external TLs at the drill level. Multinomial logistic regression models using per-minute external TL metrics classified Development Goal

Category and Specific Goal Type with 66% accuracy (κ=0.60), accompanied by large Akaike information criterion (AIC) reductions (ΔAIC=1224.1; 2540.7). Key associations included high-intensity decelerations, vertical PlayerLoad, and high-speed running distance. Accumulated training time differed significantly between Specific Goal Types, indicating some systematic variation in emphasis across the season and partial intent–outcome alignment.

Collectively, this thesis provides descriptive reference information for internal and external TL benchmarks across years, terms, and positions within this academy sample; identifies calendar-driven load patterns; characterises how coaches interpret and apply monitoring; and operationalises fidelity checks linking intended training objectives with delivered stimuli. Monitoring is most effective when embedded as a context-sensitive, coach-informed practice that connects measurement, decision-making, and developmental planning within a single applied framework.

Chapter 1: Introduction

1.1 Overview

High-performance youth basketball academies have become a prominent pathway to senior competition, providing a multi-year developmental environment where technical–tactical learning, physical preparation, and academic progress can occur (Bergeron et al., 2015; Bonal et al., 2020; Calleja-González et al., 2016; Lloyd et al., 2016). Adolescents in these programs navigate dense weekly schedules and term calendars that combine on-court sessions, strength and conditioning, competition, and travel around school obligations (Bonal et al., 2020; Calleja-González et al., 2016; Murray, 2017). In conjunction with these demands, the academy years (15–18 years) coincide with rapid, non-linear growth and maturation, compounding the physical and psychological stress of training and heightening the need for structured, developmentally appropriate environments (Bergeron et al., 2015; DiFiori et al., 2018; Malina, 2011). Hence, systematic monitoring and load management are critical to guide player development for future career transition into college or professional leagues (Bergeron et al., 2015; DiFiori et al., 2014; Lloyd et al., 2016).

Against this academy backdrop, training load (TL) monitoring is positioned as a means of describing what happens within these high-demand environments (Lloyd et al., 2016; Saw et al., 2016). Although TL monitoring is widespread in professional adult sport, its systematic application in youth academies remains under-examined (Bergeron et al., 2015; Lloyd et al., 2016). Understanding how to embed TL monitoring so that it consistently informs planning, from session design and weekly periodisation to term-by-term sequencing and development planning, is therefore an important consideration in supporting player developmental priorities (Bourdon et al., 2017; Halson, 2014). Accordingly, research using monitoring not only as a descriptive tool, but also as an instrument to aid design and verify outcomes within shared, academy-specific TL definitions and reporting windows is required to guide and evaluate practice. Quantifying and interpreting TL in youth basketball is central to preparing athletes for the demands of professional pathways. Systematic monitoring supports TL management, enhances performance readiness, and informs individual development planning, helping ensure that TLs progress in alignment with youth athletes' physical development (Bourdon et al., 2017; Halson, 2014; Lloyd et al., 2016; Saw et al., 2016). However, much of the applied knowledge in youth basketball still relies on experiential decision-making or extrapolation from adult or short-term studies (Fox et al., 2017; Russell, McLean, Impellizzeri et al., 2021). Establishing an evidence base that integrates longitudinal exposure, player responses and coaching perceptions and practice provides the foundation for data-informed development within academy environments (Bergeron et al., 2015; Impellizzeri et al., 2019).

Typically, the literature refers to TL as the quantifiable physical and perceptual demands arising from training and competition participation (Impellizzeri et al., 2019). Accordingly, this thesis will adopt this definition and examine TL within the structured academy training environment. Across team sports, internal TL is used to quantify the psychophysiological response to exercise, whereas external TL represents the work performed or dose of training (Foster et al., 2001; Impellizzeri et al., 2019, 2023). In basketball, frequent accelerations, decelerations, multi-directional movements, and repeated jumps contribute to the high mechanical demands quantified as external TL, while internal TL is commonly indexed through session-RPE multiplied by duration (Fox et al., 2017; Vázquez-Guerrero, Fernández-Valdés, Jones et al., 2019). Monitoring tends to influence practice when metrics are trusted, timely, and aligned with coaching workflows (Saw et al., 2016; Weston et al., 2015). In academy settings organised by school terms, pairing external and internal TL provides a shared view of dose and response that can be used consistently across sessions, weeks and phases without altering underlying definitions (Bergeron et al., 2015; Impellizzeri et al., 2020; Saw et al., 2016).

Despite increased interest, evidence of TL use in high-performance youth basketball remains fragmented, with most studies limited to short windows such as single seasons, tournament blocks, or brief mesocycles (Conte et al., 2018; Fox, Scanlan, Sargent et al., 2020; Petway et al., 2020; Russell, McLean, Impellizzeri et al., 2021; Scanlan, Wen et al., 2014). These short-term 'snapshots' provide limited insight into multi-year academy contexts and do not clearly show how internal and external TL accumulate over training blocks or differ by playing position. Although many contemporary studies employ microsensor or LPS technologies and report multiple acceleration-based variables, total and relative distance are frequently presented as central external load descriptors (Brandão et al., 2019; Petway et al., 2020; Pino-Ortega et al., 2019). However, distance-based summaries alone may under-represent basketball's acceleration-, deceleration-, and jump-dense profile (Fox et al., 2017; Vázquez-Guerrero, Fernández-Valdés, Gonçalves et al., 2019). Yet academy-specific, term-level descriptions that differentiate by year-in-program and position remain scarce. Without such references, it is difficult to anchor internal TL interpretation to delivered doses, compare between terms, or anticipate when clusters of increased training exposures or other intense loading patterns may warrant proactive adjustment (Akenhead & Nassis, 2016). Using research to establish longitudinal patterns therefore supports planning by providing empirically grounded reference ranges that inform TL management and progression within comparable developmental contexts.

Within basketball-specific monitoring, studies consistently report high accelerations, decelerations and jump counts with short sprint efforts and frequent changes of direction, alongside contextual differences between practice formats and official matches (Conte et al., 2018; Fox, Stanton et al., 2020; Vázquez-Guerrero, Fernández-Valdés, Jones et al., 2019). Positional roles also shape exposure profiles, yet youth samples are often small and observed over brief periods, limiting inferences about typical patterns across terms or years (Russell, McLean, Impellizzeri et al., 2021; Scanlan, Wen et al., 2014). Moreover, heterogeneous external TL definitions (e.g., varying acceleration thresholds, event detection settings, or composite indices) along with inconsistent position classification schemes, reduce comparability across studies and programs (Russell, McLean, Impellizzeri et al., 2021). Together, these factors highlight the value of generating academy-specific, longitudinal evidence that reflects the internal and external TLs across an academic calendar and allows interpretations to be anchored to the dose delivered.

Another challenge is ensuring coaches integrate TL monitoring, as data seldom influences practice unless it aligns with their existing decision-making frameworks and daily workflows (Saw et al., 2016; Weston et al., 2015). In youth academies, where staff balance technical–tactical goals, selection pressures, and academic calendars, successful integration relies on clear metrics, workflow compatibility, and trust of both the data and staff delivering it (Taylor & Garratt, 2013; Weston et al., 2015). Understanding how coaches conceptualise performance and development and identifying where monitoring complements or conflicts with their processes can guide what to report and when. Coaches design drills to elicit specific adaptations, yet intended labels do not always translate into distinct external or internal TL profiles (Sosa Marín et al., 2025). Drills designed for reduced TL can become unexpectedly demanding when constraints elevate work rate; conversely, drills meant to deliver a high-intensity stimulus can be blunted by long rests, conservative rules, coaching instruction or interruptions (Akenhead & Nassis, 2016; Conte et al., 2016; Gabbett, 2016; Klusemann et al., 2012). Routine comparisons of intended and delivered TLs provide a methodological basis to evaluate the fidelity of training design. Research that quantifies these intent–outcome relationships enable systematic analysis of how well prescribed objectives are translated into measurable internal and external TLs (Akenhead & Nassis, 2016; Sosa Marín et al., 2025). Collectively, these factors identify a research priority: to integrate TL data with coaches' decision-making frameworks across macro-, meso-, and micro-training contexts, transforming descriptive monitoring into explanatory models that link training design, delivery, and developmental intent.

Taken together, these constraints define the central research problem addressed in this thesis: the absence of coherent, empirically validated frameworks linking TL measurement, coaching decision processes, and the fidelity of delivered stimuli. To address this, the current thesis is organised as four linked studies: (1) characterising how internal TL accumulates across years, terms, and playing positions; (2) profiling external TLs across years, terms, and playing positions; (3) examining how coaches' perspectives on athlete development shape monitoring use and decision-making; and (4) testing whether drill "intent" matches the delivered dose.

1.2 Thesis Aims

The overarching aim of this thesis is to investigate how TL monitoring can be integrated into the player development pathways and coaching practices of a high-performance youth basketball academy.

Specifically, the thesis pursued four aims:

1. To quantify longitudinal patterns of internal TL and training exposure across years, terms, and playing positions (Study 1).
2. To describe external TL across years, terms, and playing positions within the academy program (Study 2).
3. To examine coaches' philosophies and perspectives on athlete development and the use of TL monitoring (Study 3).

4. To evaluate the alignment between coaches' intended training objectives and the measured TL outcomes of drills and sessions (Study 4).

Taken together, the thesis is structured to build an integrated account of youth basketball TL, spanning longitudinal patterns, drill-level demands, coaching beliefs, and intent-to-exposure alignment, which Chapters 3–6 address in turn. Given the limited empirical evidence describing TL within highly trained youth basketball academy environments, the studies within this thesis were primarily exploratory and descriptive in nature. Rather than testing a priori directional hypotheses, the research was designed to characterise patterns of training exposure, external demands, and coaching intent within a novel applied context.

1.3 Significance of Thesis

This thesis provides an original contribution by extending basketball TL monitoring research from adult professional contexts to the under-examined setting of high-performance youth academies, where athletes face unique developmental, educational, and competitive demands (Bergeron et al., 2015; Lloyd et al., 2016). Existing youth basketball studies are largely confined to short-term observations or single-season analyses (Conte et al., 2018; Fox, Scanlan, Sargent et al., 2020; Scanlan, Wen et al., 2014), offering only partial insight into how training exposure and responses evolve over multiple years of development. This gap partly reflects ecological challenges, whereby sustaining multi-year studies in youth sport is difficult due to limited resources, staffing demands, and high athlete turnover (Jacobsson et al., 2017; Shipherd et al., 2019; Strachan et al., 2016). By generating longitudinal evidence of both internal and external TL within an academy system, this thesis extends current understanding of how training demands are distributed across terms, years, and playing positions, and interprets these findings within the context of this age group and maturity status of such a playing cohort (Malina, 2011). In doing so, it offers rare multi-year data from a high-performance setting that has been largely absent from the literature.

The thesis also contributes to improving the translation of sport-science knowledge into coaching practice. While the collection of TL metrics has become increasingly feasible through wearable technologies and session-RPE tools (Bourdon et al., 2017; Foster et al., 2001), the degree to which these data are used by coaches remains inconsistent. Coaches often prioritise information that aligns with their pedagogical philosophies, decision-making processes, and the practical realities of session planning (Taylor & Garratt, 2013; Weston et al., 2015). By incorporating coaches' perspectives on athlete development and monitoring, this thesis contributes to broader academic discussions on knowledge translation in sport science (Fullagar et al., 2019; Saw et al., 2016), emphasising that the value of monitoring is determined not only by the accuracy of measurement but also by its perceived relevance and usability in applied contexts.

Finally, the research offers practical value by examining the alignment between intended training objectives and the actual physical demands imposed on athletes. Previous work in team sports has highlighted the risk of a mismatch between session design and physiological outcomes (Akenhead & Nassis, 2016; Gabbett, 2016), yet systematic investigation of this issue in youth basketball has been absent. By directly comparing coach-prescribed goals with measured TL outcomes, this thesis provides a novel framework for evaluating the fidelity of training design. Such an approach not only informs practice within basketball academies but is also transferable to other youth sport contexts where bridging the gap between coaching intent, athlete experience and developmental outcomes is essential (Calleja-González et al., 2016). Each aim maps to a corresponding study (Chapters 3–6), moving from description to interpretation and evaluation; this sequencing enables the thesis to offer new longitudinal data, drill-level context, coach-centred perspectives, and an assessment of intent–exposure alignment.

1.4 Limitations

Several limitations of this thesis should be acknowledged:

- Data were collected within a single high-performance youth basketball academy. While this approach provided ecological validity and methodological consistency, it constrains the generalisability of findings to other academies or systems with different calendars, resources, or developmental philosophies (Calleja-González et al., 2016).
- The research examined only youth male athletes. As such, conclusions may not directly apply to female basketball players, where growth, maturation, and competition demands can differ substantially (Malina, 2011).
- Internal TL was assessed primarily using session-RPE, and external TL via IMUs. Although these tools are widely used and validated (Foster et al., 2001; Lupo et al.,

2017; Scanlan, Wen et al., 2014), alternative approaches such as heart-rate-based training impulse, hormonal markers, or video-based analyses were not included, which may limit comparability with studies employing different monitoring methods.

- All studies were observational and descriptive or analytical in nature, without experimental manipulation of TL or monitoring practices. While this approach strengthens ecological validity, it limits causal inference; associations between TL, development goals, and outcomes can therefore not be interpreted as causal effects (Akenhead & Nassis, 2016).
- The thesis focused primarily on physical TL and its alignment with coach-prescribed developmental objectives. Other key domains of athlete development, such as technical skill progression, tactical decision-making, psychological attributes, and academic outcomes, were outside the scope of this investigation, though clearly important for broader youth development (Bergeron et al., 2015; Lloyd et al., 2016).
- TL monitoring was limited to academy-led sessions in the home environment; any training conducted with national teams or individually was not recorded.

1.5 Delimitations

This thesis was designed with several delimitations that set the scope of inquiry:

- The research was delimited to male athletes within a single high-performance youth basketball academy. This focus ensured homogeneity of context and program design but excluded female athletes and other developmental systems.

- Data collection was limited to the years during which the academy program operated under a consistent training curriculum. Athletes' prior playing histories and post-academy careers were outside the scope of this investigation.
- Internal TL was operationalised through session-RPE, and external TL through National Basketball Players Association (NBPA) approved accelerometer-derived metrics (e.g., PlayerLoad (PL), accelerations, decelerations, jumps). Other potential markers of TL (e.g., heart-rate variability, biochemical measures) and broader developmental outcomes (e.g., technical skills, academic performance, psychological growth) were not assessed.
- The thesis employed descriptive, comparative, and classification analyses within an observational framework. Intervention studies or experimental manipulations of TL were not undertaken, to preserve ecological validity within the academy environment.
- Qualitative data were delimited to the perspectives of academy coaches directly involved in the program. Broader viewpoints from athletes, parents, or staff in other sports were beyond the intended scope.

Chapter 2: Literature Review

2.1 Overview

Basketball is a high-intensity, intermittent sport that requires frequent bursts of speed, jumps, and directional changes (Ben Abdelkrim et al., 2007; Russell, McLean, Impellizzeri et al., 2021; Stojanović et al., 2018). At the high-performance youth level, academies serve as development programs for adolescent players that integrate multi-year, structured basketball training with formal education and coordinated support services (Bonal et al., 2020; Calleja-González et al., 2016; Klusemann et al., 2013). These largely school-integrated programs combine rigorous on-court practice with integrated performance support (e.g., strength and conditioning, sports medicine, nutrition, and academic services), delivered both on-court and off-court and emphasise appropriate progression over immediate competitive success (Bonal et al., 2020; Calleja-González et al., 2016; Klusemann et al., 2013). They aim to prepare youth athletes for higher levels of play by fostering technical skill, tactical understanding, and personal growth, while tempering the win-at-all-costs ethos common in youth competition (Bonal et al., 2020; Calleja-González et al., 2016).

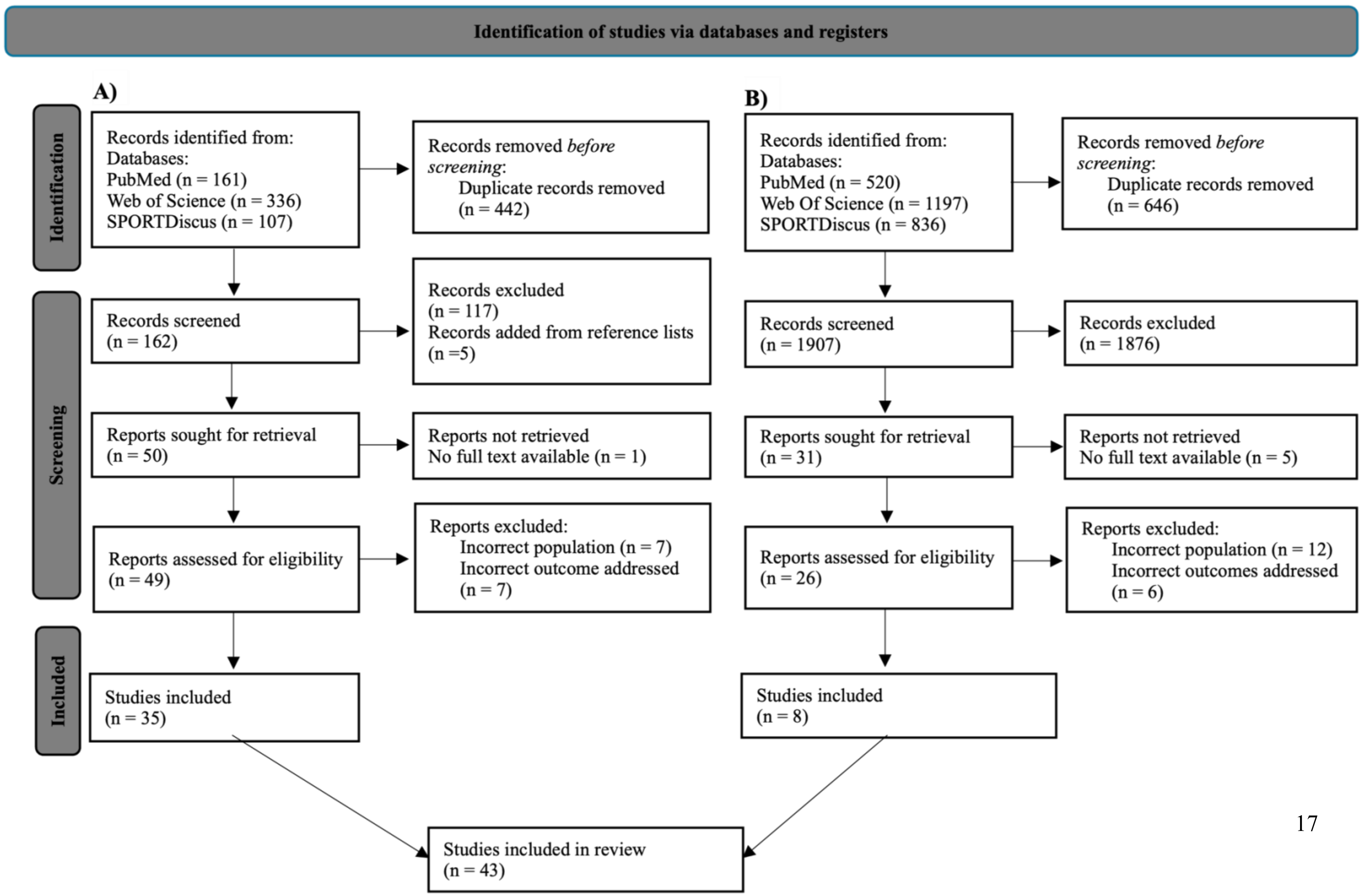
This intensive dual model imposes substantial physical and cognitive demands across year-round schedules. Layering multiple weekly practices and competition onto ongoing academic responsibilities creates a dual-career load that complicates week-to-week TL management and is associated with heightened risk of overuse problems, illness, and motivational drop-off in youth athletes (Bergeron et al., 2015; DiFiori et al., 2014; Lloyd et al., 2016; Saw et al., 2016). Inter-individual variation in maturation further means identical external work can elicit different internal stress responses (Dudley et al., 2023). Accordingly, systematic TL monitoring, which quantifies both external and internal TL, is used to individualise training, monitor fatigue, and adjust training programs to support development while safeguarding health (Scantlebury et al., 2018). To effectively support youth athlete development, it is crucial that monitoring outputs align with coaches' daily planning and terminology, thereby facilitating their successful adoption.

Despite growing interest, the scientific literature on TL monitoring in high-performance youth basketball remains limited. Few published studies have longitudinally documented TLs across entire academy seasons or quantified how TL patterns evolve across different phases of training and competition. Furthermore, evidence remains scarce on how coaches use TL data to inform planning and adjustment, and little empirical work has examined the correspondence between coaches' intended training objectives and the measured TL profiles of those drills. This chapter synthesises current knowledge on internal and external TL in youth basketball, evaluates how monitoring practices are applied and integrated into coaching decision-making, and highlights key gaps in both scientific evidence and practitioner adoption. By consolidating findings across macro- (season/year), meso- (term), and micro- (session/drill) timescales, and across playing positions, the review aims to clarify what is well established, identify where results are inconsistent, and determine what further evidence is needed to guide developmentally appropriate TL management and the integration of monitoring within coaching practice in academy basketball.

2.2 Methods

This narrative review employed a structured search in two parallel streams aligned with this chapter's aims: (A) TL monitoring (internal and external) and (B) coaching use/adoption of TL monitoring (Figure 2.1). The final search was conducted in July 2025 across MEDLINE (PubMed), SPORTDiscus and Web of Science. Search strings combined population terms (basketball, youth, adolescent, junior, academy) with stream-specific constructs (Stream A: training load, internal load, external load, RPE, sRPE, accelerometery, IMU, LPS/UWB, wearable technology; Stream B: coach*, coaching practice/philosophy, pedagogy, athlete-centred/centred, decision making, coaching behaviour/behaviour, strategy, talent development, coach–athlete relationship, learning environment). To support construct transferability Stream B included broader team-sport terms. Reference lists of included papers were hand-searched. Included studies were peer-reviewed and focused on male youth basketball players in academy, school-based, or high-performance youth settings. Eligible designs encompassed observational, validation/methods, qualitative, or mixed methods approaches, and studies needed to report outcomes related to TL quantification/validity, positional/seasonal/drill differences, or coaching adoption/decision-making. Meanwhile, non-English publications, non–peer-reviewed items, professional or adult cohorts, and studies lacking relevant outcomes were excluded. Because the intended study population for this thesis is male youth basketball players, studies involving female youth athletes were excluded from the primary synthesis to maintain a homogeneous inference set. Relevant findings from female basketball pathways are cited narratively for context.

Figure 2.1 PRISMA flow diagram for the Stream A and B narrative reviews



Records were de-duplicated and screened by title/abstract, then full text, against stream-specific criteria. Data were synthesised narratively within streams and then integrated to address alignment questions across macro- (season/year), meso- (term), and micro- (session/drill) timescales and positional roles. Given the heterogeneity of designs and metrics, no formal risk-of-bias tool was applied. All article screening and data extraction were conducted by the doctoral candidate. Given the narrative review design and the exploratory purpose of the synthesis, a second independent reviewer was not employed. Subsequently, 43 studies met the inclusion criteria (35 in Stream A; 8 in Stream B). Two PRISMA-style flow diagrams (one per stream) summarise identification, screening, and inclusion (Figures 2.1A and 2.1B). For comparative figures, mean values were extracted directly from published tables or figures and plotted as reported. No statistical pooling or recalculation beyond unit harmonisation was performed.

2.3 Youth Academies and Development Pathways

High-performance youth academies operate within formal talent development and identification pathways that channel athletes toward senior professional and collegiate environments (e.g., national leagues and senior teams, U.S. college basketball, development leagues) (Bonal et al., 2020, 2019; Calleja-González et al., 2016; Mercer et al., 2022; Saw et al., 2016; Weston et al., 2015). Although pathway architectures vary by region and sex, a common design logic underpins academy calendars: gradually increase exposure to adult-like match demands while maintaining a development-first philosophy that emphasises incremental skill acquisition and decision-making alongside safeguarding growth, learning, and health (Calleja-González et al., 2016; Petway et al., 2020). In practice, this entails periodised sequences of training and competition that are constrained by schooling, as well as by players' maturation status and role selection or playing position. Within these constraints, session and weekly TLs are adjusted to balance technical–tactical skill acquisition with physical robustness (DiFiori et al., 2014, 2018; Lloyd et al., 2016). This pathway context informs the research aims that follow, shaping the rationale for TL monitoring and the interpretation of internal (session-RPE–based) and external (tracking-derived) TL metrics across different phases and playing positions.

2.3.1 Youth Academy Structures

Youth basketball academies are professionally staffed, multi-year environments for high-potential youth athletes that integrate on-court technical/tactical work with coordinated off-court support (strength and conditioning, sports medicine, nutrition, psychology) and formal schooling (Bonal et al., 2020; Calleja-González et al., 2016; Fox, Scanlan, Stanton et al., 2020; Murray, 2017). In most academy models, the primary function is developmental, preparing athletes for senior and collegiate levels; however, competition-centred circuits (e.g., parts of the US Amateur Athletic Union (AAU) system) may emphasise exposure and tournament play to a greater extent than school-integrated programs typical of Europe and Australia (Bonal et al., 2020; Calleja-González et al., 2016; DiFiori et al., 2018; Klusemann et al., 2013). Compared with seasonal, tournament-centred club/state pathways, academies typically deliver year-round programming with a higher practice-to-match ratio, and, in some systems, implement competitive matches against adult opponents to accelerate exposure to higher-level competition (Calleja-González et al., 2016; Klusemann et al., 2013).

Reported weekly exposures vary widely between systems (Figure 2.2). Examples range from ~10–12 $h \cdot wk^{-1}$ in parts of Europe (Calleja-González et al., 2016) to ~20 $h \cdot wk^{-1}$ in Australian high-performance settings (Klusemann et al., 2013), with occasionally higher outliers, for instance in Chinese academies, reporting up to 40 $h \cdot wk^{-1}$ (Bonal et al., 2020). Hours alone are insufficient as a TL descriptor; content, density, intensity, and age-appropriate progression are needed to characterise exposure. Variations in calendars and resources limit comparability across programs and reinforce the distinct status of academies within youth development pathways (Bonal et al., 2020; Calleja-González et al., 2016; Conte et al., 2015; Joseph et al., 2021; Russell, McLean, Impellizzeri et al., 2021). Taken together, these ranges emphasise that training hours are insufficient to describe athlete TL, as it fails to capture elements such as training intensity, movement quality, and contextual demands (Bourdon et al., 2017; Akenhead & Nassis, 2016; Fox et al., 2017; Vázquez-Guerrero et al., 2019; Impellizzeri et al., 2019; Sosa et al., 2025). Accordingly, program design decisions hinge on what fills those hours (training content, density of sessions, intensity) and how progression is staged by athlete age and maturation (Bergeron et al., 2015). These structural features are not merely logistical variations; they also reflect broader cultural philosophies of athlete development, which differ across regions and in turn shape academy calendars.

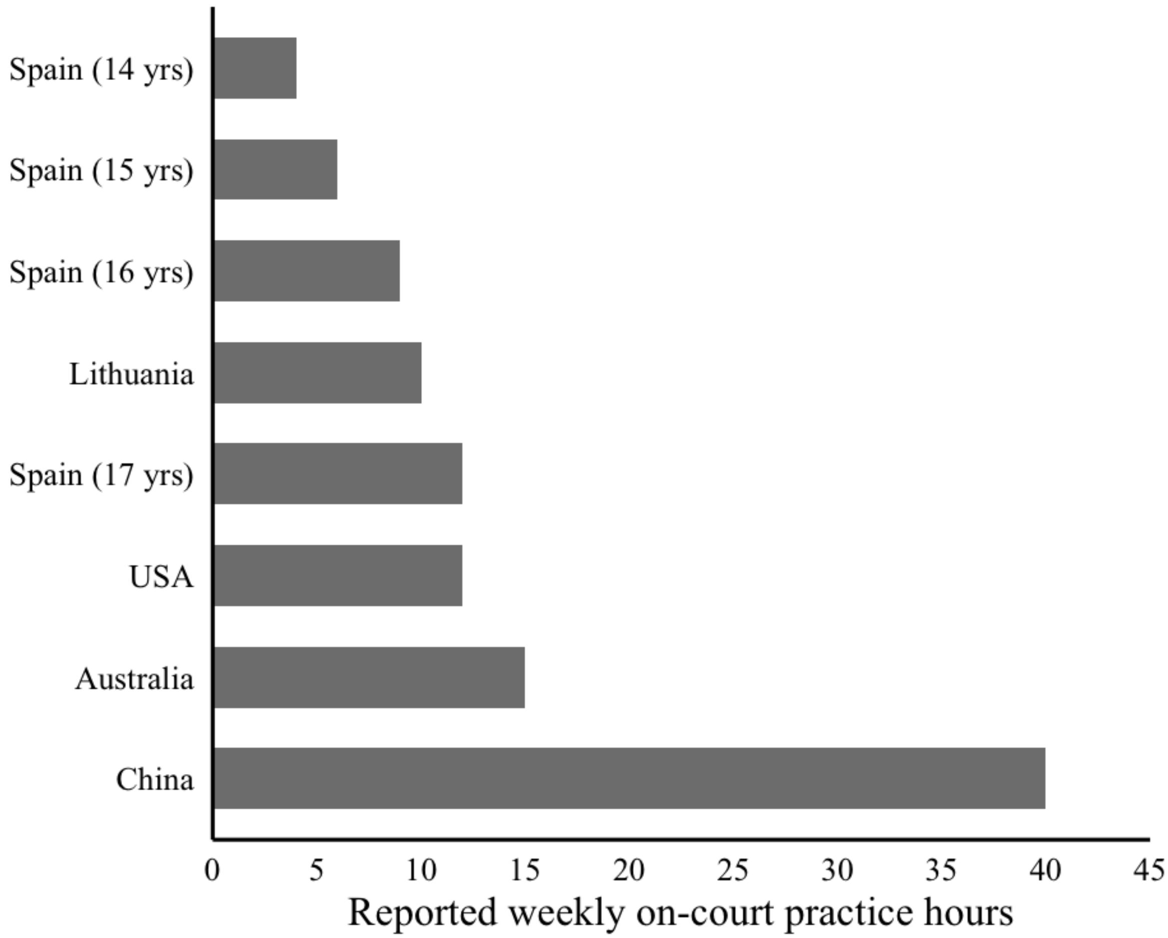
Clear cross-cultural differences in academy philosophy exist across major basketball regions, although systematic comparative research remains sparse. In Europe, many systems (notably in Spain and Lithuania) operate dedicated youth academies or sport schools that combine high-volume technical training with formal education under club or federation structures. In Spain's national model, weekly on-court practice increases from roughly 5 to 12 hours between ages 14 and 17 (Calleja-González et al., 2016), mirroring professional demands (Calleja-González et al., 2016). Lithuania's pathway likewise emphasises fundamental skill development and substantial TLs from early adolescence (Paulauskas et al., 2019). Australia's Centre of Excellence and affiliated programs emphasise holistic development, integrating education, wellbeing services, and long-term athlete support alongside intensive training (Basketball Australia, 2021).

By contrast, U.S. school- and club-based systems (e.g., AAU, high school, prep circuits) are not integrated academies but competition-oriented pathways prioritising exposure and recruitment visibility through dense tournament schedules (USA Basketball, 2024). The Americas FIBA's Youth Development Program (FIBA, 2023), and the NBA Academy initiative, operate globally in Australia, Mexico, and Africa, combining daily training, competition, academic schooling, and life-skills education within structured high-performance environments (National Basketball Association, 2022). Collectively, these systems reveal that academy calendars reflect not only logistical and resource constraints but also broader cultural priorities, whether competition, holistic education, or technical creativity, which shape how TL is structured and monitored. While this thesis focuses on a high-performance academy based in Australia, acknowledging these differences clarifies that its TL patterns may not directly generalise across all youth development systems.

2.3.2 Demands of the Academy Environment

Academies impose dual demands. For example, practice-heavy training schedules run alongside ongoing schooling and assessments, requiring staff to balance technical–tactical objectives with academic timetables and exam periods (Bonal et al., 2020; Fox, Scanlan, Stanton et al., 2020; Murray, 2017). This duality shapes day-to-day TL management, as microcycles must prioritise school obligations and accommodate travel and tournament windows (Edwards et al., 2018; Russell, McLean, Impellizzeri et al., 2021). As maturation and training age vary within squads, nominally identical external work can elicit divergent internal responses (Gryko et al., 2018; Moreira et al., 2012; Phibbs et al., 2017). Academy squads, by design and circumstance, mix younger and older adolescents and varied roles (Bonal et al., 2020; Murray, 2017), which increases between-athlete variability in physiological cost and necessitates role- and maturity-sensitive progressions (DiFiori et al., 2018; Lloyd et al., 2016).

Figure 2.2 Reported weekly on-court practice hours in key youth basketball development pathways



Note: Data included from Calleja-González et al., 2016; Paulauskas et al., 2019; Kutson et al., 2024; Klusemann et al., 2012; and Bonal et al., 2020.

The competition calendar compounds these demands. Academy teams typically play domestic age-grade leagues plus periodic tournaments, leading to variability in competitive density, where low-frequency league play is interspersed with congested microcycles (e.g., multiple matches over 2–3 days) (Calleja-González et al., 2016; Kamarauskas et al., 2022). These oscillations shift the practice-to-match balance and alter the weekly TL profile over the year. Across youth basketball samples, matches generally exhibit higher per-minute intensity than practices, while total session volumes can be similar between the two in certain phases, though not consistently across all cohorts (Conte et al., 2017; Pino-Ortega et al., 2019).

Furthermore, playing role influences internal TL: non-starters have in some cases reported higher session RPE than starters when playing time is very limited (Brandão et al., 2019; Vaquera et al., 2018). At younger ages, typical single-session intensities cluster in the moderate range (RPE ≈ 4.5–5 on CR-10), with variability driven by match context and opportunity rather than competition alone (Arede et al., 2022). In addition to session duration, the movement profile of youth basketball is central to interpreting TL. Wearable external TL systems quantify the frequent bursts, abrupt decelerations, and repetitive landings that typify indoor play; for example, youth matches in high school cohorts have recorded approximately 43 jumps and 47 explosive actions per match, underscoring the plyometric and change-of-direction burden layered atop aerobic and anaerobic work (Arede et al., 2021; Askow et al., 2023). These mechanical characteristics explain why time alone is insufficient to represent exposure and why both internal and external TL are core components of monitoring practice.

Given this context, monitoring at multiple timescales is warranted. Within individual weeks, youth programs accumulate moderate-to-high session RPE values (approximately 6–7 on the CR-10 scale, corresponding to ~500–600 AU per session) (Lupo et al., 2017). Across multi-week blocks, total weekly sRPE spans 600–1,700 AU, with spikes during congested or intensive weeks (Conte et al., 2017; Lupo et al., 2017). These patterns emphasise the importance of tracking both the distribution and the dose of TL (Conte et al., 2017; Lupo et al., 2017). Accordingly, these demands warrant monitoring at macro-, meso-, and micro-timescales so that exposure can be planned and adjusted around calendar and cohort constraints. Yet much of the youth-specific evidence remains limited (single teams, short windows) and is further constrained by broader methodological issues around heterogeneous devices and definitions that limit youth-specific reference ranges and practice transfer (Bourdon et al., 2017; Impellizzeri et al., 2019), which will be further explained in ensuing sections regarding metrics and technologies.

2.3.3 Training and Competition Load Profiles

Competition density oscillates across the year, as domestic fixtures are interspersed with tournament blocks, redistributing the practice-to-match balance and compressing recovery during congested microcycles (Calleja-González et al., 2016; Klusemann et al., 2013; Petway et al., 2020). Match play within academies often elicits higher relative intensities than practices, although these effects are mediated by playing role and exposure; as non-starters can report greater perceptual demands than starters when match minutes are unevenly distributed (Vaquera et al., 2018). Positional differences have been examined, but findings suggest minimal effects. For example, in an elite U18 tournament study, Backcourt players accumulated ~1.4 ± 0.3 PL·min^{-1} versus ~1.3 ± 0.3 for Forwards and ~1.3 ± 0.4 for Centres, a nonsignificant difference (Pino-Ortega et al., 2019). Beyond competition volume, the mechanical demands of academy basketball, frequent accelerations, decelerations, landings, and repeated jumps, add substantial stress even when session durations are modest, underscoring why time alone is insufficient to characterise exposure (Arede et al., 2021; Askow et al., 2023). Collectively, these features highlight that academy training demands are shaped by the interplay of competition density, positional roles, and movement-specific mechanical loads, reinforcing the need for thorough monitoring approaches that integrate internal and external indices across macro-, meso-, and micro-timescales.

2.4 Monitoring Internal Training Load

Internal TL refers to the physiological and perceptual response to training or competition, typically indexed via heart-rate metrics, blood lactate, or the RPE (Impellizzeri et al., 2005, 2019). In youth athletes, internal TL is especially important because two individuals completing the same training can exhibit different internal responses due to differences in biological maturation, fitness, or training history (Scantlebury et al., 2018). For example, Scantlebury et al. (2018) found that less mature adolescents recorded higher heart rate and RPE values than their more mature peers when performing the same drills. This disparity, which can likewise stem from varying maturity, familiarity and fitness levels, illustrates the need for individualised interpretation of internal TL.

2.4.1 Concepts and Measures of Internal Training Load

Perceptual metrics, most prominently the sRPE method, are widely used in basketball because they are non-invasive, low-cost, and practical for repeated use (Scanlan, Wen et al., 2014). In this approach, athletes provide a single global exertion rating after a session, which is then multiplied by the session duration to derive sRPE. Research indicates that adolescent players can reliably self-report exertion when they are properly familiarised with the scale (Scantlebury et al., 2018). Furthermore, sRPE shows moderate-to-strong correlations with heart-rate-derived internal TL measures (e.g., Edwards' TRIMP), supporting its use in youth populations (Lupo et al., 2017). Heart-rate–based internal TL models are often used as a point of comparison in research, but they tend to be less practical in youth settings due to time and resource restraints, and large group sizes. Consequently, many high-performance programs rely more on sRPE, which yields information that is complementary to, rather than interchangeable with, physiological indices (Moreira et al., 2012; Scantlebury et al., 2018; Svilar & Jukić, 2018). However, several key gaps persist in the youth basketball literature.

Competition-specific reliability data for sRPE in adolescents remain limited, and few studies have tracked internal TL longitudinally across multiple training years or academic terms within academy settings. Moreover, limited integration of sRPE with external TL models restricts understanding of how perceived exertion reflects the cumulative mechanical demands of training and competition. Inconsistent reporting of drill formats and intensity descriptors across studies also impedes the development of youth-specific reference ranges, leaving practitioners without clear contextual benchmarks for interpreting internal load data.

Addressing these issues, the present thesis describes multi-year internal TL trends within a high-performance academy and illustrates ways to integrate subjective and objective measures to enhance the interpretation and application of TL monitoring for coaches and sport scientists.

In youth basketball, internal TL is most commonly quantified via the Borg CR-10 RPE scale and its session-based derivative (sRPE, calculated as RPE × session duration) (Scanlan, Wen et al., 2014). Standard protocols typically involve collecting a single global RPE ~30 minutes after each session and then summing or averaging values to produce weekly TL metrics (and, sometimes, derived measures such as monotony or strain) (Manzi et al., 2010; Paulauskas et al., 2019). Such procedures have been implemented successfully in youth athlete cohorts (Scantlebury et al., 2018). Substantial evidence supports the validity and reliability of RPE-based measures in youth samples. For example, in U17 players, sRPE correlates strongly with a heart-rate-based internal TL measure (Edwards' TRIMP), and reliability coefficients for sRPE are in the acceptable-to-good range. These relationships hold for both shorter sessions (<80 min) and longer sessions (≥80 min) (Lupo et al., 2017). During standardized youth basketball exercise, sRPE correlates very strongly with HR-derived TL in the first 10–20 minutes, but the correspondence weakens beyond 20 minutes (Scanlan et al., 2017). This finding suggests that RPE captures accumulating psychophysiological strain that heart rate alone may not (Berkelmans et al., 2018; Vaquera et al., 2018). Together, these studies indicate that sRPE is a practical and responsive index of internal TL in adolescents and emphasise that sRPE provides information that is complementary to, rather than redundant with, purely physiological markers.

The accuracy of internal TL measures like RPE depend on standardised administration. Research recommends collecting RPE from each athlete in a private setting and at a consistent interval after the session, using a properly anchored CR-10 scale (Fanchini et al., 2016; Impellizzeri et al., 2019). Without these controls, factors such as peer presence or a coach's immediate influence can bias the ratings (Impellizzeri et al., 2019; Saw et al., 2016). Similarly, coach-provided RPE estimates are not interchangeable with athlete self-reports; coaches tend to underestimate players' exertion (Lupo et al., 2017; Vaquera et al., 2018), so direct athlete feedback remains essential. Finally, the agreement between sRPE and HR-based TL measures varies with session characteristics, where longer or more intermittent sessions tend to show greater divergence between the two measures. Therefore, practitioners should interpret sRPE values considering the session duration and drill format (Campos-Vazquez et al., 2015; Clemente, Teles Bredt et al., 2020; Wallace et al., 2009). In particular, very short or segmented activities may yield large sRPE–HR discrepancies, so understanding the session structure is important when evaluating internal TL data (Lupo et al., 2017; Scanlan et al., 2017). It is important to clarify that RPE denotes the 0–10 perceptual rating, whereas sRPE denotes RPE×session duration; they are related but not interchangeable, longer sessions can yield higher sRPE despite similar mean RPE.

2.4.2 Internal Training Load in Youth Basketball

Empirical research on internal TL monitoring in elite youth basketball includes both short-term observational studies and acute, drill-level experiments, though evidence spanning full seasons or multi-year periods remains scarce. Across these studies, RPE/sRPE is the predominant monitoring method (typically using a CR-10 or OMNI RPE scale administered post-session for sRPE) (Lupo et al., 2017). In this synthesis, we focus on RPE/sRPE rather than HR indices, because HR measures were inconsistently reported across youth studies and are less feasible to implement systematically in academy settings (Lupo et al., 2020; Scantlebury et al., 2018). Many reports also examine contextual moderators such as players' maturity status (Arede et al., 2022), team role (starter vs. non-starter; (Gonçalves et al., 2025)), and specific drill constraints (Sansone et al., 2020). Together, this body of work demonstrates that coaches can modify athletes' internal TL by altering training content and context (for example, by changing drill formats or competitive scenarios), although the magnitude and direction of changes are not uniform across studies (Conte et al., 2016; Vaquera et al., 2018). This variability reinforces the idea that TL monitoring may need to be tailored to the specific program and its coaching objectives. Key studies examining perceptual measures of internal TL in male youth basketball players are summarised in Table 2.1.

Seasonal and Weekly Training Load Patterns

Understanding seasonal and weekly fluctuations in internal TL is essential for interpreting cumulative load exposure in academy athletes. For instance, in one U17 program, weekly sRPE totals ranged approximately from 700 to 1,750 AU over an 8-week preseason, with higher spikes occurring in more intensive weeks (Lupo et al., 2017). A 20-week study extending into the competitive season found that average weekly sRPE totals were roughly equivalent between the preseason and in-season periods (~588 vs. 626 AU) (Brunelli et al., 2014). Notably, it found that training monotony (week-to-week similarity of TL), rather than the absolute TL, was associated with players' illness incidence (Brunelli et al., 2014). This observation aligns with findings in professional rugby athletes, where the way TL is distributed (e.g., sustained monotony versus sharp spikes) can matter as much as the total TL accumulated (Gabbett, 2020). However, given the growth-related changes in adolescents, extrapolating adult-derived TL guidelines to youth athletes must be done with caution (DiFiori et al., 2018; Gabbett, 2020; Lloyd et al., 2016).

In intensive camp environments, typified by prolonged daily practices or multiple sessions per day, studies have documented week-to-week increases in internal TL. For example, in a two-week U16 camp, total weekly sRPE increased from ~7,000 AU in Week 1 to ~8,200 AU in Week 2 (Arede et al., 2019). This pattern reflects a substantial cumulative training dose when practice density remains high. Notably, the same study reported that after accounting for differences in players' exposure (i.e., competition minutes played), biological maturity alone did not produce consistent RPE differences between athletes (Arede et al., 2019). This indicates that players of differing ages accrued similar internal TL when exposed to comparable playing time. (Arede et al., 2019). At the single-session level, typical youth practices have reported to elicit mean RPE values of ~6–7 on the CR-10 scale , corresponding to ~500–600 AU per session when multiplied by typical session durations (~75-90 minutes) (Lupo et al., 2017). In this study, sRPE values demonstrated significant correlations with HR-derived TL measures and differentiated between training formats, supporting its practical feasibility and sensitivity to variation in session demands (Lupo et al., 2017). Taken together, these findings make evident that sRPE monitoring can effectively quantify training dose in youth basketball and help track TL patterns (e.g., week-to-week changes or monotony) throughout the season.

Comparing Perceptual Loads Between Training and Competition

Comparing internal TL in training and competition reveals no universal rule that matches are always more demanding; instead, the differences depend on context (summarised in Figure 2.3). For example, in an international U16 camp that included both practices and exhibition matches, the RPE was similar between training sessions and matches (4.7 ± 0.96 vs. 4.9 ± 0.89 on the CR-10 scale), and bench players actually reported higher RPE than starters in both contexts (Vaquera et al., 2018). These findings suggest that an athlete's role and the extent of their playing time can influence internal TL, as much as whether the activity is a practice or a match. At younger ages (e.g., U12 mini basketball), match RPE values tend to be moderate-strong (~4.5 on the RPE scale) and do not differ significantly between boys and girls (Maite Fuentes Azpiroz et al., 2013). This lack of a sex difference likely reflects the similar maturity levels, limited training experience, and comparable RPE understanding of boys and girls at this pre-adolescent stage (Eston et al., 2000). Collectively, this suggests that intra-match factors and individual opportunities (such as style of play and each player's time on court) drive internal TL more than the nominal competition level itself (Arede et al., 2022). Even within competitions, situational factors play a role; for instance, one study found that in youth tournaments, championship final matches elicited higher RPE than semifinal matches, presumably due to the greater psychological and physical stakes of a final (de Arruda et al., 2019). From a methodological standpoint, these observations have prompted calls for further validation of sRPE under varied competitive scenarios. For example, researchers have suggested verifying whether RPE measures remain reliable across different match contexts, player roles, and across both male and female athletes (Conte et al., 2016). In particular, there are several competition-specific gaps to address: (i) test–retest reliability of sRPE across matches in adolescents; (ii) agreement between athlete-reported and coach-reported RPE on match days; (iii) sensitivity of sRPE to role status (starter vs. non-starter) and congested schedules; and (iv) standardised reporting of RPE collection timing and anchoring procedures.

Drill and Constraint Effects on RPE

At the drill level, manipulating player numbers, court space, and work–rest ratios can alter RPE responses, though the direction and magnitude of change depend on the specific task design (Figure 2.4). Across multiple studies, reducing the number of players results in increased RPE under otherwise comparable drill types or training conditions. For example, 2v2 drills consistently elicit higher RPE than 4v4 drills (Conte et al., 2015, 2016; Klusemann et al., 2012). Additionally, full-court formats and longer continuous bouts (e.g., 2×5 min) increase perceived TL relative to half-court or more intermittent formats (e.g., 4×2.5 min)

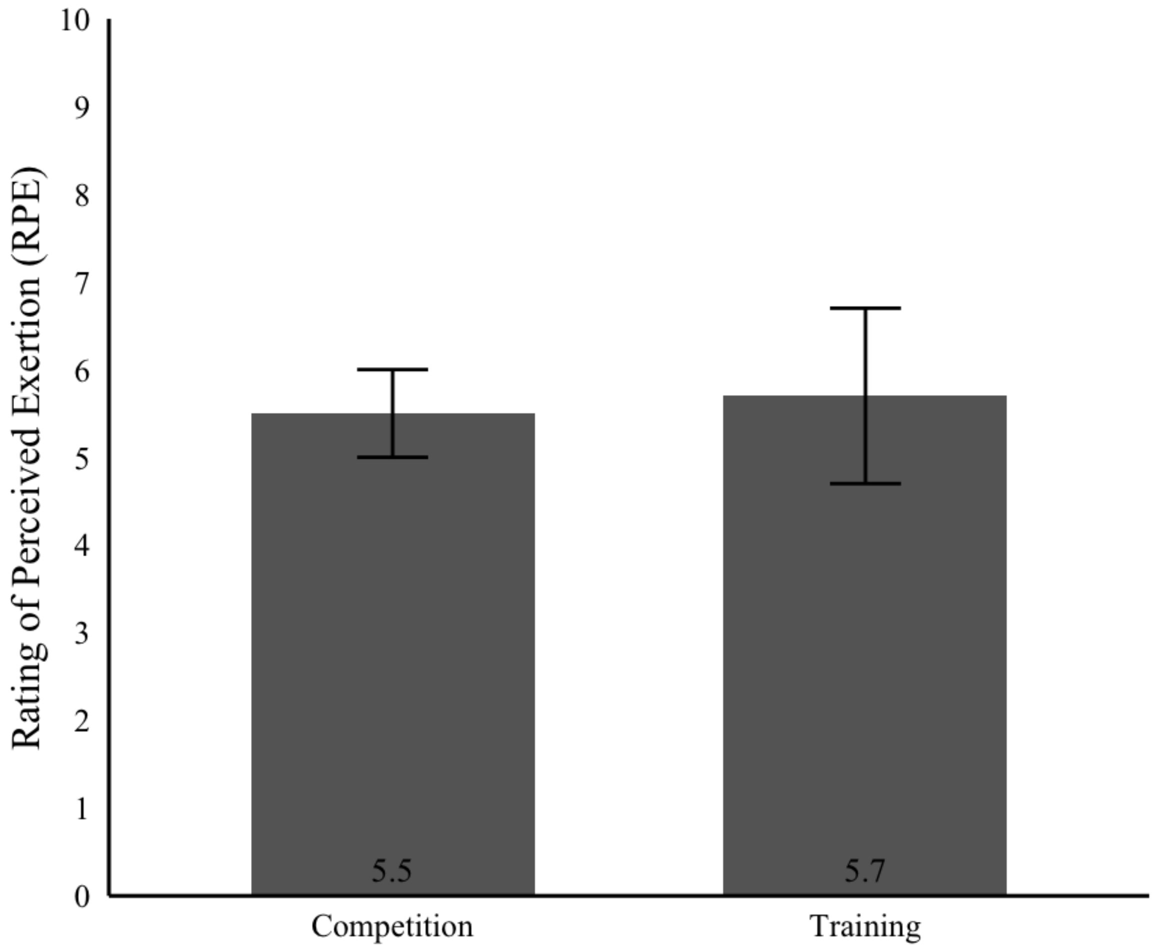
(Conte et al., 2016). In a controlled trial with elite juniors, these effects were accompanied by more time spent ≥90% HRmax during the longer continuous bouts (Conte et al., 2016). A six-week training observation likewise showed that 2v2 drills produced the highest RPE of all drill formats tested, and it revealed two practical issues for monitoring: heart rate and RPE measures did not always align by drill type, and coaches tended to underestimate athletes' exertion (Lupo et al., 2017). Both findings support embedding athlete-reported measures in daily decision-making rather than relying solely on coach judgement or HR proxies. Notably, one study varied area per player and bout structure, with 5v5 scrimmages producing greater RPE than 1v1–3v3 scenarios (Sansone et al., 2023).

Beyond player numbers, other constraints (e.g., court size and bout duration) also influence RPE, though their effects can depend on specific combinations of factors. For instance, larger court areas in a 3v3 drill raised RPE, whereas changing player numbers from 3v3 to 4v4 had minimal effect when space and work–rest ratio were held constant (Arede et al., 2019; Maite Fuentes Azpiroz et al., 2013).

Summary

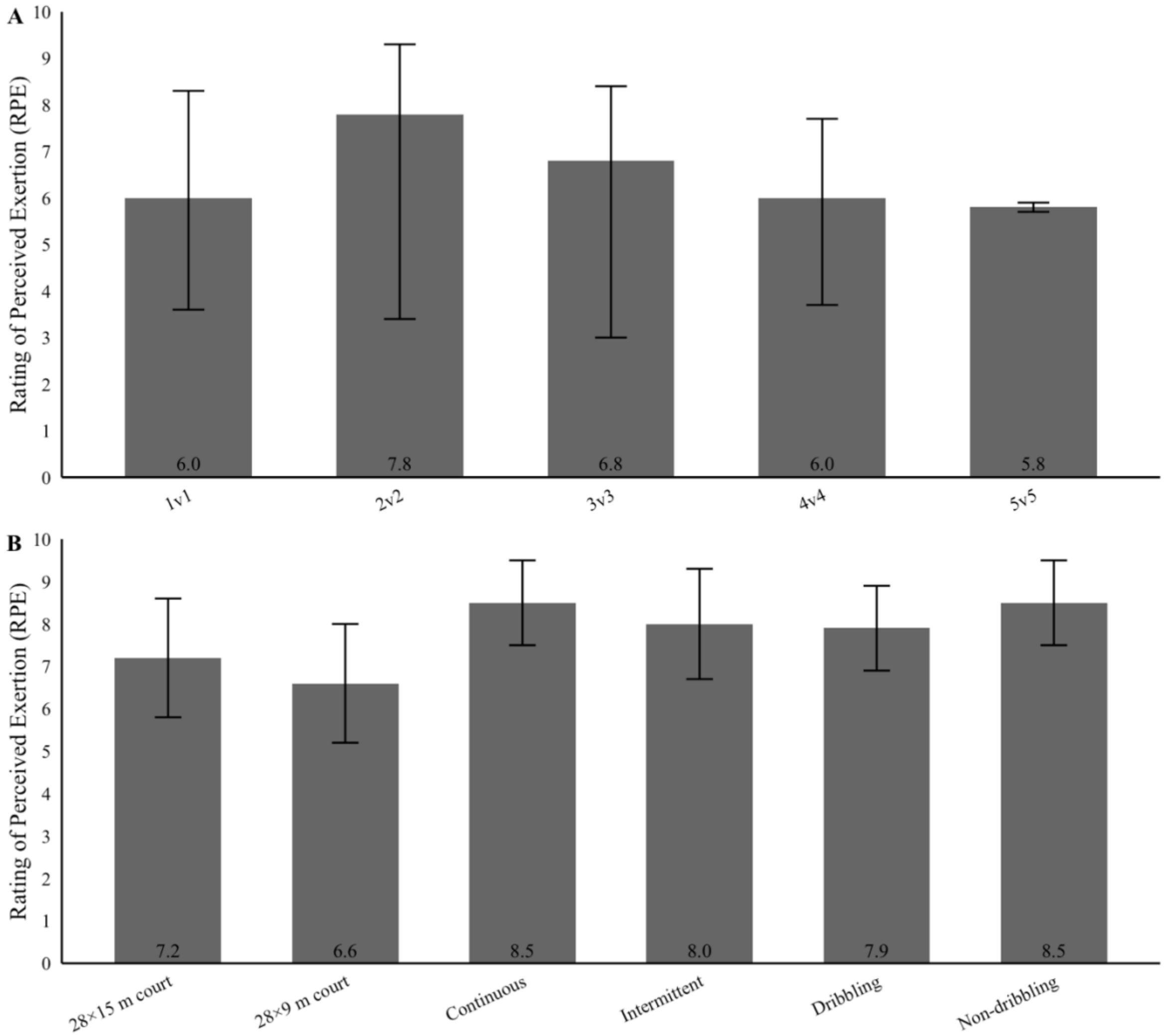
RPE- and sRPE-based monitoring in youth basketball provides an indication of the psychophysiological response to the training and competition demands that athletes experience. At the same time, it highlights that internal intensity depends on contextual factors, such as when during the season the TL occurs, what role the athlete plays, and how drills are structured. However, the current literature also exposes several important knowledge gaps. Evidence is limited regarding the reliability of internal TL measures in youth competition settings, and it remains unclear how well coaches' intended training intensities align with athletes' reported experiences. In addition, studies employ varied and sometimes underspecified drill descriptors (e.g., different definitions of small-sided games or work–rest formats), making cross-study comparisons of internal TL findings difficult. Together, these gaps highlight priorities for future research: validating internal TL metrics in match scenarios, improving the connection between coaches' intended training intensity and athletes' reported exertion, and standardizing how drill conditions are reported to enable consistent interpretation across studies. Most reports also involve a single team with a small sample (approximately 10–20 players) observed over a short period (weeks rather than full seasons), resulting in low participant numbers and limited generalisability. Addressing these issues would move the field toward a more comprehensive monitoring approach that connects macro-level TL patterns to micro-level drill designs in youth development programs.

Figure 2.3 Reported internal training loads (RPE, Borg's CR-10 Scale) in male youth basketball during training and competition



Note: Includes data from Arede et al., 2019, 2022; Lupo et al., 2017; and de Arruda et al., 2018

Figure 2.4 Reported internal training loads (RPE, Borg's CR-10 Scale) by (A) player numbers and (B) rule and contextual manipulations during drills in youth basketball training



Note: Includes data from Clemente et al., 2020; Conte et al., 2015, 2016, 2017; Klusemann et al., 2012; Marcelino et al., 2016; Sampaio et al., 2009; and Vaquera et al., 2018.

Table 2.1 Studies investigating perceptual measures of internal training load of male youth (under 18 years of age) basketball players

AGE-GROUP / LEVEL	STUDY	POPULATION	COMPETITION OR TRAINING, PHASE OR TYPE	LENGTH / SESSIONS	METHODS	PERCEPTUAL TRAINING LOAD	OUTCOMES
Youth International	Arede et al., 2019	16.02 ± 0.40; n = 12	Training, camp Competition, exhibition	18.4 ± 1.5 training sessions 2.6 ± 0.5 matches	RPE, Borg CR10	Training RPE = 4.70 ± 0.96 Matches RPE = 4.87 ± 0.89	Nonstarters display greater demands than starters in training and matches
	Arede et al., 2022	16.0 ± 0.4; n = 29	Training, camp	3 seasons, 21 sessions/year (63 total)	RPE, Borg CR10	Weekly sRPE Week 1: 7049 ± 1261 Week 2: 8217 ± 1306	TL increases as training camp progresses No differences in TL between maturity
Youth National / State	de Arruda et al., 2019	U15, U16, U17 n = 33	Competition, post season	6 matches	RPE, Borg CR10	Did not specifically report	Finals matches elicit greater RPE than semi-final matches
	Clemente et al., 2020	U14 - 12 ± 0.8 U16 - 14.3 ± 0.5; n = 20	Training, regular season, midseason	5 weeks, did not report	RPE, Borg CR10	1v1 Drills U14 - RPE = 3.65 ± 1.53 U16 - RPE = 3.65 ± 0.97 2v2 Drills U14 - 3.60 ± 0.94 U16 - 3.40 ± 0.99 3v3 Drills U14 - RPE = 3.85 ± 0.67 U16 - RPE = 3.70 ± 0.82 4v4 Drills U14 - RPE = 3.80 ± 0.95 U16 - RPE = 3.70 ± 0.82 5v5 Drills U14 - RPE = 5.70 ± 0.48 U16 - RPE = 5.85 ± 0.78	Age group did not impact RPE in different SSGs Smaller SSG require more technical actions Larger SSG elicit greater RPE
	Klusemann et al., 2012	18.2 ± 0.3; n = 8	Training, preseason	6 weeks, did not report	RPE, did not report	4v4 Drills - RPE = 6 ± 2 2v2 Drills - RPE = 8 ± 2 Half Court Drills - RPE = 6 ± 2 Full Court Drills - RPE = 7 ± 2 2x5min Drills - RPE = 7 ± 2 4x2.5min Drills - RPE = 7 ± 2	Fewer players in SSG increases the technical, physiological, and physical demands

AGE-GROUP / LEVEL	STUDY	POPULATION	COMPETITION OR TRAINING, PHASE OR TYPE	LENGTH / SESSIONS	METHODS	PERCEPTUAL TRAINING LOAD	OUTCOMES
Youth National / State	Vaquera et al., 2018	16 ± 0.4; n = 12	Training, regular season	6 weeks, 15 training sessions	RPE, Borg CR10	Drill RPE 1v1: 8.3 2v2: 9.1 5v5 and 3v2 not explicitly reported	RPE was greater in 2v2 than all other scenarios RPE and HR responses did not align by drill Coaches underestimated player RPE
	Lupo et al., 2017	16.5 ± 0.5; n = 6	Training, regular season	5 weeks, 66 individual training sessions	RPE, Borg CR10 sRPE	RPE = 6.7 ± 1.3 sRPE = 542 ± 227	sRPE are an appropriate measure of Internal TL regardless of session duration and workout portions
	Scanlan et al, 2017	16.6 ± 1.1; n =10	Training, basketball exercise simulation test	1 training session, 4 x 10min bouts	sRPE, Borg CR10	sRPE 47.0 ± 15.7 65.0 ± 17.8 65.0 ± 24.2 74.0 ± 22.7	Training dose alters responses and relationships between TL Models Sessions >20min show variability HR-based models correlate well with sRPE
Youth Regional	Conte et al., 2015	15.5 ± 0.9; n = 23	Training, regular season, dribbling vs non-dribbling drills	10 weeks, 60 training sessions	RPE, Borg CR10	Dribbling Drills RPE = 7.9 ± 0.2 Non-Dribbling Drills RPE = 8.5 ± 0.2	Drills modified to exclude dribbling elicited greater physiological demands
	Conte et al., 2016	15.4 ± 0.9; n =21	Training, regular season	Did not report	RPE, Borg CR10	2v2 Drills - RPE = 8.8 ± 0.9 4v4 Drills - RPE = 7.7 ± 1.1 Continuous Drills - RPE = 8.5 ± 1 Intermittent Drills - RPE = 8.0 ± 1.3	Fewer players in SSG increases the perceptual demands Continuous drills elicit higher perceptual demands
	Marcelino et al., 2016	18.6 ± 0.5; n = 12	Training, regular season	2 training sessions	RPE, Borg CR10	28x15m Drills RPE: 7.2 ± 1.4 28x9m Drills RPE: 6.6 ± 1.4	Lactate responses similar between court sizes RPE higher with greater court area Repeat sprint not impacted by court size

AGE-GROUP / LEVEL	STUDY	POPULATION	COMPETITION OR TRAINING, PHASE OR TYPE	LENGTH / SESSIONS	METHODS	PERCEPTUAL TRAINING LOAD	OUTCOMES
Youth **Level not reported**	Sampaio et al., 2009	15.5 ± 0.6; n = 8	Training, regular season	1 training session	RPE, OMNI Scale	3v3 Drills 3.0 ± 0.5 4v4 Drills 4.1 ± 0.8	SSG promote high physiological demands
Junior	Conte, et al., 2017	13.9 ± 0.7; n = 12	Training, preseason	2 weeks, 6 training sessions	RPE, Borg CR10	2v2 Drills - RPE = 9.3 ± 0.9 3v3 Drills - RPE = 8.4 ± 0.9	The number of players involved in drills alter the intensity of the drill
	Brunelli et al., 2014	13.3 ± 0.6; n = 11	Training, pre and regular season	6 (pre) and 14 (regular) weeks, 3 sessions/week (total 60)	RPE, Borg CR10	Weekly sRPE Preseason: 587 Regular: 625	TL did not correlate with increased illness, though training monotony did

2.5 External Load Monitoring

External TL monitoring is now common in youth basketball sports science practices, often adapting to advances in wearable technology (Fox et al., 2017; Portes et al., 2019). External TL refers to the measures related to the work completed by an athlete during training or competition (e.g., distance covered, number of accelerations, mechanical output) and is measured independently of the athlete's internal physiological or psychological responses; representing the external physical stimulus applied to the body (Impellizzeri et al., 2005, 2019). In recent years, coaches and researchers have shown increasing interest in tracking external TL in young basketball players to optimise training plans, improve performance, and mitigate the risk of overuse or burnout (Fox et al., 2017; Portes et al., 2019). However, explicitly linking external TL outputs to coaching intentions and individual development goals is still uncommon in youth basketball research, leaving an interpretive gap between measurement and program design (Saw et al., 2016; Weston et al., 2015).

2.5.1 Application in Basketball

External TL metrics quantify the work performed by an athlete, independent of internal physiological responses, and are often referred to as the 'dose' of training (Impellizzeri et al., 2019, 2023). For reporting and interpretation, external TL may be grouped into a practical framework with three components: dose (weekly/session volume measures such as total distance and total PL), intensity (rate-based indicators like PL $\cdot min^{-1}$, accelerations $\cdot min^{-1}$, and other high-speed efforts), and distribution (how load is spread, e.g. peaks and exposure across intensity bands or match quarters) (Impellizzeri et al., 2023). For instance, relative distance and PL $\cdot\text{min}^{-1}$ commonly serve as proxies for intensity (Scanlan et al., 2017; Weaving et al., 2017). Deceleration counts indicate mechanical braking demand (Ibáñez et al., 2024) and distances covered in defined velocity zones characterise the locomotor profile of activity (Rago et al., 2020). Because distinct drills can produce similar totals, these metrics must be interpreted in context (e.g., considering the number of players, court space, work–rest structure, and rules) and paired with internal indices to avoid false equivalence when evaluating TL. By understanding sport-specific external TL, coaches can prescribe appropriate drill intensities, structures and durations, manage training frequency, and balance work and recovery for youth athletes (Sansone et al., 2023). Moreover, tracking external TL helps ensure that training sessions prepare players for the high-intensity bursts and intermittent demands of competition (Sansone et al., 2023). In youth basketball academies, where athlete development is a priority (Whitaker-Campbell, 2017), external TL data may provide feedback for adjusting training programs to improve performance while safeguarding athletes' health. In summary, external TL monitoring is a useful tool for managing training stimuli in youth players. It can help expose them to sufficient stress to stimulate adaptation without overuse, and it guides coaches in tailoring training to mimic competition demands for better match preparedness.

2.5.2 Technology, Validity and Metrics

For indoor court-based sports, satellite-based Global Positioning Systems (GPS) has limited use, and basketball often relies on IMUs and Local Positioning Systems (LPS) (often ultra-wideband; UWB) for external TL monitoring (Svilar & Jukić, 2018; Vanrenterghem et al., 2017). Common tracking systems reported in youth basketball TL literature include Catapult (IMU and LPS; ClearSky) and WIMU Pro (Alonso Pérez-Chao et al., 2022; Askow et al., 2023; Kutson et al., 2024; Pino-Ortega et al., 2019; Sosa et al., 2025). Modern microsensors typically combine triaxial accelerometers, gyroscopes, and magnetometers (commonly sampling at ~100 Hz) and are worn between the shoulder blades or on the waistband of shorts to avoid impeding play. Many systems also integrate indoor LPS to add position and distance data alongside inertial data (Fox et al., 2017; Luteberget et al., 2018; Rico-González et al., 2021). Data from these devices are processed using proprietary software to derive external TL metrics. One common metric is accelerometer-derived PL, the vector sum of triaxial accelerations (Barrett et al., 2014). It shows acceptable reliability for measuring movement volume in court sports, but its exact accuracy and comparability can vary by sampling rate, firmware, and algorithm, making within-program device consistency essential (Barrett et al., 2014; Fox, Conte et al., 2021; Ibanez et al., 2020; Nicolella et al., 2018; Roell et al., 2018). Across systems, accelerometer-derived metrics are often marketed under different proprietary names (e.g., PL, Impulse Load, Body Load), all quantifying similar triaxial acceleration-based movement volume (McLean et al., 2019). In this thesis, PL is used as the primary external TL indicator, representing this broader class of inertial-sensor load metrics.

Wearable tracking systems yield a rich array of external TL metrics. Volume-oriented measures include total distance and cumulative PL, whereas intensity is often indexed via distances in velocity bands, accelerations/decelerations $\cdot min^{-1}$, or peak values (Fox, Salazar et al., 2021; Scanlan et al., 2017; Sosa et al., 2025). For example, one study on U18 match play defined high-intensity running as 18.1–24.0 km/h and sprinting as >24 km/h, enabling band-specific profiling of distance covered (Vázquez-Guerrero, Fernández-Valdés, Gonçalves et al., 2019). PL, reported in arbitrary units, aggregates the mechanical work done based on changes in acceleration in all directions (Nicolella et al., 2018). This TL metric can be expressed as a total for a session or normalized $\cdot min^{-1}$ ($PL \cdot min^{-1}$) to gauge intensity (Scanlan et al., 2020). Systems can also quantify specific movements such as jumps, landings, and explosive actions, as well as capture change-of-direction events and collision proxies (often termed "body impacts") (Arede et al., 2021; Askow et al., 2023). Video-based time–motion analyses once used for such profiling have now been largely supplanted by these microsensor outputs (Conte et al., 2015; Wang et al., 2024).

Overall, external TL metrics in youth basketball commonly reflect both the volume of activity (e.g., total distance covered, cumulative PL) and the intensity of that activity (e.g., high-speed running distance, accelerations $\cdot min^{-1}$, peak speed or acceleration values). Each metric offers distinct insights, for example, total distance and PL indicate the overall work done (Fox, O'Grady et al., 2020; Sosa et al., 2025), while counts of high-intensity sprints or accelerations capture the burst-type efforts critical in competition (Ben Abdelkrim, Chaouachi et al., 2010; Conte et al., 2015; Koyama et al., 2022). Importantly, cost and practicality can influence technology choices in youth settings; whereby elite programs may use sophisticated LPS/IMU systems, and simpler tools like heart rate monitors or smartphone apps for exertion and wellness are also employed as low-cost complements to track TL and recovery status (Kutson et al., 2024; Piedra et al., 2021).

2.5.3 External Training Load of Youth Basketball

Empirical research on external TL in youth basketball has expanded over the past decade, providing a clearer picture of the physical demands that youth players face in both training and competition. Studies have variously examined how TLs are structured across seasons, how the intensity of matches compare to that of practices, and how factors such as match quarter, player position, sex, age group, or maturation status influence external TL measures in youth contexts. Collectively, this growing body of work informs coaches about typical TL profiles for youth athletes and guides them in designing practices that appropriately mimic match demands. However, most available studies are short-term, single-team, and largely descriptive. Few have examined how external and internal TL interact across multiple years, or whether measured training outputs reflect coach intentions, key gaps this thesis seeks to address. In the discussion below, the evidence is synthesised by thematic focus and key findings are highlighted, with Tables 2.2 to 2.4 summarising research describing external TLs, training-specific load characteristics, and studies examining internal and external load measures concurrently in youth basketball.

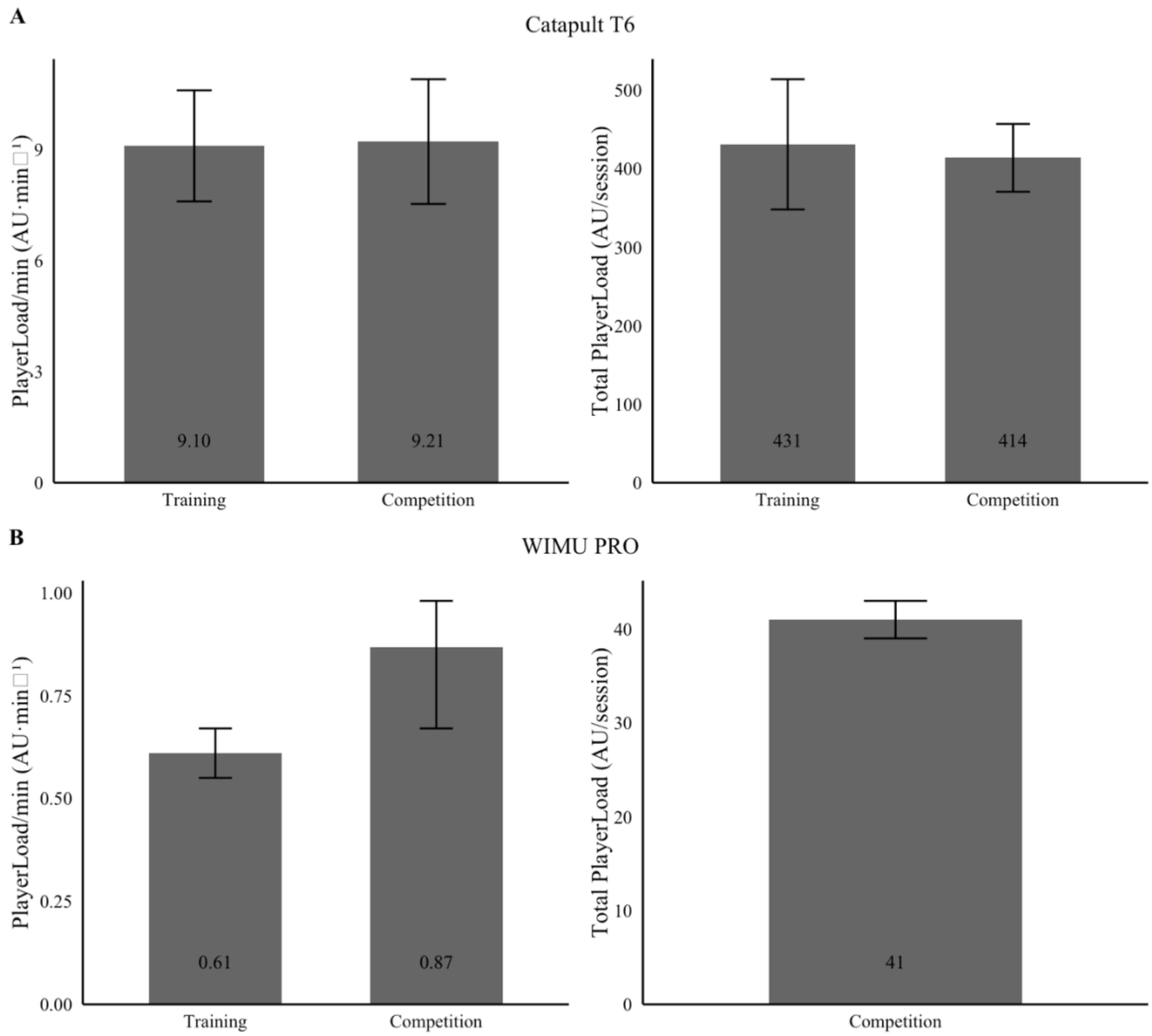
External Training Load Patterns in Youth Basketball

A central issue is the extent to which external TLs of matches can be replicated in practices, considering both cumulative volume and the frequency of high-intensity actions (Conte et al., 2015; Gonçalves et al., 2025). Several studies have directly compared the external TL of training sessions to those of official matches (Figure 2.5).

In one sample of Brazilian junior male players, no significant differences were found between the average external TL of training sessions and that of an official match in terms of distance covered (Brandão et al., 2019). This suggests that, for that team, overall practice volume was comparable to match volume. Similarly, a study of U.S. high school players showed that starters accumulated a comparable total TL in practices as they did in matches, with an average PL in practices equating to ~94% of the game value (Kutson et al., 2024). In addition, a study of youth players in Spain reported more high-intensity actions, such as explosive accelerations in games compared with training, despite similar total TL (Alonso Pérez-Chao et al., 2022). Taken together, the evidence indicates that although total training and match loads can appear equivalent, the underlying intensity distribution may differ, with matches involving more frequent maximal-effort movements that are challenging to reproduce in practice settings.

By contrast, several studies report greater demands in matches than in practices. In an observational 10-week study of U16 players, athletes attained significantly higher values in most external TL measures during official matches than during formal training sessions (Gonçalves et al., 2025).

Figure 2.5 Reported external training loads in male youth basketball by device type during training and competition; A) Catapult T6 and B) WIMU Pro



Note: Includes data from Alonso et al., 2020; Arede et al., 2020; Askow et al., 2023; Pino-Ortega et al., 2019; Portes et al., 2020; and Vazquez-Guerrero et al., 2019, 2020. Absolute PlayerLoad values differ substantially between Catapult and WIMU systems due to proprietary scaling algorithms and signal-processing methods applied to triaxial accelerometer data. Values should therefore not be directly compared across manufacturers without calibration or standardisation.

The authors concluded that these youth players “do not train as intensely as they play,” particularly for the starters who experienced the highest match loads (Gonçalves et al., 2025). This finding aligns with a case study in an elite academy that reports despite the coaches’ intent to simulate match demands, certain peak intensities observed in competition remained unmatched in training (Palmer et al., 2023). Together, these studies highlight that the relationship between practice and match loads in youth basketball can vary depending on the context. Evidence suggests that some youth programs achieve practice loads comparable to matches, whereas others show matches exceeding practice demands. Coaches are therefore advised to monitor TL in both contexts and adjust training if needed to ensure players are prepared for competitive demands. These differences are likely influenced by coaching intent and periodisation strategy. At certain points in the season, training may be designed to exceed match demands to induce overload, whereas at other times it may be reduced to prioritise competition performance. Accordingly, comparisons between practice and match loads should be interpreted within the broader training context.

Research using external TL monitoring in youth basketball across multiple weeks shows that during preseason conditions, weekly TLs are generally stable with isolated peaks. In one structured preseason, week-to-week external TL varied little until a single high-TL spike late in the block (week 9) (Palmer et al., 2023). By contrast, competition phases, especially congested tournaments, elevate cumulative and peak demands: tournament play increases movement demands across the event, and match intensity typically exceeds training intensity, whereby $PL \cdot min^{-1}$ is higher in matches than training (Petway et al., 2020; Pino-Ortega et al., 2019; Vázquez-Guerrero, Fernández-Valdés, Jones et al., 2019). Average session or match metrics can obscure short peak passages more closely linked to performance-relevant moments; youth studies report that peaks provide information beyond means, although this evidence is based on small, single-team samples and short observation windows (Fox, Conte et al., 2021). Role and exposure also matter, with starters reported to accumulate greater external TL across seasons than non-starters (Brandão et al., 2019). Routine week-by-week monitoring across phases is warranted given observed intra-season variability and occasional spikes (e.g., preseason and in-season week-to-week fluctuations; isolated peaks) (Kutson et al., 2024; Palmer et al., 2023). Between-study comparisons should be made cautiously as device brand, firmware, algorithms, and sampling rates can shift absolute values and reliability; maintaining within-program device consistency is essential (Barrett et al., 2014; Ibanez et al., 2020; Nicolella et al., 2018; Roell et al., 2018).

Competition Load Patterns

Youth basketball matches are typified by high-intensity intermittent events, and analyses show that intensity typically declines as a match progresses. At the session level, per-minute external TL is often higher in matches than practices in national-level youth cohorts, for example, Dynamic Stress Load (DSL)$\cdot$min^{-1} $\approx 2.18 \pm 0.66$, Impacts$\cdot$min^{-1} $\approx 159.5 \pm 9.8$, Steps$\cdot$min^{-1} $\approx 57.8 \pm 4.6$, and Jumps$\cdot$min^{-1} $\approx 0.83 \pm 0.23$, with matches exceeding training on most indices except jumps (Gonçalves et al., 2025). That said, some settings show comparable practice–match volumes (distance) (Brandão et al., 2019), or practice totals approximating game PL. Within matches, outputs typically decline across quarters: in elite

U18 competition, total distance and PL are lower in Q4 than Q1, with a concurrent reduction in high-intensity actions (Vázquez-Guerrero, Fernández-Valdés, Gonçalves et al., 2019). While the absolute drop in total distance is small (Vázquez-Guerrero, Fernández-Valdés, Jones et al., 2019), the parallel decline of high-speed efforts and PL is the practically relevant pattern, consistent with pacing/fatigue effects. Peak ("worst-case") external demands also attenuate from Q1 to later quarters in U18 matches (Salazar et al., 2025), and short-duration peaks are substantially lower by Q4 (Alonso et al., 2020).

External Training Load Profiles of Drills

Several studies quantify drill-level external TL to characterise training intensity. In youth practices, Sansone et al. (2023) compared common formats, technical skills, 1×1, 3×3 half-court, and 5×5, using PL·min^{-1} to quantify average and peak outputs. Distinct external TL profiles emerged by drill type: small-sided or live drills produced higher work density (e.g., PL·min^{-1}, accelerations·min^{-1}), whereas full 5×5 play generated the largest short-duration peaks but moderate session averages due to stoppages and off-ball periods (Sansone et al., 2023). In a national U15–U16 cohort, live-play drills elicited higher per-minute external TL than typical training activities, illustrating the influence of format and competition constraints on load (Gonçalves et al., 2025). To interpret such differences, TL data can be viewed through a dose–intensity–distribution framework, where session totals represent the dose, per-minute outputs the intensity, and short-duration peaks the distribution (Impellizzeri et al., 2023).

Table 2.2 Studies investigating measures of external competition load of male youth (under 18 years of age) basketball players

AGE GROUP / LEVEL	STUDY	PARTICIPANTS	COMPETITION TYPE	LENGTH / SESSIONS	TECH	PLAYERLOAD (AU)	SUPPLEMENTARY MEASURES	OUTCOMES
YOUTH **INTERNATIONAL**	Alonso et al., 2020	17.56 ± 0.67; n = 12	Tournament	8 matches	Inertial, Catapult T6	PL·min^{-1} = 7.53 ± 1.53 Total PL = 370.67 ± 105.85	N/A	Significant differences between most intense and average demands Average demands underestimate peak demands
	Pérez-Chao et al., 2022	16.6 ± 0.96; n = 13	Regular season	9 matches	LPS, Catapult ClearSky S7	Reported in epochs by quarter	Distance in velocity bands (walking, jogging, running, sprinting) Accelerations, Decelerations	Peak demands decline across quarters
	Pino-Ortega et al., 2019	17.6 ± 0.8; n = 94	Tournament	13 matches	LPS, WIMU PRO Inertial	Guards - PL·min^{-1} = 1.4 ± 0.3 Forwards - PL·min^{-1} = 1.3 ± 0.3 Centres - PL·min^{-1} = 1.3 ± 0.4 *Additional comparisons made between team rankings and match periods	Guards Distance·min^{-1} = 73.9 ± 13.9 High Speed % = 3.5 ± 2.4 Acceleration·min^{-1} = 16.3 ± 2.2 Deceleration·min^{-1} = 15.9 ± 2.2 Peak Speed = 18.8 ± 3.3 Peak Acceleration = 3.4 ± 0.5 Forwards Distance·min^{-1} = 72.2 ± 15.3 High Speed % = 3.6 ± 2.7 Acceleration·min^{-1} = 16.1 ± 1.9 Deceleration·min^{-1} = 15.7 ± 2.0 Peak Speed = 18.4 ± 3.7 Peak Acceleration = 3.3 ± 0.5 Centres Distance·min^{-1} = 66.1 ± 19.8 High Speed % = 3.3 ± 2.9 Acceleration·min^{-1} = 16.3 ± 4.2 Deceleration·min^{-1} = 15.9 ± 4.2 Peak Speed = 17.2 ± 5.2 Peak Acceleration = 2.9 ± 0.7	Team quality, playing position and match period influenced kinematic demands during competition Better teams played with higher intensity, the worst teams had a greater volume of movement Guards and forwards performed more movements than centres Movement demands decreased across quarters Movement demands increased throughout the tournament

AGE GROUP / LEVEL	STUDY	PARTICIPANTS	COMPETITION TYPE	LENGTH / SESSIONS	TECH	PLAYERLOAD (AU)	SUPPLEMENTARY MEASURES	OUTCOMES
YOUTH INTERNATIONAL	Vazquez-Guerrero et al., 2019	17.4 ± 0.74; n = 94	Tournament	13 matches	LPS, WIMU PRO Inertial	PL·min⁻¹ = 1.26 - 1.50 ± 0.26 - 0.29 *Comparisons were made between positions by quarter	Total Distance Distance covered in velocity bands Peak Speed Peak Acceleration Accelerations >2m/s Decelerations < -2m/s	Physical demands reduced between quarters for all playing positions
	Vazquez-Guerrero et al., 2020	17.4 ± 0.75; n = 94	Tournament	13 matches	LPS, WIMU PRO Inertial	*Comparisons made between playing position by time epochs, and by team quality by time epochs	Accelerations (Distance) Accelerations (Count) Decelerations (Distance) Decelerations (Count) Relative Distance Relative Distance in Velocity Bands	No difference in physical demands between playing level, match scores or playing periods Position-related differences in physical demands
YOUTH NATIONAL	Arede et al., 2020	16.02 ± 0.40; n = 12	Exhibition	2.6 ± 0.5 matches	LPS, WIMU PRO Inertial	PL·min⁻¹ = 6.52 ± 1.40	Games Distance·min⁻¹ = 36.18 ± 3.74 High Intensity Acc·min⁻¹ = 0.78 ± 0.21 High Intensity Dec·min⁻¹ = 0.67 ± 0.20 Peak Speed (km/h) = 20.77 ± 0.98 Peak Acc m/s = 3.50 ± 0.19 Peak Dec m/s = -3.51 ± 0.28 Body Impacts·min⁻¹ = 2.65 ± 0.64	Movement demands were dependent on playing status, regardless of training or match
	Arede Et al., 2021	13.45 ± 1.22 U14 and U16; n = 30	Simulated games	3 matches	IMU, WIMU PRO	N/A	Distance·min⁻¹: 80.34 ± 2.05 Accels·min⁻¹: 20.21 ± 1.12 Decels·min⁻¹: 20.02 ± 1.13 Avg Speed: 5.23 ± 0.31 km/h Peak Speed: 17.83 ± 1.82 km/h Impacts·min⁻¹ 21.28 ± 10.93	Opponent maturity alters match demands Younger players had lower external volume

AGE GROUP / LEVEL	STUDY	PARTICIPANTS	COMPETITION TYPE	LENGTH / SESSIONS	TECH	PLAYERLOAD (AU)	SUPPLEMENTARY MEASURES	OUTCOMES
YOUTH NATIONAL	Castillo et al., 2021	15.7 ± 1.7; n = 30	Competition, simulated	1 match	LPS, WIMU PRO Inertial	N/A	U14 (·min^{-1} variables) Total Distance = 93.99 ± 9.26 Cruising distance = 18.90 ± 6.34 High Speed Distance = 1.04 ± 0.83 Sprinting Distance = 0.10 ± 0.32 Accelerating = 17.28 ± 0.90 Decelerating = 17.20 ± 0.83 Jumps = 1.07 ± 0.64 U16 (·min^{-1}variables) Total Distance = 97.69 ± 6.60 Cruising distance = 23.53 ± 2,81 High Speed Distance = 2.18 ± 1.01 Sprinting Distance = 0.69 ± 0.72 Accelerating = 17.84 ± 0.56 Decelerating = 17.79 ± 0.62 Jumps = 1.29 ± 0.73 U18 (·min^{-1}variables) Total Distance = 96.48 ± 4.19 Cruising distance = 23.71 ± 1.83 High Speed Distance = 3.31 ± 1.23 Sprinting Distance = 0.82 ± 0.85 Accelerating = 16.84 ± 0.74 Decelerating = 16.73 ± 0.67 Jumps = 0.94 ± 0.38	Physical fitness is greater in older players Match activity vary across age groups Younger players with superior fitness exhibit higher external TLs
	Gonçalves et al., 2025	15.3 ± 0.88; n = 13	Regular season	10 weeks,10 matches	LPS, WIMU PRO	N/A	Dynamic Stress Load·min^{-1} : 3.72 ± 1.50 Impacts·min^{-1}: 175.92 ± 13.66 Steps·min^{-1}: 73.92 ± 8.93 Jumps·min^{-1}: 0.56 ± 0.15	External TL greater during matches than training, other than jump counts Starters had greater TL than rotation players in matches

AGE GROUP / LEVEL	STUDY	PARTICIPANTS	COMPETITION TYPE	LENGTH / SESSIONS	TECH	PLAYERLOAD (AU)	SUPPLEMENTARY MEASURES	OUTCOMES
YOUTH NATIONAL	Kutson et al., 2024	17.5 ± 0.5; n = 11	Regular season	1 season, n not reported	IMU, Catapult T6	High Minute: 6020 ± 1070 Moderate Minute: 4999 ± 1721 Low Minute: 4251 ± 3423	PlayerLoad reported as monthly totals	High variability in TL across the season High minute players accumulate highest TL
	Sampaio et al., 2014	17.4 ± 1.1; n = 10	Simulated	2 matches (outdoors)	GPS, GPSports	N/A	Did not specifically report Distance covered in speed zones	Activity workload affected court position and tactical performance Faster speeds led to more predictable court positioning
YOUTH CLUB	Askow et al., 2023	17.6 ± 0.7; n = 11	Regular season and tournament	23 matches	LPS, Catapult ClearSky T6	Guards 506.5 ± 103.1 Forwards 322.3 ± 87.9	*Comparisons by position, role (starter vs nonstarter), competition type, competition result and game quarter Jumps by intensity High Intensity Accelerations High Intensity Decelerations Left CoD Right CoD Explosive Movements	Starters produce greater external TL Practice and match volumes were similar, but game intensity was higher TLs Fluctuated week-to-week with match frequency
	Branadao et al., 2019	16.40 ± 0.6; n = 13	Not reported	1 match	Inertial, Polar Team Pro	N/A	Distance (m) = 2240 ± 617	Distance travelled did not differ between training and competition
	Pérez-Chao et al., 2021	16.6 ± 1.0; n = 13	Regular season	9 matches	LPS, Catapult ClearSky S7	Did not specifically report	Did not specifically report	Less playing time (<16.6min) overall and before intense passages lead to higher peak demands

AGE GROUP / LEVEL	STUDY	PARTICIPANTS	COMPETITION TYPE	LENGTH / SESSIONS	TECH	PLAYERLOAD (AU)	SUPPLEMENTARY MEASURES	OUTCOMES
YOUTH CLUB	Portes et al., 2020	17 ± 1; n = 25	Tournament	3 matches, 55 individual samples	LPS, WIMU PRO Inertial	Total PL = 43 ± 27 PL·min^{-1} = 0.95 ± 0.37 *Additional comparisons made between positional groups	Total Distance = 2776 ± 1529 High Intensity Distance = 453 ± 263 Sprint Distance = 49 ± 59 Accelerations = 372 ± 273 Decelerations = 367 ± 273 Accelerations·min^{-1} = 8.6 ± 5 Decelerations·min^{-1} = 8.5 ± 5 Accelerations:Decelerations = 1.02 ± 0.04	There are differences in external TLs, particularly high intensity and accelerometery demands between positions and gender

Table 2.3 Studies investigating measures of external training load of male youth (under 18 years of age) basketball players

AGE GROUP / LEVEL	STUDY	AGE (YEARS)	TRAINING TYPE / PHASE	LENGTH / SESSIONS	TECH	PLAYER LOAD (AU)	SUPPLEMENTARY MEASURES	OUTCOMES
YOUTH NATIONAL	Arede et al., 2020	16.02 ± 0.40; n = 12	Camp	18.4 ± 1.5 training sessions	LPS, WIMU PRO Inertial	Training $PL \cdot min^{-1} = 4.7 \pm 0.96$	Training $Distance \cdot min^{-1} = 35.15 \pm 4.33$ High Intensity $Acc \cdot min^{-1} = 0.76 \pm 0.36$ High Intensity $Dec \cdot min^{-1} = 0.67 \pm 0.36$ Peak Speed (km/h) = 22.95 ± 0.74 Peak Acc m/s = 3.91 ± 0.30 Peak Dec m/s = -3.86 ± 0.33 Body $Impacts \cdot min^{-1} = 2.42 \pm 0.65$	Movement demands were dependent on playing status, regardless of training or match
	Gonçalves et al., 2025	15.3 ± 0.88; n = 13	Regular season	10 weeks, 32 training sessions	LPS, WIMU PRO	N/A	Dynamic Stress $Load \cdot min^{-1}$: 2.18 ± 0.66 $Impacts \cdot min^{-1}$: 159.54 ± 9.75 $Steps \cdot min^{-1}$: 57.84 ± 4.58 $Jumps \cdot min^{-1}$: 0.83 ± 0.23	External TL greater during matches than training, other than jump counts No difference between starters and role-players
	Kutson et al., 2024	17.5 ± 0.5; n = 11	Regular season	1 season, doesn't specifically state n	IMU, Catapult T6	Per Month High Minute: 6020 ± 1070 Moderate Minute: 4999 ± 1721 Low Minute: 4251 ± 3423	N/A	High variability in TL across the season Practices accumulated greater TL than matches

AGE GROUP / LEVEL	STUDY	PARTICIPANTS	TRAINING TYPE / PHASE	LENGTH / SESSIONS	TECH	PLAYER LOAD (AU)	SUPPLEMENTARY MEASURES	OUTCOMES
YOUTH CLUB	Askow et al., 2023	17.6 ± 0.7; n = 11	Regular season	41 training sessions	LPS, Catapult ClearSky T6	Guards 466.5 ± 143 Forwards 291.9 ± 95.4	*Comparisons by position, role (starter vs nonstarter), competition type, competition result and match quarter Jumps by intensity High Intensity Accelerations High Intensity Decelerations Left CoD Right CoD Explosive Movements	Starters produce greater external TL Practice and match volumes were similar, but match intensity was higher TLs Fluctuated week-to-week with match frequency
	Branadao et al., 2019	16.40 ± 0.6; n = 13	Not reported	4 training sessions	Inertial, Polar Team Pro	N/A	Distance (m) = 2273 ± 1170	Distance travelled did not differ between training and competition
	Palmer et al., 2023	15.1 ± 1; n = 14	Preseason	10 weeks, doesn't specifically state n	IMU, VX Sport	N/A	Load·min^{-1} Week 1: 79 ± 9.7 Week 2: 69.8 ± 10.5 Week 3: 85.1 ± 12.9 Week 4: 77.4 ± 8.8 Week 5: 76.5 ± 13.3 Week 6: 74.1 ± 11.5 Week 7: 77.9 ± 11 Week 8: 79.9 ± 10 Week 9: 91.3 ± 11.2 Week 10: 71.7 ± 7.7	No meaningful week-to-week changes, other than a peak in week 9 Performance tests were stable Cross method correlations were weak
	Sansone et al., 2023	15.2 ± 0.3; n = 15	Regular season	10 weeks, 391 drill data points	IMU, Zephyr Medtronic BioHarness 3	N/A 'Impulse Load'	N/A	Peak TLs 84% greater than average TLs Skill and 4v0 drills highest average intensity SSG highest peak intensity

Table 2.4 Studies investigating both measures of external and internal training load of male youth (under 18 years of age) basketball players

AGE GROUP / LEVEL	STUDY	PARTICIPANTS	TRAINING TYPE / PHASE	LENGTH / SESSIONS	MEASURE OF DEMANDS	EXTERNAL LOAD	INTERNAL LOAD	OUTCOMES
YOUTH CLUB	Benson et al., 2021	16.5 ± 0.6; n = 25	Training and competition, regular season	Not reported	IMU, VERT	Jump Height and Count, not explicitly reported	sRPE, not explicitly reported	High injury incidence in youth players Low chronic workload may contribute to injury risk High workload spikes immediately prior to injury
	Sansone Et al., 2022	15.2 ± 9.3; n = 14	Training, regular season	10 weeks, 20 training sessions	IMU & HR, Zephyr Medtronic Bioharness 3 sRPE, Borg CR10	'Impulse Load' All: 14267 ± 2227 Guards: 13599 ± 2269 Forwards: 14934 ± 2173	All SHRZ: 244 ± 43 sRPE: 431 ± 166 Guards SHRZ: 239 ± 45 sRPE: 345 ± 132 Forwards SHRZ: 247 ± 43 sRPE: 505 ± 158	Frontcourt players had higher external and perceived TL, though no difference in internal TL Large correlation between external and internal TL
YOUTH LEVEL NOT REPORTED	Abade et al., 2025	13.3 ± 0.9; n = 18	Training, regular season	3 weeks, 3 training sessions	GPS, STATSports Apex	Total distance: 364.3 ± 94.1 Low-speed: 217.3 ± 27.6 Moderate-speed: 133.8 ± 64.2 High-speed: 12.9 ± 14.5 Maximum-speed: 0.1 ± 0.3 Average speed: 3.6 ± 0.9 Low Accels: 22.6 ± 4.6 Moderate Accels: 26.4 ± 5.3 High Accels: 19.9 ± 10.0 Low Decels: 21.5 ± 6.4 Moderate Decels: 31.3 ± 6.9 High Decels: 15.9 ± 7.4	RPE: 2.4 ± 1.3	Standard rule SSG had lowest external and internal demands when compared with possession and passing modifications

Within this framework, greater continuous involvement increases average TL but reduces 1-min peaks (Sansone et al., 2023), while larger court areas allow higher attainable speeds yet exert smaller effects on mean intensity (Klusemann et al., 2012). Positional and player-role effects on drill external TL appear minimal, with no significant starter–role-player differences in DSL·min^{-1}, Impacts·min^{-1}, or Steps·min^{-1} in the U15–U16 cohort and only small, non-significant trends in a regional sample (Gonçalves et al., 2025; Sansone et al., 2023).

Collectively, these findings indicate that drill selection and constraints (player numbers, space, rules, work–rest) meaningfully shape external TL responses. Accordingly, average and peak intensities should be considered separately when evaluating training stimulus, with high averages not necessarily implying exposure to match-like peaks (Sansone et al., 2023). Emerging drill-specific evidence can inform periodisation hypotheses (e.g., sequencing more continuous/small-sided-game style drills to accumulate volume and targeted live play to reproduce peaks), but current studies are limited in scope and duration, often sampling a narrow drill set or short windows (Sansone et al., 2023). Future research should undertake comprehensive, session-wide monitoring across full seasons to map typical youth training patterns and to examine how drill-level external TLs relate to match preparedness developmental priorities. In addition, longitudinal designs spanning preseason and in-season phases will clarify whether week-to-week stability under controlled training persists once competition congestion and role exposure are introduced.

Positional Differences in External Training Loads

Playing position exerts measurable but context-dependent effects on external TL in youth basketball. At elite U18 tournaments, Backcourt players (guards) generally accumulate higher per-minute TLs than Frontcourt players, reflecting their greater involvement in high-velocity and change-of-direction actions (Pino-Ortega et al., 2019). For example, position-related differences in $PL \cdot min^{-1}$ were small and often not significantly different in elite U18 competition (Pino-Ortega et al., 2019). Similarly, Vázquez-Guerrero et al. (2019) observed more accelerations $\cdot$ min^{-1} and decelerations $\cdot$ min^{-1} among guards than centres in U18 international competition, consistent with position-specific movement demands. In contrast, at sub-elite and high school levels, positional differences are minimal, likely reflecting a more homogeneous playing style and shared tactical responsibilities. For example, Askow et al. (2023) found comparable seasonal totals across positions (guards = 466.5 ± 143 AU.; forwards = 291.9 ± 95.4 AU), and Brandão et al. (2019) reported similar total-distance values between positions (~2,240 ± 620 m per match). Collectively, these findings indicate that positional divergence in external TL emerges progressively with competition level and position specialisation, and that most differences are expressed in movement type and intensity, such as accelerations, decelerations, and directional changes, rather than in total load volume.

Maturational Differences in External Training Loads

Age and biological maturation also have a clear influence on external TL in youth basketball. Older and more physically mature players consistently achieve greater mechanical outputs than younger cohorts under comparable match conditions, reflecting developmental gains in speed, strength, and movement efficiency (Arede et al., 2021;

Castillo et al., 2021; DiFiori et al., 2018; Lloyd et al., 2016). For instance, Castillo et al. (2021) reported that U18 athletes covered more high-speed distance (3.31 ± 1.23 $m \cdot min^{-1}$) and performed a higher frequency of accelerations and decelerations than U14 players (1.04 ± 0.83 $m \cdot min^{-1}$) during matched simulations, indicating greater capacity to sustain intense efforts. However, these group trends mask notable inter-individual variability: exceptionally well-conditioned younger players can register external TL metrics comparable to older teammates, while athletes of the same chronological age may differ markedly depending on biological maturity, playing role, and exposure (Arede et al., 2021; Impellizzeri et al., 2019). Such variability highlights that maturational status must be considered when interpreting external TL data, as nominally identical drills can impose unequal demands across athletes. Accordingly, future analyses of youth TL should account for maturity status or training age to ensure that observed differences reflect developmental context rather than chronological age alone.

Interpreting External Training Load-Performance Relationships

Relationships between external TL and performance outcomes in youth basketball appear modest and context dependent. While higher intensities are typically observed in matches than in training, such as greater $PL \cdot min^{-1}$ or more frequent high-intensity movements (Fox, O'Grady et al., 2020; Sansone et al., 2020), these averages often conceal short peak passages that more accurately represent performance-relevant demands. Moreover, tactical, positional, and situational factors influence these relationships independently of total volume or session intensity (Sosa Marín et al., 2025). Evidence from small-sample studies suggests that variations in external TL can modify collective and technical behaviour, for example, changes in spacing and movement coordination following high cumulative TLs (Sampaio et al., 2015). Similarly, indicators such as the distribution of decelerations or the efficiency of high-intensity efforts may differentiate starters from non-starters in developmental cohorts (Arede et al., 2021), though causal inferences remain limited. Collectively, these findings suggest that external TL–performance links are non-linear and task-specific, reflecting the interaction of mechanical load with tactical intent, physiological readiness, and skill execution. Consequently, external TL metrics may be best viewed as partial indicators that complement, rather than define, broader evaluations of performance and development in youth basketball.

Summary

Despite substantial progress in characterising external TL profiles in youth basketball, important gaps remain. Building on this review, the present thesis contributes to youth-specific monitoring by 1) synthesising internal and external indices to characterise session and weekly TLs in academy settings; 2) documenting contextual dependencies (e.g., role, drill format) in TL profiles; and 3) applying standardised reporting of drill descriptors to support comparability. Broader extensions, such as multi-site samples across age bands and prospective links to performance change or injury risk, remain important future directions for the field (Impellizzeri et al., 2019). These gaps motivate further work to refine how external TL is monitored and interpreted in youth settings. Specifically, the present thesis combines drill-level external TL with perceptual internal TL (e.g., sRPE) to inform coaching decisions, while recognising that broadening population coverage and formal external TL–performance dose–response modelling are important priorities beyond its immediate scope (Impellizzeri et al., 2019; Sansone et al., 2023).

Synthesising across studies, internal and external indices together enable comparison of intended vs. delivered stimulus at the drill level, but their utility depends on how well outputs map to routine coaching decisions (Impellizzeri et al., 2019; Sansone et al., 2023). Evidence indicates that while practice volume can approximate match volume, the mechanical and pacing profiles often differ (e.g., greater stop–start density and deceleration exposure in drill-heavy sessions, and higher short-duration peaks in competition) (García et al., 2020; Kutson et al., 2024; Sansone et al., 2023). Accordingly, a key implication is the need to evaluate whether drill-level monitoring outputs truly reflect the coach-intended training stimulus across various playing positions and phases of the calendar, rather than assuming a session's design will automatically reproduce competition-relevant demands (Sansone et al., 2023). These gaps in linking external TL and internal TL with coach intentions highlight the need to examine how monitoring is embedded in decision-making processes, the focus of Section 2.6.

2.6 Coaching and Athlete Development in Youth Basketball

Despite considerable technological progress in external TL monitoring, empirical evidence on the integration of monitoring within coaching practice remains limited, particularly in youth male basketball. Consequently, this section draws on several strands: youth basketball studies of training design and methodology (Brooker et al., 2000; Cañadas Alonso et al., 2015), research on coach behaviour and immediate athlete responses (Zach & Furman, 2022), and studies of what coaches' value in decision-making (Rogers et al., 2022; Williams et al., 2022). These are complemented by broader youth-sport pedagogical perspectives on athlete development and TL monitoring guidance. This section outlines how youth-sport development frameworks and monitoring practices intersect with coaching and decision-making in basketball, with emphasis on age- and maturity-appropriate progression, the translation of intended training objectives into drill-level external and internal TLs, and evidence on the agreement between intended and delivered stimuli.

Drawing on prior literature, a conceptual model of academy coaching can be described. Training design is aligned from macro- to micro-level planning through deliberate drill development and implementation, which are delivered by day-to-day coaching behaviours (Abraham et al., 2006; Bompa & Buzzichelli, 2019; Otte et al., 2019; Partington & Cushion, 2013). In turn, these are used to shape both acute responses and longer-term adaptation under individual development goals (IDGs) that oversee the planning process. Hence, the alignment of training dose with IDGs is an ideal scenario, though one that is rarely reported in research or analysed in academy programs. Conceptually, decision-making cycles often include: 1) appraising athlete readiness, 2) individualising in-session training dose, 3) selecting or adjusting drills to deliver the intended stimulus, and 4) verifying progression across training blocks. Moreover, coaches reportedly adopt monitoring more readily when the data directly informs these steps, rather than using it purely as a retrospective surveillance tool (Coyne et al., 2018; Sansone et al., 2020; Weston, 2018). In the following sections, these links are made explicit (the focus of Stream B) and limit the scope to academy practice, while acknowledging where concepts are adapted from other youth sport or school-based contexts.

2.6.1 Coaching Philosophies in Youth Athlete Development

Coaching in high-performance youth sport is fundamentally developmental, whereby the goal is to guide athletes through adolescence toward adaptable, well-rounded performance rather than short-term success (Dowling et al., 2020; Preston, 2017). Across sports, a consistent theme emerges as players mature biologically and psychologically; training should evolve from broad, skill-rich experiences toward more specialised practice that supports preparedness for senior competition (Bergeron et al., 2015; DiFiori et al., 2018). Within basketball, this philosophy emphasises balancing physical preparation, technical refinement, and tactical understanding so that increases in workload are matched to individual maturity and learning needs. Broader youth-sport models have articulated this logic in various forms, yet their value here lies mainly in illustrating the general principle of progressive, age-appropriate progression rather than prescribing fixed stages (Lloyd et al., 2016; Malina, 2011).

Within this developmental view, physical preparation is valuable because it enables athletes to express technical skill execution and tactical understanding more effectively (Granacher et al., 2016). Strength, endurance, and speed underpin, rather than replace, the qualities that define performance (e.g., decision-making under fatigue, spatial awareness and coordinated movement) (Granacher et al., 2016). Effective youth training should therefore blend physical and technical components within realistic, match-like environments instead of isolating them in pursuit of abstract physical targets (Otte et al., 2019). Recent basketball research reflects this integration, examining how TL, drill design, and contextual constraints shape both physiological stress and skill execution (Sansone et al., 2023). Monitoring data on running load, jumps or accelerations should be interpreted as indicators of how practice design supports overall development, not as ends in themselves (Saw et al., 2016). This perspective aligns with contemporary views of representative learning, where physical and technical qualities are developed together through realistic, match-like environments that link skill execution with physiological demand (Otte et al., 2019),

2.6.2 Training Design and Drill Architecture

Effective training design cascades from the macrocycle (annual plan) to mesocycles (multi-week blocks), microcycles (weekly plans), and individual drills (Bompa & Buzzichelli, 2019; Sampaio et al., 2015). This top-down planning aims to align daily practices with developmental goals and competition demands. TL monitoring can verify whether the delivered stimulus matches the intended plan (Piñar et al., 2022). At the macrocycle level, high-performance youth programs typically alternate phases that emphasise physical capacity-building with phases oriented to tactics and competition preparation (Curtis et al., 2025). Observational evidence indicates that TL progression in youth basketball usually follows a stepwise, phase-linked pattern rather than abrupt spikes, consistent with gradual overload principles. For example, weekly sRPE totals increased progressively from ~700 to ~1,750 AU across an eight-week U17 preseason (Lupo et al., 2017), and across a 20-week observation including preseason and in-season phases, weekly sRPE averaged 588 ± 175 AU vs. 626 ± 162 AU, respectively, indicating modest, planned increases rather than large spikes (Conte et al., 2017). Despite these patterns, the evidence base remains predominantly descriptive: studies generally report within-team tracking over weeks to months, with few controlled comparisons of alternative periodisation schemes in youth basketball and limited tests of causal links between specific sequencing strategies and adaptation (Conte et al., 2017; Gabbett, 2016; Lupo et al., 2017). Notably, no studies have employed longitudinal designs, which would be valuable for establishing how training exposure and load sequencing influence development across multiple phases of training or years of academy participation.

In youth basketball, drill structure, playing position, and maturational stage jointly shape TL responses (Arede et al., 2021; Conte et al., 2016; DiFiori et al., 2018; Pino-Ortega et al., 2019; Sansone et al., 2023), underscoring the need to validate rather than assume the fidelity of practice design. Across studies, drill format exerts a consistent influence on external demands: small-sided and continuous drills generate greater average intensity (e.g., higher $PL \cdot min^{-1}$ and acceleration density), whereas full-court scrimmages elicit the highest short-duration peaks but lower mean TLs due to stoppages and off-ball time (Camacho Lazarraga et al., 2020; Sansone et al., 2023). These task-specific differences can outweigh positional factors; even so, playing position contributes nuance whereby guards typically register more accelerations and decelerations, and forwards accrue more jumps and contact impacts (Arede et al., 2020; Pino-Ortega et al., 2019). Layered on top are maturational influences, whereby the same external TL can evoke disparate internal responses: less-mature or younger players report higher perceived exertion and heart-rate responses under matched drills than older or more physically developed peers (DiFiori et al., 2018; Lloyd et al., 2016; Moreira et al., 2012; Phibbs et al., 2017). Together, these findings indicate that drill configuration, position, and biological maturity interact to determine both mechanical and perceptual TL, emphasising that monitoring outputs should be interpreted in consideration of athlete age, role, and task design when evaluating alignment between intended and delivered stimuli.

2.6.3 Individual Development Goals

IDGs anchor practice design to long-term priorities and provide a practical basis for checking whether internal and external TLs reflect session intent (Martindale & Nash, 2013). High-performance youth programs increasingly employ IDGs to formalise and personalise the developmental trajectory of each athlete. IDGs specify the technical, tactical, physical, or psychosocial capacities that a coach aims to develop over a defined period, often spanning a training block or academic term (Preston, 2017; Vella et al., 2013). In basketball academies, these goals typically integrate multiple domains: a guard may be tasked with improving repeated accelerations and decision-making under fatigue, while a forward may be challenged to enhance second effort jumping and contesting shots or rebounding. IDGs thus act as anchors linking practice design to long-term developmental priorities.

The conceptual roots of IDGs can be traced to broader youth-sport pedagogy, which emphasise staged, individualised progression calibrated to biological and psychosocial development (Bergeron et al., 2015; Côté & Fraser-Thomas, 2007; Lloyd et al., 2016). While such frameworks provide valuable general guidance, they are largely consensus-based and cross-sport in origin, highlighting the need for basketball-specific evidence to verify how developmental principles translate to observable on-court behaviours. Basketball is distinct not only for its dense, multidirectional movement patterns (Petway et al., 2020; Vázquez-Guerrero et al., 2020) but also for the constant coupling of physical execution with tactical decision-making and perceptual demands in confined spaces (Otte et al., 2019; Sampaio et al., 2015). These intertwined physical, cognitive, and tactical loads make basketball development contextually different from other team sports, warranting sport-specific validation of general youth development principles (Bergeron et al., 2015). This limitation reinforces the importance of empirically testing alignment between intended and delivered training stimuli at the drill and session level. In practice, IDGs serve two functions. First, they provide a purposeful structure for practice, ensuring that athletes are not merely exposed to generic drills but to stimuli tailored to their developmental stage and positional role (Williams et al., 2022). Second, they facilitate monitoring alignment, allowing coaches and support staff to judge whether external and internal TLs accumulated during drills map onto the intended outcomes. For example, if a guard’s IDG is focused on repeated late-possession accelerations, coaches may employ small-sided matches with short shot clocks and then assess whether accelerometer-derived acceleration counts and sRPE confirm the drill delivered the intended stress (Sansone et al., 2023).

IDGs also support athlete motivation and engagement. Goal-setting theory in youth sport suggests that clear, individualised goals enhance self-regulation, feedback uptake, and perceived competence (Vella et al., 2013). Additionally, coaches have reported that IDGs improve communication and buy-in, particularly when athletes can see progress tracked against tangible indicators (Rogers et al., 2022). In contrast, some recent evidence indicates that highly specific IDGs can introduce performance pressure or even identity-related tension for young athletes, tempering these benefits (Pietsch et al., 2024; Williamson et al., 2024). However, empirical validation in youth basketball is sparse. Most available evidence is descriptive or based on coach perceptions; few studies have prospectively linked IDGs to measurable improvements in skill transfer, tactical execution, or long-term retention. Interdisciplinary coordination is also a challenge:

unless technical coaches, strength and conditioning staff, and performance analysts work from the same IDG framework, training content can drift from intended goals (Impellizzeri et al., 2019; Sansone et al., 2023). Monitoring can help detect such drift, for instance, when a player's accumulated weekly jump load exceeds what is consistent with their IDG, signalling a misalignment between technical and physical staff priorities. To date, no studies have tested whether IDGs correspond to distinct TL profiles or whether intended developmental foci are reliably delivered in practice, a gap addressed in this thesis.

2.6.4 Coaching Decision Loops

In academy environments, coaching decisions unfold through iterative loops that operate at the pace of practice: articulating intent, observing and monitoring, adjusting in real time, and reflecting afterwards (Lambert & Borresen, 2006; Russell, McLean, Impellizzeri et al., 2021; Saw et al., 2016). These loops extend beyond physical monitoring to include technical and tactical markers that coaches prioritise in youth basketball, such as repeated defensive close-outs, transition run frequency, and late clock shot execution (Russell, McLean, Impellizzeri et al., 2021; Saw et al., 2016). Before sessions, coaches may appraise readiness using a combination of wellness (sleep, soreness, mood) and physical (neuromuscular performance) indices, recent TL profiles, and subjective impressions. High cumulative sRPE, persistent fatigue, or injury history may prompt modifications to an athlete's planned dose (DiFiori et al., 2018).

During sessions, coaches may manipulate drill constraints in response to monitoring feedback. If a "high-tempo" drill fails to elicit the intended intensity, for example, accelerometer data show fewer high-speed efforts than planned, coaches may tighten work–rest ratios or enlarge playing space to increase demands (Scanlan, Wen et al., 2014). Conversely, if TLs exceed expectations, a drill may be shortened or modified to avoid excessive strain. Such adjustments are driven foremost by the coach's eye and interpretation, with monitoring devices serving as supplementary tools (Abraham et al., 2006; Partington & Cushion, 2013; Saw et al., 2016; Taylor & Garratt, 2013). Observation of execution quality, decision-making speed, and technical breakdowns remains central. After sessions (or microcycles), staff review whether the intended objectives were met, comparing TL summaries (e.g., PL, high-intensity decelerations, session RPE) with planned IDGs and team goals (Impellizzeri et al., 2019). Reports of coach–monitoring decision loops in youth basketball are largely anecdotal or inferred from broader team-sport literature. Existing descriptions are typically qualitative or observational (e.g., practice audits, interviews), and standardised, basketball-specific integration frameworks, such as explicit links between drill intentions, internal/external TL targets, and review processes, remain undeveloped (Impellizzeri et al., 2019; Sansone et al., 2023). Identifying agreement between intended and delivered stimuli represents a measurable intermediate step toward developing such frameworks.

Limited evidence indicates that monitoring can refine dose while preserving session aims, but in youth basketball these processes are predominantly described narratively, with few quantitative evaluations of intended–delivered alignment at the drill level (Arede et al., 2021; Impellizzeri et al., 2019; Sansone et al., 2023). Accordingly, the literature supports examining alignment empirically rather than assuming that session design reproduces competition-relevant demands. Moreover, decision loops that incorporate technical/tactical proxies alongside physical loads remain under-researched, despite their clear importance for coaches hesitant to rely exclusively on technology.

2.6.5 Adoption and Integration

The successful adoption of monitoring in youth basketball depends on three interrelated conditions: interpretability, timeliness, and individualisation (Saw et al., 2016). Interpretability refers to the extent to which outputs are translated into the language of basketball actions rather than presented as abstract units. Coaches are more likely to integrate monitoring when the data directly maps onto the tasks they design, such as repeated close-outs, transition run frequency, or late-clock accelerations, rather than when they receive raw values such as PL (Weston, 2018). The timeliness of feedback is equally important, since information delivered rapidly, ideally on the same day or in real time, enables coaches to adjust subsequent sessions and refine task constraints as training unfolds. Conversely, reports delivered after the relevant block has passed are of limited practical use (Lambert & Borresen, 2006; Russell, McLean, Impellizzeri et al., 2021; Sansone et al., 2020; Saw et al., 2016). Individualisation also underpins successful integration, since TLs must be contextualised according to maturity, playing role, and training history. For instance, a jump exposure that is acceptable for a third-year Frontcourt player may be excessive for a first-year guard, highlighting the importance of scaling metrics appropriately to preserve fairness and credibility (DiFiori et al., 2018; Lloyd et al., 2016).

Qualitative studies confirm that coaches engage with monitoring when outputs are actionable, rapid, and clearly relevant to practice design, while disengagement occurs when data are generic, overly technical, or burdensome to interpret (Sansone et al., 2020). As a result, many academies have shifted towards what has been described as a "light-touch" model, where a small, shared set of indices, typically including PL $\cdot min^{-1}$, acceleration and deceleration counts, jump exposures, and session RPE, are used as prompts to adjust practice design rather than as prescriptive directives (Sansone et al., 2023). Despite its intuitive appeal, evidence demonstrating the impact of such approaches on long-term developmental outcomes in youth basketball remains limited. Much of the guidance in this area continues to be extrapolated from adult sport or based on anecdotal reports, underscoring the need for longitudinal studies that test whether coach-declared intentions, monitoring indices, and delivered training exposures consistently align across a training season.

In summary, Section 2.6 positions coaching as the organising context within which TL monitoring gains practical meaning. Coaches shape athlete development through coherent training design, behaviours that influence acute and long-term responses, targeted individual goals, and decision loops that adjust dose to preparedness. Monitoring supports these processes when it is expressed in basketball language, delivered in real time, and individualised to context. Yet the literature on youth basketball is largely descriptive, often drawn from small samples, and rarely demonstrates whether intended and delivered training stimuli align in practice. These limitations motivate the empirical studies that follow, which examine how coaches articulate developmental philosophies, how monitoring is embedded in their decision processes, and whether training exposures correspond to stated developmental goals.

2.7 Gaps and Rationale

Existing research documents youth basketball TLs at multiple timescales but rarely connects these metrics to coaching intentions or decision-making. General long-term development frameworks exist, but sport-specific models linking coaching objectives to practice design and actual TLs are scarce. Most youth basketball TL studies are context-specific (often a single team, season or training block) and rarely span multiple years. This narrow scope is problematic because adolescence is a dynamic period: players' exposure, roles, and maturation change over time, influencing internal responses and cumulative external TL (Arede et al., 2019; Vaquera et al., 2018). Notably, weekly practice volume can equal match volume; however, intensity patterns differ. Matches typically demonstrate the highest short-term intensity peaks, whereas drill-heavy practices involve more frequent stops and greater braking loads (Alonso et al., 2020; Brandão et al., 2019; Kutson et al., 2024; Vázquez-Guerrero et al., 2020). As a result of these differences, matching weekly training volume does not guarantee equivalent intensity distribution or worst-case TL exposures.

To address these gaps, longitudinal descriptions are needed that account for training phase (preseason vs. in-season), training age, and playing position to properly contextualise TL. For instance, tracking the same athletes across preseason and in-season, while distinguishing between training years within the program and adjusting for maturity, would help isolate true training stress from developmental progression. Additionally, mainstream youth contexts (e.g., high school or girls' basketball) remain understudied, and even in high-performance cohorts' researchers often fail to adjust for maturity or training age, risking a conflation of developmental differences with physiological load (Arede et al., 2019; Vaquera et al., 2018).

Different drill formats consistently produce distinct TL "signatures." For example, continuous technical drills tend to yield high average intensity but lower peaks (Conte et al., 2016; Klusemann et al., 2012; Sansone et al., 2023). In contrast, full-court scrimmages produce higher short-duration peaks but lower average intensity (Conte et al., 2016; Sansone et al., 2023). Additionally, factors such as player involvement and court size can further influence TL outcomes (Conte et al., 2016; Klusemann et al., 2012). Indeed, drill design can even outweigh player position or starter status in youth samples (Conte et al., 2016; Sansone et al., 2023). However, these drill-specific TL profiles are rarely mapped explicitly to coaches' developmental objectives. In practice, coaches rely on experiential and observational judgement to determine whether a drill fulfils its intended purpose, often without objective confirmation from monitoring data.

Internal and external TL represent different aspects of training stress (response vs. dose) and should be aligned within a single framework. Many youth studies quantify only one or the other, and even when both are tracked, inconsistent definitions or analysis windows (e.g. session averages vs. short rolling peaks) complicate comparison (Impellizzeri et al., 2019). Furthermore, evidence linking TL to performance or developmental outcomes in youth remains limited and is often extrapolated from adult populations (Askow et al., 2023; DiFiori et al., 2018; Lloyd et al., 2016), underscoring the need for context-specific monitoring and interpretation.

Coaches are most likely to engage with monitoring outputs that are practically relevant, timely, and tailored to individual players' roles and maturity (Russell, McLean, Impellizzeri et al., 2021; Saw et al., 2016). Yet there is little research on how youth coaches interpret TL reports and act on the information. As highlighted in Section 2.6, monitoring has practical value only when embedded in the coaching context, anchored to individual development goals and used to verify that practice design is delivering the intended stimulus. Currently, there is limited detail on how academy coaches define their development objectives, translate those objectives into practice design, and adjust their plans based on TL feedback.

To make monitoring actionable, this thesis focuses on metrics that align with modifiable training variables and are feasible in an academy setting. Key indices include session RPE-based internal TL (Foster et al., 2001; Scantlebury et al., 2018), counts of accelerations and decelerations (Arede et al., 2021; Askow et al., 2023), PL and its vertical component (Barrett et al., 2014; Fox, Conte et al., 2021), high-speed running distance (Vázquez-Guerrero, Fernández-Valdés, Gonçalves et al., 2019), and jump count (Conte et al., 2015). These particular metrics were selected both because they align with coach-controlled practice constraints and they have been validated for use in basketball by the National Basketball Players Association (National Basketball Association, 2017). They correspond to variables coaches can manipulate (e.g. drill duration, court size, work-to-rest ratio), so the data map directly onto decisions about adjusting intensity or rest. Moreover, the thesis uses consistent drill definitions and standardised analysis windows, summarising TL weekly and expressing drill outputs on a per-minute basis to ensure consistency and comparability. This methodological rigour addresses a common limitation in youth TL literature, where disparate devices, intensity thresholds, and drill classifications have hindered comparisons between studies (Impellizzeri et al., 2019).

Guided by these research needs, the thesis is structured around four linked studies that collectively address key gaps in the evidence base. Study 1 quantifies multi-year internal TLs and training exposures across terms and positions to establish academy-specific benchmarks, while Study 2 extends this analysis to external TL, detailing the training dose and movement demands in a high-performance youth basketball academy. Study 3 examines coaches' perceptions of player development and their use of TL monitoring, and Study 4 tests whether coach-prescribed IDGs produce distinct drill-level TL profiles that align with the intended training stimulus. Collectively, these investigations address the absence of coherent, empirically validated frameworks linking TL measurement, coaching decision processes, and the fidelity of delivered stimulus by integrating internal and external metrics within shared analysis windows to verify that practice designs deliver the intended demands at both physiological and mechanical levels.

Together, these studies form the foundation for the empirical chapters that follow. The overarching aim of this thesis is to investigate how TL monitoring can be integrated into the player development pathways and coaching practices of a high-performance youth basketball academy. By establishing longitudinal TL baselines, integrating internal and external metrics, examining coaching practice, and testing the alignment between intended and realised drill stimuli, the thesis proposes a framework for context-aware monitoring to ensure that TLs in a high-performance youth academy are applied deliberately and effectively to support player development.

Chapter 3: Study 1

Longitudinal Internal Training Load and Exposure in a High-Performance Basketball Academy

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3.1 Executive Summary

The first study addresses the thesis's initial aim: to quantify longitudinal patterns of internal TL and training exposure across years, terms, and playing positions. Establishing these patterns represents a critical first step in understanding how training demands evolve within the academy and how training exposure and workloads change across the academy pathway. By describing changes in internal load and session exposure over time, Study 1 provides the empirical foundation for the subsequent studies.

3.2 Abstract

This study describes the longitudinal training exposure (session counts) and internal TL (Rating of Perceived Exertion; RPE and Session Rating of Perceived Exertion; sRPE) of youth basketball players at a high-performance academy, based on the training year, training term, and playing position. Historical internal TL and training exposure data were collated from 45 male high-performance youth basketball athletes between 2015 and 2019. Data included session duration, RPE, sRPE, training type and date. Linear mixed models and pairwise comparisons were performed on the weekly means and categorised by training year (Year 1, Year 2, Year 3), term (Term 1, Term 2, Term 3, Term 4) and playing position (Backcourt, Frontcourt). Linear mixed models indicate that the individual athlete had the greatest influence on variance in TL and exposure. Significant differences were observed for increased session count, duration and sRPE ($p<0.001$) in Year 2 compared to Year 1. These measures also increased within each year whereby Term 3 and Term 4 ($p<0.001$) were significantly greater than Term 1 and Term 2. No significant differences were observed between playing positions ($p>0.05$). Training exposure and internal TL increase in Year 2 from Year 1 for high-performance youth basketball academy athletes. Differences between TL and exposure for terms (i.e., training blocks) suggest the phase of season influences training prescription, while playing position has limited effect.

3.3 Introduction

Pathways for elite youth basketball players to the National Basketball Association (NBA) or other professional leagues are evolving, whereby athletes can opt to follow a different path to the typical route via high school and college (National Collegiate Athletics Association; NCAA) (Bonal et al., 2020). The emergence of professional-like development academies provides talented high school aged student-athletes a full-time structured basketball program to enhance their physical, technical, and tactical development, which serve as an increasingly popular pathway into professional leagues (Bonal et al., 2020; Mancha-Triguero et al., 2019). Often coupled with completing senior years of high school, academies provide multi-year programs which aim to increase targeted training exposure and intensity to prepare players for the next level in their career (Bergeron et al., 2015; Kelly & Williams, 2020). These academy pathways are common and often paired with professional clubs in other sports like rugby (Kelly & Williams, 2020) and Australian Rules football (Burgess & Naughton, 2010) where descriptions of multi-year training exposure and demands provide context for player physical training development. However, there is currently limited evidence regarding the longitudinal training demands and exposure in basketball academies. These descriptions of training exposure within the developmental pathway can assist coaching and performance staff in the monitoring and management of their physical development programs.

Measuring longitudinal TL or intensity in basketball has typically been a difficult task given the limitations of available monitoring tools (Fox et al., 2017; Fox, Scanlan, Sargent et al., 2020; Russell, McLean, Impellizzeri et al., 2021). A common method in many sports involves collecting perceptual measures of intensity to quantify the psychophysiological response to an external stimulus, often referred to as internal TL (Impellizzeri et al., 2019). The session Rating of Perceived Exertion (sRPE) TL modality (Foster et al., 2001) is a widely used and validated approach to quantifying training intensity in basketball (Lupo et al., 2017; Manzi et al., 2010; Moreira et al., 2012). Given the historical lack of external TL measures due to technological limitations (McLean et al., 2019; Fox et al., 2017; Fox et al., 2019) sRPE has been a default tool to monitor training exposure, duration, and intensity and thus inform training prescription in basketball.

Despite the ease of internal TL monitoring, currently no peer-reviewed evidence of longitudinal training exposure or TL exists in youth basketball academies. This makes it difficult to ascertain whether such academies are providing evidence-based physical development, or whether they provide sufficient preparation for athletes to successfully transition to senior (professional) basketball. The most relevant available data describes the training structure of a high-performance youth basketball academy in Spain between 1996 and 2001, where reported training duration, session frequency and competition exposure increasing linearly between the ages of 14 and 17 (Calleja-González et al., 2016). The authors reported that athletes progressed from 3-4 sessions/week totalling up to 5 hours, to 5-6 sessions/week resulting in up to 12 hours/week of training (Calleja-González et al., 2016). These findings provide descriptive insight into the macro-cycle training exposure in youth basketball increases during academy programs; however, these studies lack description of intensity of training or the context within a training/competitive season. Furthermore, there is no data available within the last decade, with demands of the match having changed whereby the pace has increased and teams have more possessions (Strumbelj et al., 2019), which requires further exploration to inform practice.

Whilst lacking in longitudinal data, some evidence exists in youth basketball describing acute demands of training. Brunelli et al. (2014) reports high week-to-week fluctuations in sRPE TL throughout a junior regional league pre-season and competitive season. Meanwhile, Conte et al. (2016) reported that small-sided drills with less players elicit greater perceived exertion, with Clemente, Sanches et al. (2020) having reported that a greater number of players in a drill increased the perceived exertion. Further, Klusemann et al. (2012) reported that RPE was greater in drills with less players and a larger court area. However, such information provides limited context to an extensive multi-year program.

Additionally, the existing literature pertaining to internal training demands of youth basketball players does not address the apparent position-specific differences (Vazquez-Guerrero et al., 2018; Pino-Ortega et al., 2019). Position-specific differences in basketball are distinct and important because they are dictated by the technical and tactical roles, they play (Scanlan, Tucker et al., 2014; Vázquez-Guerrero et al., 2018) and inform the off-court physical development process (Barazetti et al., 2019). For instance, Svilar et al. (2018) reported greater RPE and sRPE for Guards when compared with Forwards and Centres among professional players. Such positional classifications however may not be applicable to a youth basketball academy, as player development is holistic in nature, whereby they are exposed to a wide range of skills, rather than being confined to one position. Moreover, current literature utilises state or regional level athletes who train part-time (Brunelli et al., 2014; Clemente, Sanches et al., 2020; Conte et al., 2016) and often of younger age (Brunelli et al., 2014), limiting their relevance to a full-time high-performance academy setting. An understanding of training based on position is paramount in ensuring these athletes are provided appropriate individualised training exposure to facilitate transition and future success in professional basketball.

This study aims to describe the longitudinal training exposure (session counts) and internal TL (s-RPE TL) of youth basketball players at a high-performance academy, accounting for the training year, training term and playing position.

3.4 Methods

Experimental Approach to the Program

This study analysed historical internal TL (s-RPE TL) and training exposure (session counts) data of training sessions previously completed between 2015 and 2019 under the guidance of the same Head Coach. Given the developmental nature of the programs, and the academic commitments of the athletes, calendar years (January to December) comprise a 'season'. While competition and tournaments are interspersed throughout the year, training is largely structured around school terms (Terms 1-4). Typically, athletes would complete morning and afternoon training sessions with schooling throughout the day from Monday through Friday, and a morning session on Saturday. Training sessions include both on-court basketball training and off-court strength and conditioning (typically ~4-5 hours per week); however, measures reported within this study pertain only to the court-based basketball sessions as strength and conditioning sessions were monitored separately. Specifically, basketball training sessions were led by the technical coaches, with focus on team-based training (i.e., tactical concepts), skills training (i.e., small group or positional skills including ball-handling and finishing) and shooting.

Subjects

Data from 45 male high-performance youth basketball athletes (age =17.3±0.8y, height=201.6±9.6cm, mass=93.4±14.2kg) at an academy in Australia were obtained for research purposes from appropriate stakeholders and ethical approval was granted by the relevant Human Research Ethics Committee (20220901), along with ratification from the local university ethics committee (ETH22-7841). The athletes all held scholarships in a high-performance basketball academy between 2015 and 2019. This program provides a fulltime residential basketball development program for National level players while they complete senior high school.

Procedures

Data was collected via an online mobile application, designed by high-performance staff within the Australian Institute of Sport and Basketball Australia, within 30min of completion of the session (Edwards, 1994), where all training sessions (and where applicable, competition) were entered by players whilst part of the program. Specifically, players entered the session duration (minutes), internal TL (RPE), session type (i.e., team training, skills, shooting) and injury/training status (i.e., healthy, modified, injured) upon completion of the session. Upon induction into the academy, all players are familiarised with the mobile application, including education about RPE from the strength and conditioning coach, including the anchors of the scale. Entries were completed individually and not in the presence of peers to minimise social influence, consistent with recommended sRPE collection procedures. Within the study timeframe, this data collection system was continually utilised with strength and conditioning coaches provided on-boarding education of the process from the institution.

Internal TL was calculated using the s-RPE method, whereby the RPE was multiplied by the session duration (minutes) and reported in arbitrary units (AU) (Foster et al., 2001). RPE was recorded using the category-ratio 1-10 scale (CR-10) (Borg, 1998), which has been previously validated for use among youth basketball players (Lupo et al., 2017; Moreira et al., 2012). Session duration was defined as the total duration of training (i.e., from the start of practice to the end of practice), including stoppages and the warmup. Session duration was provided to the players at the completion of the session by the strength and conditioning coach.

Training exposure can be defined as the time spent performing a particular training or competitive activity (Jones et al., 2017), and thus is reported through session volume (duration in minutes) and session count. Measures of training exposure have been typically used in literature discussing injury rates (Bourdon et al., 2017), however has also been used to identify training patterns in collegiate basketball (Anderson et al., 2003).

TL and training exposure data were categorised in training cycles. A training cycle is defined as seven days from Monday to Sunday, reflecting how the academy program operates. The in-season phase of competitive basketball is typically categorised into weekly microcycles containing between one and three matches (Conte et al., 2018).

Further to this, data is reported across training blocks, aligning to academic terms (typically 8-11 weeks in length; T1, T2, T3, T4). With this model, the terms loosely align to typical phases of a season, whereby T1 and T2 are considered ‘in-season’, T3 is largely associated with ‘off-season’ and T4 is considered ‘pre-season’. The time commitment of the athletes remains the same throughout the year, however the developmental focus shifts from basketball to physical development in T3 and T4.

Participants were categorised into two positional groups, being ‘Backcourt’ (B; Point Guard and Shooting Guard) and ‘Frontcourt’ (F; Small Forward, Power Forward and Centre), which reflects the evolution of the game of basketball challenging the traditional five position system (Russell, McLean, Impellizzeri et al., 2021) and aligns with how the coaches plan training and match tactics. Additionally, this categorisation may be deemed more appropriate for youth basketball programs, where exposure to a broader range of skills and playing styles, as opposed to specialisation to single position, is emphasised for effective player development. In addition, athletes were categorised based on their training environment age, referring to how many years they have been within the academy (i.e., one, two or three years; Y1, Y2, Y3) and based on each player’s scholarship commencement date.

Data was screened for compliance prior to analysis. Based on the typical training schedule, at least five out of the six (regular weeks; ≥83.3%), or four out of the five (modified weeks; ≥80%) training days must have been reported to represent a week of training. A minimum of 15 total eligible weeks and >50% of exposed opportunity (e.g., if an athlete presented data across 40 weeks, at least 20 must have been deemed eligible by the above criteria) must have been achieved to be included in the study. These criteria ensured that only athletes with a minimum reporting compliance of ≥80% per eligible week and ≥50% overall exposure were included in the final dataset. This resulted in a total of 45 out of 73 athletes eligible for inclusion, with n = 37, n = 33 and n = 9 providing data points in Y1, Y2 and Y3 respectively. Of the 45 athletes, 18 were classified as Backcourt while 27 were classified as Frontcourt. Inclusion was determined solely by reporting compliance rather than performance or positional characteristics; however, athletes with incomplete reporting may have differed in availability (e.g., injury or time in program), which should be considered when interpreting the findings.

Statistical Analyses

Prior to analysis, assumptions of variance and independence were checked utilising Levene's and Shapiro-Wilk test's respectively and scatterplots and Cook's Distance were used to determine potential influential data points, though no points were deemed to have a major effect on the model. Four mixed models were created, one for each outcome variable (i.e., session count, duration, RPE and sRPE) whereby the fixed effects were training year, term and playing position. To account for individual differences, a random intercept was set at the individual athlete level. This allowed an examination of the effect the fixed variables had on the outcome variables. Mixed modelling was used for its ability to cope with unbalanced and repeated-measures data (Cnaan et al., 1997). For all fixed factors, pairwise differences were assessed post hoc using Tukey's HSD. Significance was set at $p \leq 0.05$. Statistical analyses were conducted in R Studio (Version 4.2, R Core Team) using the lme4 and lmerTest packages.

3.5 Results

Session Count

For session count (Table 3.1), training year, term and position respectively accounted for ~2% of variance in sessions/week. The random effect of the individual athlete accounted for ~35% variance when combined with training year and term, and ~32% when combined with position. As shown in Figure 3.1, pairwise comparisons indicate session counts/week in Y2 ($p<0.001$) and Y3 ($p=0.002$) were significantly higher than Y1. Count of sessions/week in T2 ($p=0.012$), T3 ($p=0.001$) and T4 ($p<0.001$) were significantly lower than T1 (Figure 3.2). No significant differences were observed between positions for sessions ($p=0.2$) (Figure 3.3).

Duration

For duration (Table 3.1), training year, term, and position each accounted for ~2% variation in training duration/week. When considering the individual athlete as a factor combined with training year and training term, 37% variance was explained, while ~32% was explained when combined with position. As per Figure 3.1, pairwise comparisons indicate that total weekly duration in Y2 ($p<0.001$) was significantly greater than Y1, and Y3 ($p=0.006$) was significantly less than Y1. Total weekly duration in T2 ($p<0.001$), T3 ($p<0.001$), and T4 ($p<0.001$) was significantly lower than T1 (Figure 3.2). T3 ($p=0.036$) total weekly duration was significantly less than T2. No significant differences were observed between positions ($p=0.200$) (Figure 3.3).

Ratings of Perceived Exertion

For RPE, training year ($R^2 = 0.002$), term ($R^2 = 0.004$) or position ($R^2 = 0.004$) did not explain variation (<1%). When combined with the individual athlete as a random factor training year, term and position accounted for ~47% of the variation in RPE. Pairwise comparisons did not indicate significant differences between years (Figure 3.1). For terms, T2 was significantly greater than T1 (p=0.023) and T3 (p=0.009) (Figure 3.2). No significant differences were observed between positions (p=0.156) (Figure 3.3).

Internal Training Load (sRPE)

For weekly sRPE TL, training year, term and position individually accounted for ~2% in variation. When combined with the individual athlete as a random factor, training year, term and position explained 35%, 34% and 32% of variation respectively. Pairwise comparisons indicate weekly sRPE in Y2 (p<0.001) and Y3 (p=0.007) were significantly greater than Y1 (Figure 3.1). Weekly sRPE in T3 (p<0.001) and T4 (p<0.001) were significantly less than T1, while T3 (p<0.001) and T4 (0.020) were significantly less than T2 (Figure 3.2). No significant differences were observed between positions (p=0.112) (Figure 3.3).

Table 3.1 Results of each of the four mixed models

Model 1 - Session Count			**Model 2 - Duration**			**Model 3 - RPE**			**Model 4 - sRPE**		
Predictors	*Estimates*	*CI*	*Predictors*	*Estimates*	*CI*	*Predictors*	*Estimates*	*CI*	*Predictors*	*Estimates*	*CI*
Year 1	7.48 ***	7.01 – 7.96	Year 1	585.04 ***	542.72 – 627.37	Year 1	5.95 ***	5.74 – 6.16	Year 1	3578.84 ***	3302.61 – 3855.08
Year 2	0.61 ***	0.35 – 0.87	Year 2	48.89 ***	26.37 – 71.41	Year 2	0.10 *	0.00 – 0.19	Year 2	338.83 ***	185.59 – 492.07
Year 3	1.02 ***	0.42 – 1.62	Year 3	78.66 **	27.26 – 130.06	Year 3	0.07	-0.14 – 0.29	Year 3	529.18 **	180.49 – 877.87
σ^2		4.5	σ^2		32838.97	σ^2		0.54	σ^2		1524121.13
τ_{00}		2.32_{Name}	τ_{00}		18408.08_{Name}	τ_{00}		0.47_{Name}	τ_{00}		774844.72_{Name}
ICC		0.34	ICC		0.36	ICC		0.47	ICC		0.34
Marginal R^2 / Conditional R^2		0.018 / 0.352	Marginal R^2 / Conditional R^2		0.015 / 0.369	Marginal R^2 / Conditional R^2		0.002 / 0.467	Marginal R^2 / Conditional R^2		0.016 / 0.347
Term 1	8.27 ***	7.80 – 8.74	Term 1	663.37 ***	621.31 – 705.44	Term 1	5.95 ***	5.73 – 6.16	Term 1	4052.09 ***	3773.20 – 4330.97
Term 2	-0.47 **	-0.77 – -0.17	Term 2	-49.12 ***	-74.70 – -23.53	Term 2	0.15 **	0.05 – 0.26	Term 2	-197.12 *	-371.76 – -22.47
Term 3	-0.58 ***	-0.89 – -0.27	Term 3	-85.25 ***	-111.58 – -58.93	Term 3	-0.02	-0.13 – 0.09	Term 3	-551.55 ***	-731.20 – -371.90
Term 4	-0.83 ***	-1.14 – -0.52	Term 4	-80.30 ***	-106.67 – -53.93	Term 4	0.06	-0.04 – 0.17	Term 4	-464.73 ***	-644.70 – -284.75
σ^2		4.51	σ^2		32307.5	σ^2		0.54	σ^2		1505218.67
τ_{00}		2.02_{Name}	τ_{00}		16709.78_{Name}	τ_{00}		0.48_{Name}	τ_{00}		724126.67_{Name}
ICC		0.31	ICC		0.34	ICC		0.47	ICC		0.32
Marginal R^2 / Conditional R^2		0.014 / 0.320	Marginal R^2 / Conditional R^2		0.024 / 0.357	Marginal R^2 / Conditional R^2		0.004 / 0.471	Marginal R^2 / Conditional R^2		0.021 / 0.339
Backcourt	8.16 ***	7.48 – 8.84	Backcourt	641.79 ***	580.33 – 703.24	Backcourt	6.07 ***	5.74 – 6.40	Backcourt	4007.87 ***	3608.44 – 4407.30
Frontcourt	-0.57	-1.45 – 0.30	Frontcourt	-51.25	-130.58 – 28.07	Frontcourt	-0.13	-0.55 – 0.30	Frontcourt	-417.54	-933.13 – 98.05
σ^2		4.59	σ^2		33383.73	σ^2		0.54	σ^2		1549167.9
τ_{00}		2.00_{Name}	τ_{00}		16467.30_{Name}	τ_{00}		0.49_{Name}	τ_{00}		690715.54_{Name}
ICC		0.3	ICC		0.33	ICC		0.47	ICC		0.31
Marginal R^2 / Conditional R^2		0.012 / 0.312	Marginal R^2 / Conditional R^2		0.012 / 0.339	Marginal R^2 / Conditional R^2		0.004 / 0.473	Marginal R^2 / Conditional R^2		0.018 / 0.321

*Note: Estimates may also be noted as coefficients. CI = Confidence intervals set at 95%.. σ2 = within-person variance. T00 = between-person variance. ICC = Intraclass Correlation Coefficient. Marginal R2 = fixed effects. Conditional R2 = fixed + random effects. * $p<0.05$ ** $p<0.01$ *** $p<0.001$*

Figure 3.1 Training Exposure and Internal Training Load by Training Term.

* = $p<0.05$
** = $p<0.01$
*** = $p<0.001$

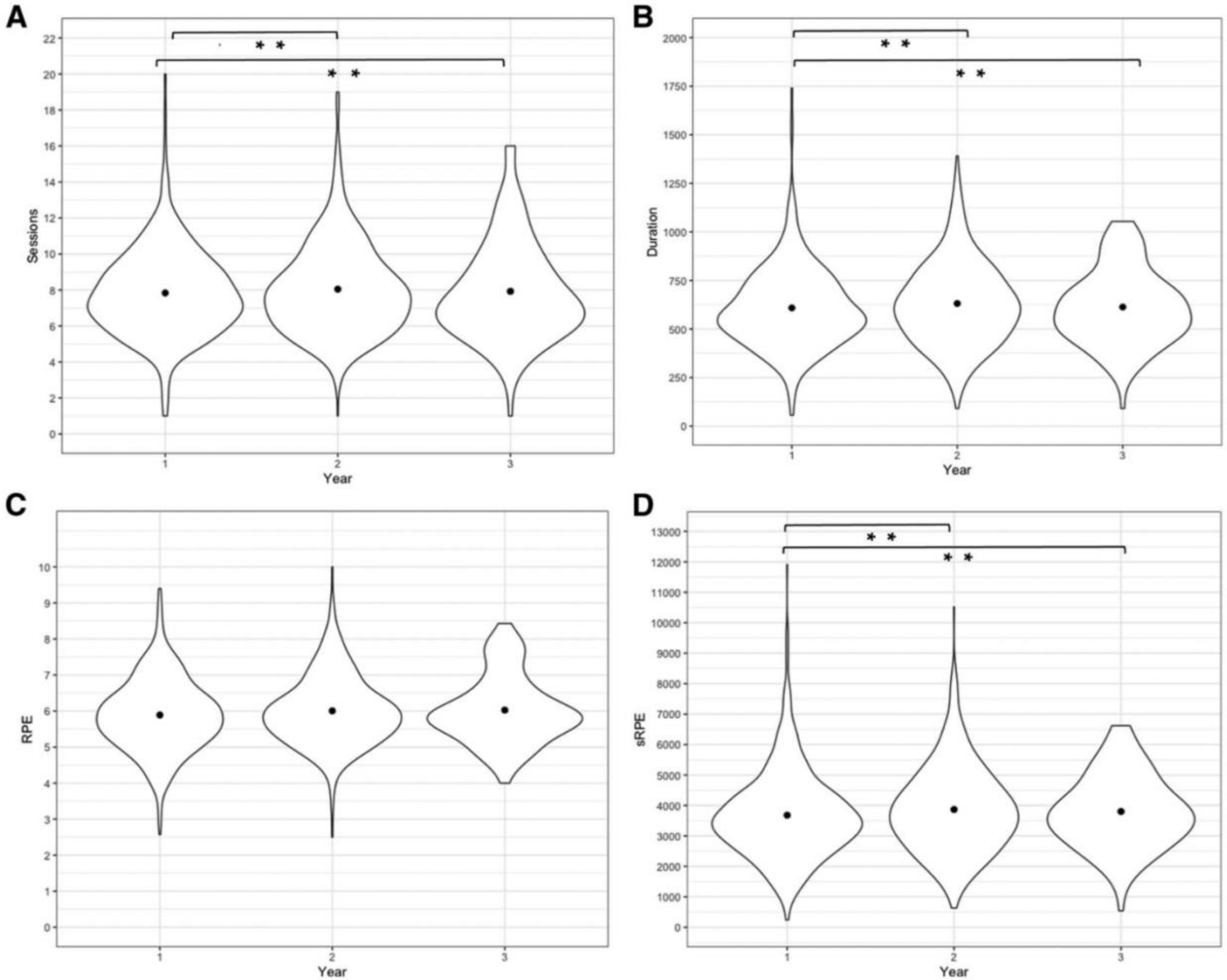


Figure 3.2 Training Exposure and Internal Training Load by Year.

* = p<0.05
** = p<0.01
*** = p<0.001

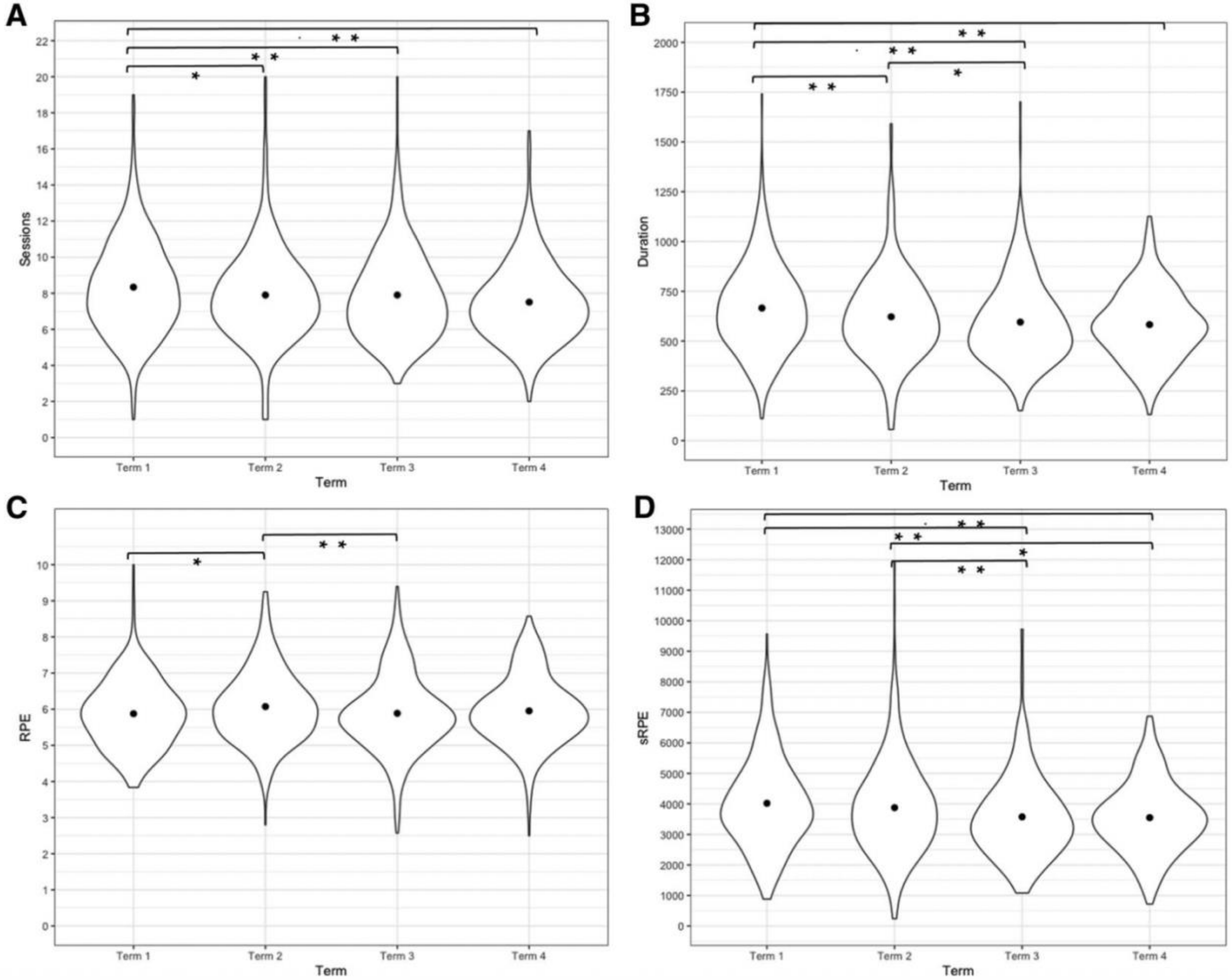
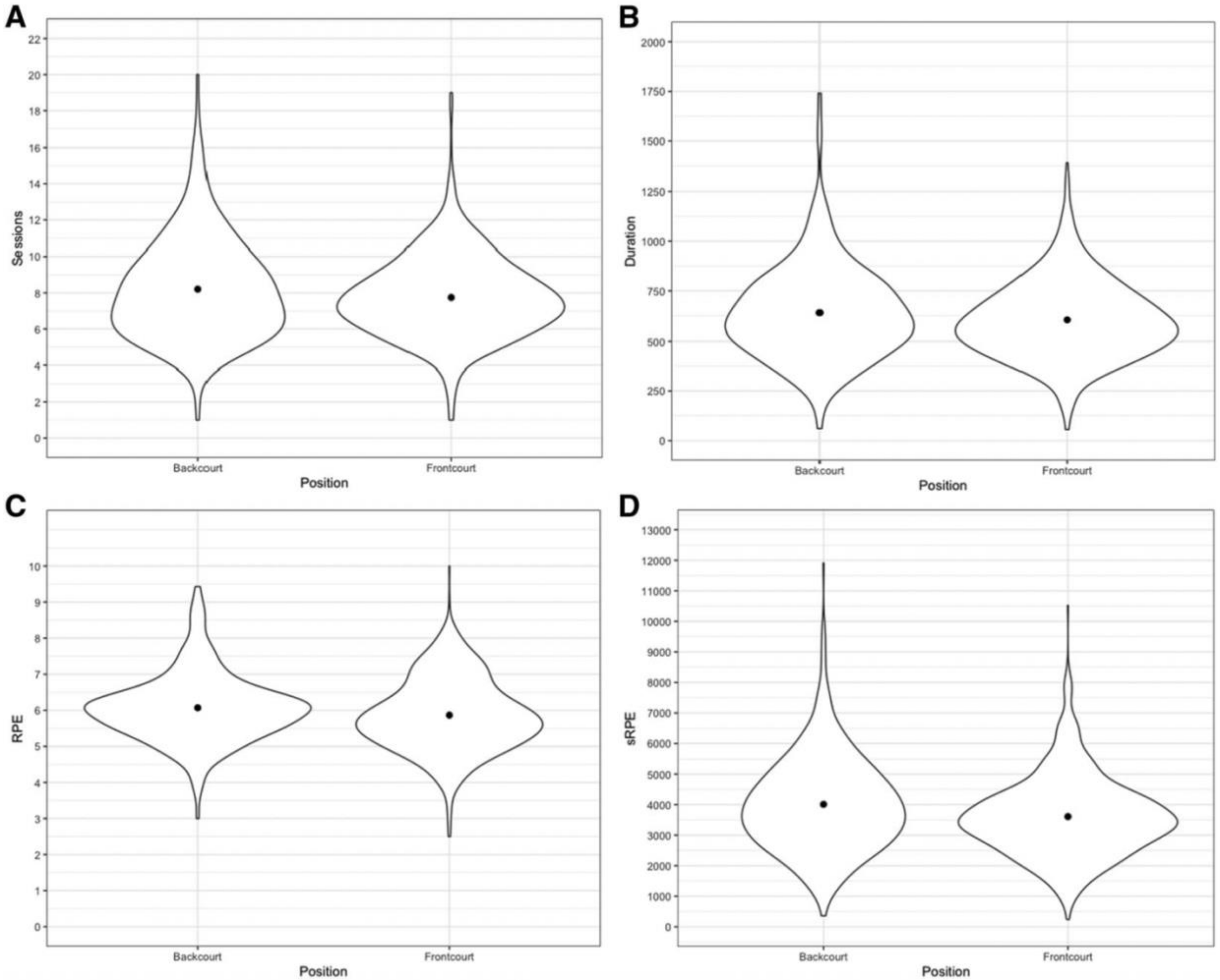


Figure 3.3 Training Exposure and Internal Training Load by Position.

* = p<0.05
** = p<0.01
*** = p<0.001



3.6 Discussion

This study is the first to describe the longitudinal exposure to training and internal TL among high-performance youth basketball academy athletes while also examining the relationship between internal TL with training year, term and playing position. Firstly, the outcomes of this study indicate that athletes report higher weekly training exposure, duration, and internal TL (sRPE) in their second year compared with their first. Secondly, within a year, training exposure, duration, intensity (RPE) and internal TL (sRPE) differed by training block, whereby they were greater in the first half of the year (i.e., T1 and T2) than the second half of the year (i.e., T3 and T4). In addition, the individual athlete had the greatest impact on changes in training exposure and TL, while playing position had limited to no effect. Collectively, this study provides novel data that will better inform the training practices of multi-year youth basketball academies by providing reference points for practitioners of the training exposure, intensity and TL that is present when developing high-performance basketball players.

Our results showed increases in session count, duration, and internal TL per week between Y1 and Y2, although limited changes in RPE. Similar progression has been reported within a Spanish basketball academy, where athletes begin at 14 years-of-age completing 3-4 sessions/week at 75min/session and train up until 17 years-of-age and complete 6 sessions/week at 135min/session (Calleja-González et al., 2016). This linear progression within a youth cohort is paramount in ensuring athlete wellbeing (Bergeron et al., 2015) while still adequately developing their technical, tactical, and physical capacities (Calleja-González et al., 2016). The increased training exposure presented in our study by means of sessions/week (7.8±2.4 vs 8.0±2.4) and duration/week (611±215min vs 629±205min) and resultant increase in sRPE TL (3696±1458AU vs

3853±1365AU) demonstrate small increases between training years 1 and 2. Although Y3 displayed significantly greater sessions/week, duration/week and sRPE/week than Y1, the same linear progression was not observed from Y2 to Y3. A possible explanation for this may be the unique nature of the academy whereby limited athletes remain in the program for 3 years, or that a larger proportion of their weekly exposure and TL is attributed to increased competition frequency. Similarly, Spanish basketball academy athletes showed the number of competitive matches per year increases year-to-year (from 20 at 14 yrs to >40 at 17 yrs) (Calleja-González et al., 2016). The results of this study provide reference points of the training demands of youth basketball academies and provide practitioners at the senior/professional level an understanding of the training base of incoming athletes, to aid the transition from youth to senior basketball.

The results of this study support the notion that the level of athlete and/or competition they compete in may influence the intensity and volume of training (Petway et al., 2020). For example, Arede et al., (2019) described perceived training demands in a national team selection camp, where the RPE of training sessions were 4.7±0.96, which is lower than the weekly RPE (5.80–6.13) described in this study. Meanwhile Lupo et al., (2017) concluded that regular season training sessions were reported at 6.7±1.3 on the Borg CR-10 scale by state level youth players. In-season (i.e., T1 and T2) average weekly RPE from this study range between 5.8 and 6.1, with the disparity supporting previous findings. Previously, weekly TLs across an eight-week in-season training block among regional level juniors (12 years of age) reported between 707AU and 1753AU/week (Brunelli et al., 2014), which is far less than the TLs reported in this study (i.e., upwards of 3600AU per week). Much of this difference is likely attributed to the number and duration of training sessions completed by the groups in the week, associated with the level of athlete and thus the expectations of the training environment. This too seems evident within a Spanish high-performance basketball academy, whereby in their second-year athletes typically complete more training each week than those in their first year. Whilst senior semi-professional players are reported to complete between 1064AU and 2233AU of work in a week, including competition (Fox, Conte et al., 2021), though these competition demands don't reflect a typical week within a national youth basketball academy. As such, practitioners should be aware of the level of athlete reported in the literature when seeking comparisons for training plans and look to cater individually to the level of athlete they are working with.

Competitive basketball seasons are typified by a short pre-season (6-8 weeks) and long in-season (8 months) (Pliauga et al., 2018), which is somewhat reflected by the typical annual calendar within the high-performance youth basketball academy. However, given the difference in the overall aims of the academy (i.e., long-term athlete development as opposed to short-term success), periodisation of training may be atypical to that of a professional environment. Our results showed significant differences in TLs between training blocks (i.e., terms) across the year, whereby they were greater in the first half of the year (i.e., T1 and T2) than the second half of the year (i.e., T3 and T4). A possible explanation for this may be due to the shift in training priorities. T3 and T4 within the academy consist of 'offseason' and 'preseason' training, with an increased focus on physical development including aerobic and anaerobic conditioning as well as speed and agility training. Whilst the time commitment of the athletes to training remains the same, this increased and targeted exposure to physical preparation results in increased TL

(Ibanez et al., 2020) from greater perceived exertion. Although T1 and T2 comprise the competitive season, the primary focus of the academy remains developmental as opposed to performance. As such, TL and exposure may still be greater among this group when compared to semi-professional and professional players. For example, Russell et al., (2021) presented weekly training duration of NBA athletes with starting players completing 215 mins, rotation players completing 301 mins and bench players completing 302 mins during the regular season. In contrast, academy athletes completed upwards of 500 mins of training/week. Whilst this discrepancy may be lessened when competition minutes are included, it highlights the difference between a developmental and performance setting, and the increased training exposure implemented to prepare junior athletes for senior basketball.

Although there is a general consensus that playing position affects TLs in basketball (Russell, McLean, Impellizzeri et al., 2021), this was not evident in the current study. Positional differences in TLs seem more prominent in literature utilising external TL measures, suggesting internal TL measures may be less sensitive to position-specific demands. Professional basketballers reported stable RPEs across positional groups, though guards reported higher sRPE than forwards and centres (Svilar et al., 2018). We present similar findings in this study where Backcourt players report 4148±1385AU per week while Frontcourt players report 3614±1223AU, with RPE remaining similar at 6.0±0.9 and 6.0±1.0 respectively. The results of the LMM suggest that the individual athlete has substantially greater impact on internal TL than playing position, aligning with the principle of specificity and individuality in basketball (Mercer et al., 2022; Svilar & Jukić, 2018). This high athlete-to-athlete variation in TLs highlights the need for a detailed monitoring process in a basketball academy setting, whereby daily training modifications may be required at the individual level based on an athlete's responses to a training dose.

Whilst this investigation presents a novel study describing the longitudinal training demands of a high-performance youth basketball academy, it is not without limitations. Despite sRPE data being collected under the supervision of the academies experienced performance staff using validated protocols, self-reported TL remains subject to potential reporting bias, individual interpretation, and occasional missing data (Scantlebury et al., 2018). Unfortunately, given the applied nature of this study and the fact the dataset is retrospective, this is unavoidable. Additionally, given that RPE is an output and different activities can lead to the same RPE, additional information would be beneficial to discern between RPE responses in training. Provided the limited cohort of the academy, a low statistical power given the small cohort for Y3 athletes may have influenced the results of this group. However, this is unavoidable given the applied nature of the study and period in which it was undertaken, and the unique nature of the academy setting.

This study described the training exposure and internal TL experienced by athletes in a high-performance youth basketball academy and investigated the relationship of these measures with training age, term and playing position. Training year and training term influenced the number of training sessions, duration and sRPE TL athletes reported in a week. Athletes in their second year reported a greater exposure to training (sessions/week) and internal TL (sRPE) than those in their first year. In addition, significant differences between terms indicate the use of periodisation strategies, resulting in greater training exposure and TL at the beginning of the year (i.e., T1 and T2) during the in-season phase. The outcomes of this study could be used as reference points of training exposure and training demands in high-performance youth basketball, while also supporting the use of perceptual measures of TL in youth basketball. Future research should look to quantify the longitudinal training demands in a high-performance basketball academy at a more granular level (e.g., external TLs).

3.7 Practical Applications

Collectively, the findings of this study provide a description of the training exposure and training demands experienced within a high-performance youth basketball academy that previously did not exist. This knowledge may assist coaches and performance practitioners in preparing their athletes for transition into such an environment or assist practitioners who begin working with an athlete transitioning out of this environment into a new training program. A thorough understanding of the frequency, intensity and volume of training completed may allow for a more effective and efficient transition from junior to senior basketball. In addition, recognition of the athletes' training age allows coaching staff to ensure progression of training exposure and demands continues. Furthermore, emerging high-performance youth basketball academies may wish to use this data to inform the development of their weekly training structure and schedules.

Chapter 4: Study 2

Quantifying the Training Demands of Highly Trained Male Youth Basketball Players by Year, Term and Position

As per the peer-review manuscript accepted and published in the *Journal of Sports Sciences*.

Lever, J. R., Duffield, R., Murray, A., Bartlett, J. D., & Fullagar, H. H. K. (2024). Quantifying the training demands of a highly trained male youth basketball players by year, term and position. *Journal of Sports Sciences*, *42*(17), 1597–1604. https://doi.org/10.1080/02640414.2024.2402619

4.1 Executive Summary

The second study addresses the second aim of the thesis to describe external TL across years, terms, and playing positions within the academy program. Building on the multi-year internal TL patterns identified in Study 1, which quantified athletes' psychophysiological responses to training, this investigation examines the external TLs captured through wearable technology to characterise the physical stimulus underlying those responses. Whereas Study 1 established how training exposure and internal load varied across the academy calendar, Study 2 extends these findings by quantifying the volume and intensity of movement demands imposed during training. In doing so, this study advances understanding of how physical training demands are structured longitudinally within a highly trained youth basketball development pathway.

4.2 Abstract

This study describes the training demands of highly trained male youth basketball players, based on training year, term, and playing position. Data was collected from 41 male youth basketball players over two seasons from all on-court coach-led training sessions utilising a LPS. Linear mixed-models and pairwise comparisons were used to analyse by training year (Y1, Y2, Y3), term (T1, T2, T3, T4) and playing position (Backcourt, Frontcourt). Results showed no differences in external TL metrics between training years. Significant differences existed between training terms, with total distance greater in both T3 and T4 than T1 and 2 ($p<0.03$). Total PlayerLoad was significantly greater in T4 than T1 ($p<0.001$) and 3 ($p=0.004$). Distance·min^{-1} was greater in T2, T3 and T4 than T1 ($p<0.01$). PlayerLoad·min^{-1} was higher in T4 than T1 and T2 ($p<0.01$). Backcourt players showed significantly greater distance·min^{-1} ($p=0.011$), PlayerLoad·min^{-1} ($p=0.011$) and deceleration counts ($p<0.001$). Overall, limited year-on-year change existed in external TL metrics ($p>0.05$), though volume ($p<0.001$) and intensity ($p<0.001$) differed between terms. Backcourt players completed higher intensities ($p=0.011$) than Frontcourt players. This study provides a description of external TLs of training in highly trained youth basketball players assisting coaches and performance practitioners to better understand physical demands within youth basketball development pathways.

4.3 Introduction

Youth (15-24 years of age) (UN Instruments, 2008) basketball academies provide exposure to structured training environments and are increasingly popular in the development of high-performance players (Calleja-González et al., 2016). These academies aim to improve the transition from youth to senior basketball by increasing youth athletes' exposure to targeted and specialised training, with the collective goal of producing national, international, and professional calibre players. As per the Participant Classification Framework (McKay et al., 2022), these academies would be considered a 'Tier 3, Highly Trained/National Level' cohort. However, current insights on the training demands within highly trained youth basketball academies are limited, with some practitioners reported to utilise subjective match ratings from coaches and scouts, and isolated athletic assessments i.e., combine testing of speed, agility and jumping ability (Calleja-González et al., 2016). Nevertheless, such evidence does not inform the training structure, exposure, and periodisation of basketball academy programs. In contrast, other professional sports articulate the importance of adequate monitoring of TL and exposure, such as internal and external TL, as part of player development throughout specialized youth athlete training environments (Bergeron et al., 2015; Murray, 2017). A comprehensive description of the demands of training experienced by highly trained youth basketball players within an academy environment would be of benefit not only to coaches and practitioners in planning, monitoring, and modifying effective training plans, but to better inform evidence-based procedures implemented by the overarching administrators of basketball academies.

Previous literature has described longitudinal training demands of highly trained youth basketballers using perceptual responses to training. Calleja-Gonzalez and colleagues (2016) reported the structure of the training program of a youth basketball academy in Spain from 1996-2001. Athletes completed between 3-6 sessions per week, resulting in 5-12 hours of training as they transitioned through the program from 14-17 years of age (Calleja-González et al., 2016). Similarly, Study 1 reported on the training frequency and internal TL of a full-time youth basketball academy, whereby second year athletes completed more sessions/week resulting in a greater internal TL than first year athletes. Additionally, it was reported that training exposure and TL were greater during the in-season phase (at the beginning of the year). Whilst useful as an overview, there remains a lack of detail on the specific physical demands of highly trained youth athletes' experience and how they may differ between training blocks or playing positions. Furthermore, these findings remain to be reported elsewhere and may not be generalisable to modern-day academy structures and commitments of youth athletes (Bergeron et al., 2015).

Data regarding acute and longitudinal external TL training stimulus (Impellizzeri et al., 2019; Russell, McLean, Stolp et al., 2021) imposed on highly trained youth basketball players is limited (Russell, McLean, Impellizzeri et al., 2021). Multiple studies by Vazquez-Guerrero and colleagues (García et al., 2020; Pino-Ortega et al., 2019; Vázquez-Guerrero et al., 2018; Vázquez-Guerrero, Fernández-Valdés, Gonçalves et al., 2019; Vázquez-Guerrero, Fernández-Valdés, Jones et al., 2019; Vázquez-Guerrero et al., 2020) described external TLs experienced by international youth players in tournament settings (13 matches). Within this context, positional differences were observed, whereby centres performed significantly less high-intensity accelerations (both count and distance) and decelerations (count) than guards (Vázquez-Guerrero et al., 2020). Additionally, distance covered, PL and high-intensity accelerations and decelerations decreased between quarters as matches progressed (Vázquez-Guerrero, Fernández-Valdés, Jones et al., 2019). Further, team quality (i.e., tournament ranking) influenced the high-speed running distance with intensity markers (i.e., PL·min^{-1}, high intensity running, peak speed, accelerations·min^{-1}, and decelerations·min^{-1}) increasing as the tournament progressed (Pino-Ortega et al., 2019), which poses the question whether the training environment of more highly-trained players follow this trend. Similarly, in competition, Castillo et al. suggested that older/more experienced youth athletes (i.e., U18 vs U16) presented greater high-speed running distance (Castillo et al., 2021), suggesting longitudinal exposure to physical development training may influence basketball-specific physical capacities.

Existing literature is limited to snapshots of training, such as 18 training sessions at a youth national team training camp (Arede et al., 2020) and between 2 and 4 individual training sessions at the club and state level (Brandão et al., 2019; Valvassori et al., 2020). Arede et al., describe U16 national team players' training demands to involve 35 ± 4.3 m·min^{-1}, 0.76 ± 0.3 high intensity accelerations·min^{-1} and 0.67 ± 0.3 high intensity decelerations·min^{-1} (Arede et al., 2020). The available data provide discreet comparisons of this age cohort, though lack insight on long-term training demands and exposure to prepare for such competition. Moreover, all available evidence stems from European academies, which may pose different structures and thus demands to academies from other regions. Despite being the pinnacle of junior basketball development in Europe (Calleja-González et al., 2016) and serving as a conjugate between youth and senior basketball, the external TL in these academy settings and the strategies used to prepare these players for senior basketball has not yet been reported.

To this end, this study aims to describe the external TLs from training experienced across multiple seasons by highly trained youth basketball players. Specifically, external TL metrics will be described by training age, term, and playing position to identify differences in training demands.

4.4 Methods

Experimental Approach to the Program

This prospective cohort study used external TL data collected during on-court coach-led training sessions (Figure 4.1) throughout the 2021 and 2022 training seasons. Due to official matches being conducted outside the daily training setting in an uncontrolled environment (i.e., no LPS infrastructure), data was not collected from competition. A typical training week within the structured training environment of the youth basketball academy involved 12-16 coach-led hours on-court, 4-5 hours of strength and conditioning and 1-2 hours of injury prevention each week, along with structured recovery sessions 2-3 times per week. On-court sessions include shooting, team or individual practice, volume shooting (standardised drills to track shooting performance) and scrimmages. In addition, athletes are encouraged to engage in self-led skills training (e.g., shooting and ball handling) throughout the week.

Figure 3.4 Typical weekly training schedule of the academy across 2021-2022 seasons.

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
AM	Shooting	Individual	Individual	Volume Shooting	Shooting S&C	Individual Scrimmage	Off
PM	Monitoring S&C Team Practice	Team Practice	S&C	Prehab	Team Practice		

Shooting: *All shooting drills. May be individual, partner or group shooting. May include technique or competitive drills.*
Monitoring: *Weekly physical and wellness monitoring including counter-movement jump testing and subjective questionnaires.* ***S&C:*** *Strength and conditioning training lead by the S&C coaches in the gym.*
Team Practice: *Includes all Athletes. Main sessions of the week with a focus on technical and tactical development at the team level. May include some skill development and simulated gameplay.*
Individual: *Small-group training often completed in positional groups. Focus on position/role specific skills.*
Volume Shooting *: A standardised set of shooting drills whereby shooting percentage is calculated and tracked throughout the year.*
Scrimmage: *Simulated gameplay whereby athletes are encouraged to apply the technical and tactical learnings from Team Practice. May include full simulated games or modified games.*

Subjects

Data was collected from 41 highly trained youth basketball players (age = 17.4±0.9 years, height = 203.2±8.3 cm, mass = 91.2±13.3 kg) on scholarship with an academy in Australia across two training years (24 months). The academy provides a fulltime residential basketball development program alongside academic commitment. Following their tenure at the academy, these players are typically recruited to Division 1 National Collegiate Athletic Association (NCAA) schools or professional teams (e.g., Australia's National Basketball League or NBA G-League). Data was collected with permission from relevant governing bodies (Australian Institute of Sport - AIS, Basketball Australia, and National Basketball Association) and ethical approval was granted by the Institutional Human Research Ethics Committee (ETH22-7626). Furthermore, the training environment observed within this study operates under the youth training guidelines (DiFiori et al., 2018).

Procedures

In compliance with NBPA guidelines (National Basketball Association, 2017), external TL data from all coach-led on-court training sessions were collected using a commercially available Local Positioning System (LPS) device (Catapult Vector S7, Catapult Sports, Melbourne, Australia) worn in a customised supportive vest (Catapult Sports, Melbourne, Australia; fitted for each player) between the scapulae (McLean et al., 2018), with players wearing the same device each session to minimise inter-device variability (Jennings et al., 2010; McLean et al., 2018; Nicolella et al., 2018). Players were categorised by playing position (Backcourt, n=18 and Frontcourt, n=23) with classification based on previous recommendations (Russell, McLean, Impellizzeri et al., 2021). Players were further categorised by training age based on their tenure within the academy (Year 1 (Y1), n=30; Year 2 (Y2), n=18; Year 3 (Y3), n=6). Training age refers to the athlete's relative year within the academy program, not the number of seasons monitored within this study. As the monitoring period spanned two competitive seasons, some athletes progressed in training age during this timeframe depending on their entry and exit dates. Accordingly, individual players could contribute data to multiple training age categories (Y1 only n=21; Y2 only n=5; Y3 only n=1; Y1+Y2 n=9; Y1+Y2+Y3 n=4; Y2+Y3 n=1). For example, those who contributed data across Y1, Y2 and Y3 likely started and finished their tenure within the academy midway through a training year. TL data were categorised, using weeks of the year, into terms which aligned with academic terms (T1, T2, T3 and T4) and were 8-11 weeks in length, with 1-2 weeks break between terms throughout the year and 3-4 weeks between T4 and T1 of the following year. With this model, the terms align to typical phases of a competitive season, whereby T1 and T2 are considered 'in-season', T3 is largely associated with 'off-season' and T4 is considered 'pre-season'. The time commitment of the athletes remained the same throughout the year (i.e., amount of training sessions per week), however the developmental focus shifts from basketball (i.e., skill and tactics) to physical development (i.e., strength and conditioning and movement competency) in T3 and T4. As per routine day-to-day servicing, coaching and performance staff were provided TL reports to plan and adjust training.

External Training Load

The LPS devices obtain 10 Hz data utilising Ultra-Wide Band (UWB) communication, and contains a Triaxial Accelerometer, Gyroscope and Magnetometer each sampling at a rate of 100 Hz (Catapult Sports, Melbourne, Australia). Wearable technology such as accelerometers have become popular tools among basketball practitioners and have since been deemed valid and reliable in the sport (Barrett et al., 2014; National Basketball Association, 2017; Nicolella et al., 2018; Staunton et al., 2017). LPS devices are emerging as a popular tool in sport science as they show promise due to the higher sampling rates and increased accuracy for indoor sports (Hodder et al., 2020; Luteberget et al., 2018; Serpiello et al., 2018). However, the selection of appropriate metrics to report TL and movement demands in basketball remains difficult (Russell, McLean, Impellizzeri et al., 2021).

A laptop housing the manufacturer's proprietary software (OpenField, Catapult Sports, Melbourne, Australia) was set up 20 min prior to each training session to connect to the LPS anchor node network via ethernet cable to ensure adequate signal is obtained prior to the session commencing. Each training session was coded live by the researcher into drills based on the training plan designed by the technical coaching staff. When coding drills, recording commenced when the players began undertaking the drill (i.e., after the coach finished explaining the drill). Recording stopped once the players completed the drill and/or the time expired. In instances when players were substituted out but still active the drill recording continued. Data was downloaded from the LPS devices via the manufacturer's proprietary software (OpenField, Catapult Sports, Melbourne, Australia) after each session, when data were checked to ensure only time spent in drills (i.e., not coaching or demonstrating, not during a break) was retained for analysis. Data was exported into a spreadsheet (Microsoft Excel, Microsoft Corporation, Redmond, USA) from the manufacturer's cloud-based system (OpenField Cloud, Catapult Sports, Melbourne, Australia).

A full list and description of external TL metrics reported are provided in Table 4.1. The selected metrics comprise a mixture of the most reported metrics in the limited existing literature and anecdotal evidence from experienced practitioners. In addition, such metrics are either designated as, or derived from metrics designated as, “Pass” in the validation report for the Catapult Vector S7 provided to the National Basketball Association and National Basketball Players Association by their jointly retained experts (National Basketball Association, 2017). PL (and its derivatives) are the most commonly reported metric in basketball literature (Russell, McLean, Impellizzeri et al., 2021) and is suggested to be suitable for reporting training demands given the frequent acceleration and decelerations occurring in basketball (Stojanović et al., 2018). Deceleration efforts by intensity band are reported given the high mechanical stress it places on the body, and they may provide a valuable proxy measure of intensity (Vázquez-Guerrero et al., 2018). In addition, relative values of PL and Distance may also provide a measure of training intensity (Scanlan et al., 2020), while TL accumulated in PL bands and Distance accumulated in Velocity bands may allude to the volume of work achieved across intensity thresholds.

To be included in the analysis, based on the typical non-injured training schedule, at least five out of the six (>83.3%; regular week) or four out of the five (>80%; modified week) training days must have been available to represent a week of training. This was confirmed by checking the sessions attended and aligning this with medical records establishing athlete availability. Data from modified and injured players (including injuries within the session) were excluded from analysis. This process resulted in 63% ± 13.5% of athletes’ training weeks being included in the study.

Table 3.2 External Load Parameters obtained from the Catapult ClearSky LPS.

Parameter	Units of Measure	Definition
PlayerLoad (PL) (Total and per minute)	AU	The sum of accelerations across all axes of the triaxial accelerometer.
PlayerLoad Accumulated in Bands	AU	The sum of accelerations across all axes of the triaxial accelerometer within the specified band. Band 1: 0-1 AU Band 2: 1-2 AU Band 3: 2-3 AU Band 4: 3-4 AU Band 5: 4-5 AU Band 6: 5+ AU
Distance (Total and per minute)	Metres	The total distance covered.
Deceleration Efforts (Bands 1-3)	Count	The total number of deceleration efforts counted in the specified band. Band 1: -2-3m/s Band 2: -3-4m/s Band 3: -4+m/s
Distance Covered in Velocity Thresholds (Bands 1-6)	Metres	The total distance covered in the specified band. Band 1: 0-1m/s Band 2: 1-3m/s Band 3: 3-4.5m/s Band 4: 4.5-6m/s Band 5: 6-7m/s Band 6: 7+m/s

Statistical Analysis

Data analysis was performed on R Studio using the lme4 and lmerTest packages (Version 4.2, R Core Team). Prior to analysis, assumptions of variance and independence were checked utilising Levene's and Shapiro-Wilk test's respectively and scatterplots and Cook's Distance were used to determine potential influential data points, of which none were evident. Multilevel mixed-effects models were fit to examine the relationship of external TL metrics with training year, training block, and playing position. Mixed modelling was used for its ability to cope with unbalanced and repeated-measures data (Cnaan et al., 1997). To account for individual differences, a random intercept was set at the individual athlete level. For all fixed factors (i.e., training year, training block, and playing position), pairwise differences were assessed post hoc using Tukey's HSD. Significance was set at $p \leq 0.05$. Data is presented in weekly means (±SD).

4.5 Results

Training Year

Table 4.2 shows total training duration was significantly greater in Y3 than Y1 ($p=0.03$). No other significant differences were observed between training years for any external TL metrics ($p>0.05$).

Term

Table 4.3 shows total training duration was significantly greater in T1 ($p<0.001$), T3 ($p<0.001$) and T4 ($p<0.001$) than T2, while T4 was significantly greater than T3 ($p=0.04$). Total distance in T3 was significantly greater than T1 ($p=0.03$) and T2 ($p<0.01$), while

T4 was significantly greater than T2 ($p<0.01$). Distance·min^{-1} was significantly greater in T2 ($p=0.001$), T3 ($p=0.001$) and T4 ($p=0.001$) than T1. Total PL was significantly less in T2 than T1 ($p=0.004$), T3 ($p<0.001$) and T4 ($p<0.001$), while T4 was significantly greater than T1 ($p<0.001$) and T3 ($p=0.004$). PL·min^{-1} was significantly greater in T4 than T1 ($p<0.001$) and T2 ($p=0.003$).

Position

Table 4.4 shows significantly greater distance·min^{-1} ($p=0.011$) and PL·min^{-1} ($p=0.011$) for Backcourt players than Frontcourt players, while also performing significantly more Decelerations in Band 1 ($p=0.023$), Band 2 ($p=<0.001$) and Band 3 ($p<0.001$). No significant differences between playing positions were observed for total duration, total distance, total PL ($p>0.05$).

4.6 Discussion

This is the first study to describe the external TLs of coach-led training sessions of highly trained youth basketball athletes by training year, term and playing position. The results of this study show limited changes in training volume and intensity between years. However, within-season analysis by training term showed significant differences for most TL metrics, suggesting a seasonal component to external TLs. Finally, Backcourt players recorded greater values for relative measures (i.e., higher intensity) and volume accumulated in higher intensity running and decelerations than Frontcourt players. Overall, this suggests that this academy environment implements a periodised and structured training program within the year, likely related to maximising skill development training. Collectively, this study provides contemporary reference points, and the first outside of Europe, for practitioners for the external TLs experienced by highly trained youth basketball players.

The primary finding of this study suggests that, despite Y3 athletes completing a significantly greater weekly training duration than Y1 (371±96min vs 341±95min), most external TL metrics were not different between years. Given the increase in training duration but not external TL, it is possible that Y3 athletes additional 30min/week of training may be dedicated to an additional low-intensity skill or technical session. It could be hypothesised that volume-based measures (e.g., PL and distance) would increase as an athlete progresses within the program, especially given classic connotations of progressive overload to develop physical capacities and TL tolerance (Bergeron et al., 2015). However, no change in training volume occurred in Y2 and Y3. It may be that additional TL is achieved through competition, for which data was not able to be collected and is recognised as a limitation. A further possible explanation for this could be that TL is already high in Y1, limiting the ability for gradual linear increase. Given the athletes limited tenure within the academy (2-3 years), coaches may look to maximise the athletes' development with additional training from the program commencement in Y1. Accordingly, it may mean that total training exposure, rather than a traditional progressive overload is more apparent, with activities being modified to cater for the different phases of the life cycle within the academy.

Table 3.3 Mean ± SD of Weekly External Load Metrics by Training Year

	Year 1	Year 2	Year 3
Total Duration (mins)	341±95	346±96	371±96[a]
Total Distance (metres)	18365±5892	18932±6071	19960±5347
Distance·min^{-1} (metres)	55±10	55±9	54±7
VB1 Distance (metres)	3139±1112	3386±2243	3480±961
VB2 Distance (metres)	10865±3562	11338±3633	12045±3194
VB3 Distance (metres)	3397±1249	3385±1325	3473±1175
VB4 Distance (metres)	820±457	802±473	829±457
VB5 Distance (metres)	113±83	105±76	105±69
Total PL (AU)	2509±740	2517±857	2505±676
PL·min^{-1} (AU)	7.6±1.0	7.4±1.6	6.9±0.9
Total PLB1 (AU)	1094±339	1090±317	1186±320
Total PLB2 (AU)	1117±355	1099±372	1063±309
Total PLB3 (AU)	252±124	258±133	221±90
Total PLB4 (AU)	32±24	35±31	25±16
Total PLB5 (AU)	5±7	8±44	4±4
Deccelerations B1	280±105	274±110	281±92
Deccelerations B2	78±37	74±37	58±27
Deccelerations B3	15±9	13±9	10±8

Note: [a]Significant difference between Y3 and Y1.

Table 3.4 Mean ± SD of Weekly External Load Metrics by Term

	Term 1	Term 2	Term 3	Term 4
Total Duration (mins)	351±92	309±92[a]	348±102[d]	373±83[e,f]
Total Distance (metres)	18128±5616	17382±5366	19384±6987[b,d]	19968±5246[e]
Distance·min^{-1} (metres)	53±6	56±7[a]	56±11[b]	56±11[c]
VB1 Distance (metres)	3343±2536	2898±893[a]	3205±1179	3593±1263[e]
VB2 Distance (metres)	10710±3291	10361±3230	11905±4321[b,d]	11582±3104[c,e]
VB3 Distance (metres)	3350±1250	3215±1154	3366±1367	3670±1266[c,e,f]
VB4 Distance (metres)	778±452	801±394	749±421	933±552[c,e,f]
VB5 Distance (metres)	80±58	89±67	122±88[b,d]	146±83[c,e,f]
Total PL (AU)	2472±856	2224±699[a]	2565±788[d]	2788±655[c,e,f]
PL·min^{-1} (AU)	7.4±1.9	7.4±1.0	7.5±0.9	7.6±1.0[c,e]
Total PLB1 (AU)	1063±294	998±319	1148±363[b,d]	1194±305[c,e]
Total PLB2 (AU)	1062±355	988±334	1121±365[b,d]	1254±325[c,e,f]
Total PLB3 (AU)	258±132	208±105[a]	252±129[d]	288±122[c,e,f]
Total PLB4 (AU)	37±31	25±21[a]	33±27[d]	36±25[c,e,f]
Total PLB5 (AU)	10±53	4±4	5±5	7±10
Decelerations B1	283±107	264±98	278±114	286±104[e]
Decelerations B2	77±38	72±36	72±38	79±34
Decelerations B3	13±10	14±10	12±8	16±8[c,e,f]

Note: [a]Significant difference between T2 and T1, [b] significant difference between T3 and T1, [c] significant difference between T4 and T1, [d] significant difference between T3 and T2, [e] significant difference between T4 and T2, [f] significant difference between T4 and T3.

Table 3.5 Mean ± SD of Weekly External Load Metrics by Position

	Backcourt	Frontcourt
Total Duration (mins)	342±96	347±95
Total Distance (metres)	19175±6023	18419±5854
Distance·min^{-1} (metres)	57±10	54±9[a]
VB1 Distance (metres)	3129±1095	3341±1878
VB2 Distance (metres)	11269±3579	11060±3570
VB3 Distance (metres)	3744±1329	3183±1183[a]
VB4 Distance (metres)	885±491	770±438[a]
VB5 Distance (metres)	117±78	104±80
Total PL (AU)	2624±854	2441±721
PL·min^{-1} (AU)	7.9±1.6	7.2±0.9[a]
Total PLB1 (AU)	1073±329	1118±329
Total PLB2 (AU)	1181±381	1059±335
Total PLB3 (AU)	290±141	227±108[a]
Total PLB4 (AU)	44±34	26±17[a]
Total PLB5 (AU)	10±43	4±6[a]
Deccelerations B1	305±109	261±101[a]
Deccelerations B2	89±39	66±32[a]
Deccelerations B3	18±10	12±8[a]

Note: [a]Significant difference between Backcourt and Frontcourt.

Although year-to-year changes were not evident in most external TL metrics, within-season differences were observed between terms. Firstly, the weekly volume (Total Distance and Total PL) and intensity (Distance·min^{-1} and PL·min^{-1}) of training in the latter half of the year (i.e., T3 and T4) was greater than the first half of the year (i.e., T1 and T2). This suggests that training volume and intensity are lower during the competitive phase of the season, during which athletes are competing in 1-2 matches/week (for which data was not available).

Direct comparisons for this level of youth basketball are not currently available in the literature, and comparisons to semi-professional and professional leagues may not be appropriate due to the influence of competition load. However, when considering the preseason training of a professional team, this study reports substantially lower PL (3442AU and 3915AU per week 2565AU-2788AU) for a comparable phase of the season (Kamarauskas et al., 2023). The higher training volumes and intensities observed in T3 and T4 (offseason/preseason,) suggest a shift in training focus during those phases. In these periods, more time is likely dedicated to high-volume conditioning and individual work, as opposed to in-season training that must accommodate frequent competition. Athletes may partake in a greater number of repetitions during skill sessions and complete more running or movement-based conditioning sessions.

The disparity in external TLs between the current academy and previously published data in professional teams could be due to competition loads not being included in this study. Whilst we recognise this as an unavoidable limitation in our analyses, it is well documented in the industry that the developmental focus of academy settings, more time, and thus more TL, are likely attributed to training as opposed to the focal point of professional teams maintaining readiness to perform (Mercer et al., 2022). These results underscore the potential role of high-performance youth academies in bridging the physical preparation gap between junior- and senior-level competition. (McKay et al., 2022). Realising this potential likely requires robust load monitoring systems and dedicated performance staff to help balance training stress and recovery for athletes' long-term progression.

Previous literature highlights the positional differences in external TLs across several levels of basketball (Pino-Ortega et al., 2019; Portes et al., 2020; Svilar et al., 2018; Vázquez-Guerrero et al., 2018). We report that Backcourt players complete a greater volume of higher speed running distance throughout a training week than Frontcourt players (VB3, 3744±1329m vs 3183±1183m; VB4, 885±491m vs 770±438m), collectively resulting in higher distance$\cdot$min^{-1} (i.e., relative intensity) (57±10m$\cdot$min^{-1} vs 54±9m$\cdot$min^{-1}). Although adopting a different positional classification system, these results concur with evidence from highly trained youth players; whereby, guards ran a greater total distance and distance within high intensity speed bands than forwards and centres in competition (Ben Abdelkrim et al., 2007; Vázquez-Guerrero, Fernández-Valdés, Jones et al., 2019). These differences are typically attributed to the fact that Frontcourt players operate in a limited playing zone (i.e., inside the arc/key) (Svilar et al., 2018). Furthermore, our results indicate that Backcourt players have a greater PL$\cdot$min^{-1} (7.9±1.6 vs 7.2±0.9) and complete a greater volume of high intensity work (PLB3, 4 and 5) including counts of decelerations in Band 1, 2 and 3. Similar results have been reported by Vazquez-Guerrero and colleagues (2018) where point guards and shooting guards completed a greater total count and maximum decelerations than small forwards, power forwards and centres in competition. In contrast, Svilar and colleagues (2018) reported forwards and centres complete a greater amount and intensity of decelerations, despite guards completing more high intensity actions than centres. Guards are typically involved in more hand-to-hand tactical actions (i.e., dribbling/evading defenders and guarding offensive players) and thus lead to more high intensity decelerations and changes of direction (Vázquez-Guerrero et al., 2018). Understanding these positional differences in a high-performance basketball academy will allow practitioners, in particular strength and conditioning coaches, to modify physical development programs to the specific positional requirements of the game.

Although this study provides novel data pertaining to the external training demands of highly trained youth basketball players, it is not without its limitations. Data collection for this study took place during the COVID-19 pandemic, with the academy acquiring a government exemption to continue training due to their status as a national program governed by the health and safety protocols of the AIS. Furthermore, comparisons to certain external TL metrics reported in the existing literature was limited, as this study was conducted in line with the NBPA guidelines for wearables in basketball (National Basketball Association, 2017). As previously mentioned, coaches received external TL reports as part of routine servicing, as such it is possible that coaches adjusted training plans based on these reports which could have influenced external TLs reported in the study. In addition, given this study was conducted within a single academy operating on a single training schedule, caution should be taken in generalising the results to other youth basketball academies or teams.

This study described the external TL experienced by highly trained youth athletes from a basketball academy and investigated the relationship of these measures with training age, term and playing position. The results of this study suggest that hypothesised yearly increases in training volume and intensity were not evident, though significant differences existed between terms within a season. In addition, positional differences in external TL metrics were apparent, with Backcourt players typically completing a greater volume and intensity of actions than Frontcourt players. The results of this study may be used as reference points of training demands in highly trained youth basketball players, while also assisting practitioners and coaches alike in monitoring and managing training schedules and physical development programs. Future research should look to include competition demands and investigate week-to-week variations in external TL to further understand the periodisation strategies utilised within high-performance basketball academies. Future research may also consider how competition exposure aids the developmental pathway of youth basketball athletes.

4.7 Practical Applications

Collectively, the findings of this study provide a description of the external TLs experienced by highly trained youth basketball players that previously did not exist. This knowledge may assist coaches and performance practitioners in preparing their athletes for the transition into senior basketball. Cohort-specific data is crucial for the unique training structure (i.e., full-time) of the academy and provides a valuable resource for sport scientists and strength coaches to inform training monitoring and management practices and physical development programs.

Chapter 5: Study 3

Revisiting the Playbook: Coaches' Opinions and Current Views of Performance, Development and Load Monitoring in Highly Trained Male Youth Basketball Players

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5.1 Executive Summary

The third study addresses the thesis's third aim: to examine coaches' philosophies and perspectives on athlete development and the use of TL monitoring. Now that Studies 1 and 2 have established how TL accumulates across years, terms and by positions within the academy, this study shifts focus to the coaches responsible for designing and interpreting the programs that produce those loads. Guided by a pragmatic orientation, it seeks to understand how coaches interpret monitoring information within their professional context, emphasising practical insight and applicability over theoretical abstraction. Through qualitative interviews, it explores how coaches conceptualise performance, balance developmental priorities, and engage with monitoring data in daily practice. In doing so, Study 3 provides the interpretive context necessary to understand how TL data may translate into coaching decisions and establishes the foundation for Study 4, which evaluates the alignment between coach-prescribed training goals and the TLs ultimately delivered.

5.2 Abstract

This study examines basketball coaches' perceptions and current views on performance, player development, and TL monitoring in highly trained male youth academy basketball players. Through semi-structured interviews with nine coaches, we explore their philosophies on player performance, key indicators of success, and the integration of TL monitoring into their coaching practices. Reflexive thematic analysis identified 37 lower-order themes and 14 higher-order themes, which were categorised into four dimensions: *Holistic Preparation, Physical and Athletic Performance, Measurement of Physical Output,* and *Integration of Data.* Coaches' emphasised psychological, skill-based, and physical aspects of player development, particularly lateral quickness, explosive movements, and coachability. While some coaches' value data-informed approaches to optimise training and mitigate injury risk, others remain sceptical about its practical impact. By investigating how coaches perceive and apply performance monitoring, this study provides insights into bridging subjective coaching expertise with objective data analysis. The findings offer practical applications for sport scientists and coaching staff seeking to enhance developmental pathways for highly trained youth basketball players.

5.3 Introduction

In the past decade, basketball's global popularity, viewership and participation have grown significantly, particularly outside of the U.S (Nielson Media Insights, 2024). This rise coincides with the development of full-time youth academies, aimed at national and international talent identification and providing pathways for development (Bonal et al., 2020). With player development as the focus, coaches at such academics dedicate substantial time to technical skill and tactical training (Calleja-González et al., 2016). Understanding these coaches' views, priorities and methods is key for performance support staff at the academies in order to inform and better support a performance system through TL monitoring, program design and recovery (Reade et al., 2008). Specifically, TL monitoring is a critical part of sports science provision in basketball talent development pathways (as outlined in Study 1 and 2) to support detailed and targeted planning and modification of training exposure (Bergeron et al., 2015). However, for this process to be effective it must align with the coaches' overarching priorities for the training environment to ensure relevancy and buy-in (O'Grady et al., 2020) and concurrently address athlete health and physical development outcomes (Weston, 2018). Although survey-based evidence has examined perceptions of player monitoring and microsensor use in basketball (Fox, Scanlan, Sargent et al., 2020), limited research has explored in-depth how youth basketball coaches within high-performance academy environments perceive and implement TL monitoring to guide long-term player development.

Coaches' perceptions of TL monitoring are likely shaped by their broader philosophies on performance enhancement and player development (Redkva et al., 2017). While research in basketball is limited, these perceptions have been explored in other sports. For example, it has been reported that elite soccer (football) coaches believe monitoring TLs improves performance and reduces injury, though many rely on personal subjectivity (Weston, 2018). Comparatively, elite volleyball coaches often resist data-informed decision making due to ingrained cultural habits (Gesbert et al., 2016) while elite endurance sport coaches surveyed by researchers have reported that current scientific evidence doesn't meet their specific needs or standards (Roos et al., 2013). Though these studies offer insights into coaching practices in other sports, they appear too environment- and sport-specific, and as such offer limited translation to basketball academies. Consulting basketball coaches is key to integrating TL monitoring in youth academies. This research would guide training design and player development, addressing the current lack of data in these settings (Bartlett & Drust, 2021). Future studies are vital to enhance development pathways, which have historically prioritised competition over structured training.

Elite youth basketball is typified by various modalities of training and atypical competition schedules (McLean et al., 2019) which is even more pronounced in a full-time academy environment that offers structured long-term athletic and skill development alongside academic commitments (Bonal et al., 2019). Given the relative infancy of TL monitoring practices in basketball (Russell, McLean, Impellizzeri et al., 2021), key stakeholders such as coaches should be consulted to incorporate their expertise and experience to ensure greater buy-in for these practices (Malone et al., 2019). Provision of data and information that is relevant to coaches' objectives, along with communication between performance support staff and coaches should be essential for integrating scientific research into everyday coaching practices to ensure buy-in (Fullagar et al., 2019). Coaches' perceptions of performance and the training process they implement likely influence how academy performance support staff analyse training schedules and plans to optimise technical and tactical development while maintaining athlete health and wellbeing. Although TL monitoring is considered valuable by performance and medical staff in youth basketball (as outlined in Study 1 and 2), and despite the hesitation of some practitioners seen in other sports, there is currently no research that actively engages coaches to help shape and implement a comprehensive TL monitoring program.

Taken collectively, the current literature outlines the need to collaborate with coaching staffs on the conceptualization of sport science systems (Bartlett & Drust, 2021) in youth basketball. Therefore, this study sought to describe the philosophy on basketball performance and training design of basketball coaches at elite academies, as well as such coaches' perceptions of TL monitoring and technology in youth basketball. Subsequently, this study aims to uncover perceived key performance indicators in youth basketball as identified by such coaches along with proposed methods on how they do, or would like to, monitor them.

5.4 Methods

Participants

A convenience sample of nine coaches (Technical Director and Head Coach, n = 3, basketball coaching experience = 20.0 ± 11.3 years, age = 51.0 ± 9.5 years; Assistant/Player Development Coach, n = 6, basketball coaching experience = 8.2 ± 1.5 years, age = 39.8 ± 3.9 years) working within an international network (Australia, Africa and Mexico) of highly-trained youth basketball academies were invited to participate in this study. No coaches declined to participate, though there was no penalty for not engaging or coercion to participate. The academies provide a full-time residential basketball development program for athletes, alongside their academic commitments. Athletes are typically within the program for 2-3 years and are often considered some of the top youth basketball players from their respective countries.

Coaching staff are supported by a range of colleagues covering academics, operations, physical performance, medical and mental performance. Academy graduates have been recruited to Division 1 National Collegiate Athletic Association (NCAA) schools and professional teams (e.g., Australia's National Basketball League, G-League, NBA). All coaches were certified by the World Association of Basketball Coaches (WABC) with varying years of coaching experience at youth, collegiate, professional and international levels of basketball. All coaches provided written informed consent prior to participation, with ethical approval for the study obtained from the University Human Research Ethics Committee (ETH22-7619).

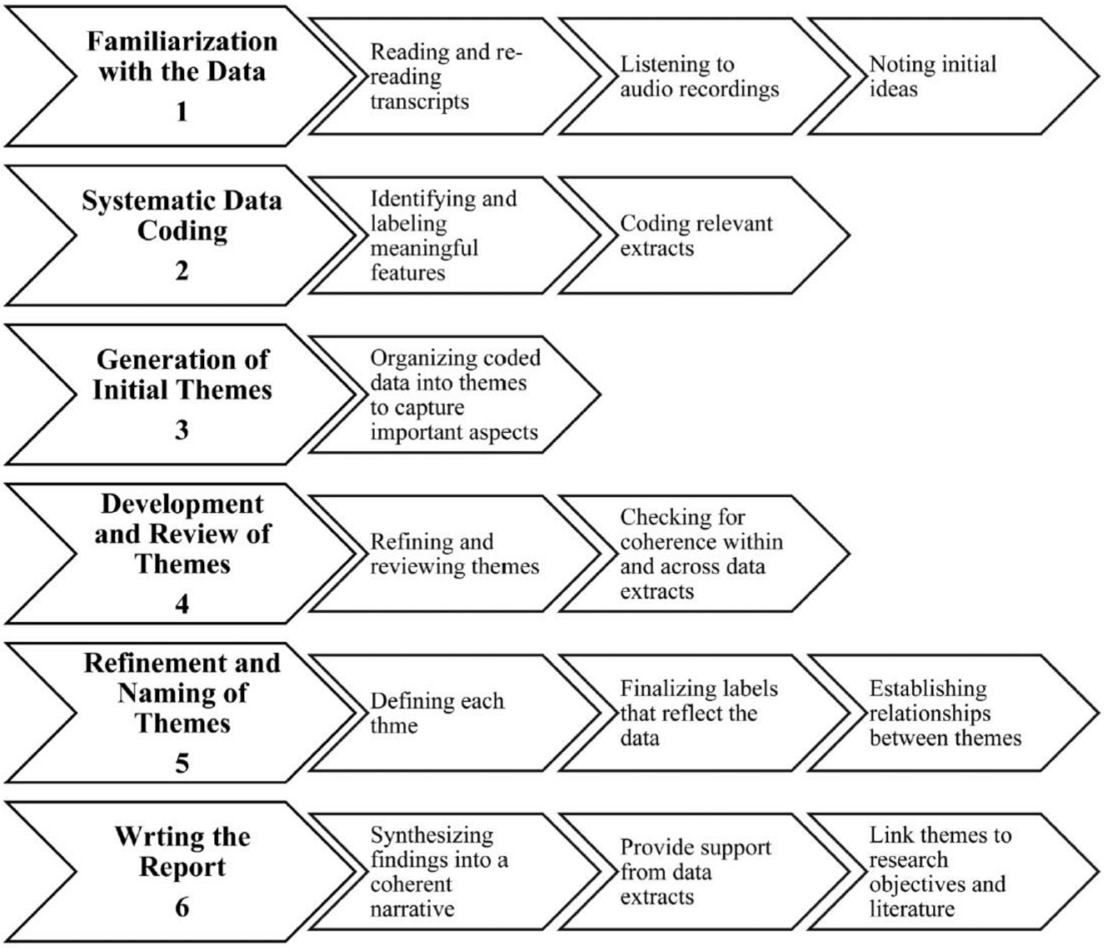
Data Collection

All participants undertook a one-on-one, semi-structured interview in person with the lead researcher (JL) with a digital audio recording of the session obtained (Otter.AI, California, USA). The interviews took place in a venue of the respondent's choice while the respondent's team competed in a U.S.-based tournament in July 2022. All interviews were conducted in English. During the interview, participants provided their playing and coaching experience in basketball. Interviews were 30-60 minutes in duration (mean 40

±9.5 min) and consisted of open-ended questions. The conversational nature of the approach allowed variation in the ordering of questions depending on responses, while ensuring consistency and completion of all elements as well as follow up of both verbal and non-verbal responses. Questions focused initially on the coach's philosophy of individual and team performance in basketball, highlighting key indicators of performance and potential positional nuances. Follow up questions focused on physical and psychological characteristics that contribute to basketball performance and how technology and the monitoring of training may assist coaches in developing youth athletes. Participants were also asked about strategies used to plan, prescribe, and assess training, and how technology may assist that process.

A team of researchers with extensive sport science, academic and sports management experience discussed and approved the interview framework before any interviews took place (interview template provided in Appendix 8). The interviewing researcher (JL) also maintained a diary to record ideas, questions, and observations from each interview to support the authors' analysis. Three participants had previously worked directly with the interviewer in a professional capacity; however, no supervisory or reporting relationships existed. While this familiarity may have influenced interpretation, reflexive thematic analysis procedures were employed, including analytic notetaking and involvement of a second author as a "critical friend" to challenge theme development. All interview recordings were transcribed verbatim (Silverman, 2006) following the interview, with small grammatical changes made to enhance the flow of the transcript. Such structure has been previously utilised for interviews within high-performance sporting environments (Bonal et al., 2019; Haraldsen et al., 2021; Vickery & Nichol, 2020).

Figure 4.1 The six stages of analysis, adapted from Braun and Clarke, 2006



5.5 Data Analysis

A reflexive thematic analysis was conducted following Braun and Clarke's six-stage process (Braun & Clarke, 2006) (Figure 5.1, adapted from Braun and Clarke, 2006). To do so, the authors completed an initial familiarization stage of reading the data and noting ideas for themes. The authors then identified codes across the entire data set, which later developed into dimensional themes. Themes were then reviewed and defined in context with the overall aim of the study. The first author completed this process, while a second author acted as a "critical friend" (Smith & McGannon, 2018; Sparkes & Smith, 2014) to discuss a sample of generated codes, challenge any bias and ensure reflexivity in the process.

Specifically, the "critical friend" provided an external perspective to review the themes for inconsistencies, alternatives or overlooked patterns while continuing to refine the themes and encourage reflexivity (Smith & McGannon, 2018; Sparkes & Smith, 2014). This process ensured codes and extracts followed a coherent pattern. This process resulted in several higher-order constructs being established along with sub-themes among each construct. Finally, the authors constructed a thematic network and subsequently named and defined each theme (Figures 5.2-5.5). Themes were not determined based on frequency alone but were identified for their analytic significance in relation to the research question (Braun & Clarke, 2006). While common themes were identified across the full cohort, there was variation in how individual coaches described and prioritised specific qualities, reflecting differences in role, experience, and personal philosophy. These differences were accommodated within the thematic structure, consistent with a reflexive thematic analysis approach that values both shared patterns and individual nuance (Braun & Clarke, 2006). Terms commonly used by coaches were defined inductively based on each participant's phrasing and context. While some variation in interpretation existed across coaches, these terms were thematically coded to reflect their intended meaning. Consistency and clarity were ensured through collaborative theme refinement and discussion (Braun & Clarke, 2006). The output reflects the dataset, the theoretical assumptions of the analysis and the analytical skills of the researchers.

5.6 Results

Following thematic analysis of the data, a total of 37 lower-order themes, fourteen higher-order themes and four-dimensional themes were developed. The four dimensions included 1) Holistic Preparation, 2) Physical and Athletic Performance, 3) Measurement of Physical Output and 4) Integration of Data (see Figures 5.2-5.5). Codes were added to the direct quotes to indicate attribution (coaching role and participant number), where HC refers to Head Coach and AC refers to Assistant Coach.

Within Holistic Preparation, coaches highlighted components of psychological, technical, tactical and physical performance as important, and which may also allude to the developmental progress in youth programs. For the Physical and Athletic Performance of basketball players, coaches described several capacity-based (e.g., speed, explosiveness and endurance), movement-based (e.g., change of direction) and anthropometric-based (e.g., height and wingspan) factors that they deemed important, both at the individual and positional level. With respect to the Measurement of Physical Output, coaches identified some key physical metrics they used during practice to assess the performance of their team. Finally, regarding the Integration of Data into their programs, the coaches discussed their perceptions of utilizing technology and associated data to help inform their decision-making and planning process.

The following sections explore how the coaches' perceptions and philosophies shape each of the four dimensions. Some of the higher- and lower-order themes have been discussed together to highlight their co-existence. The discussion of some of these themes together provides a greater understanding and importance of all themes within a youth basketball and specifically an academy setting.

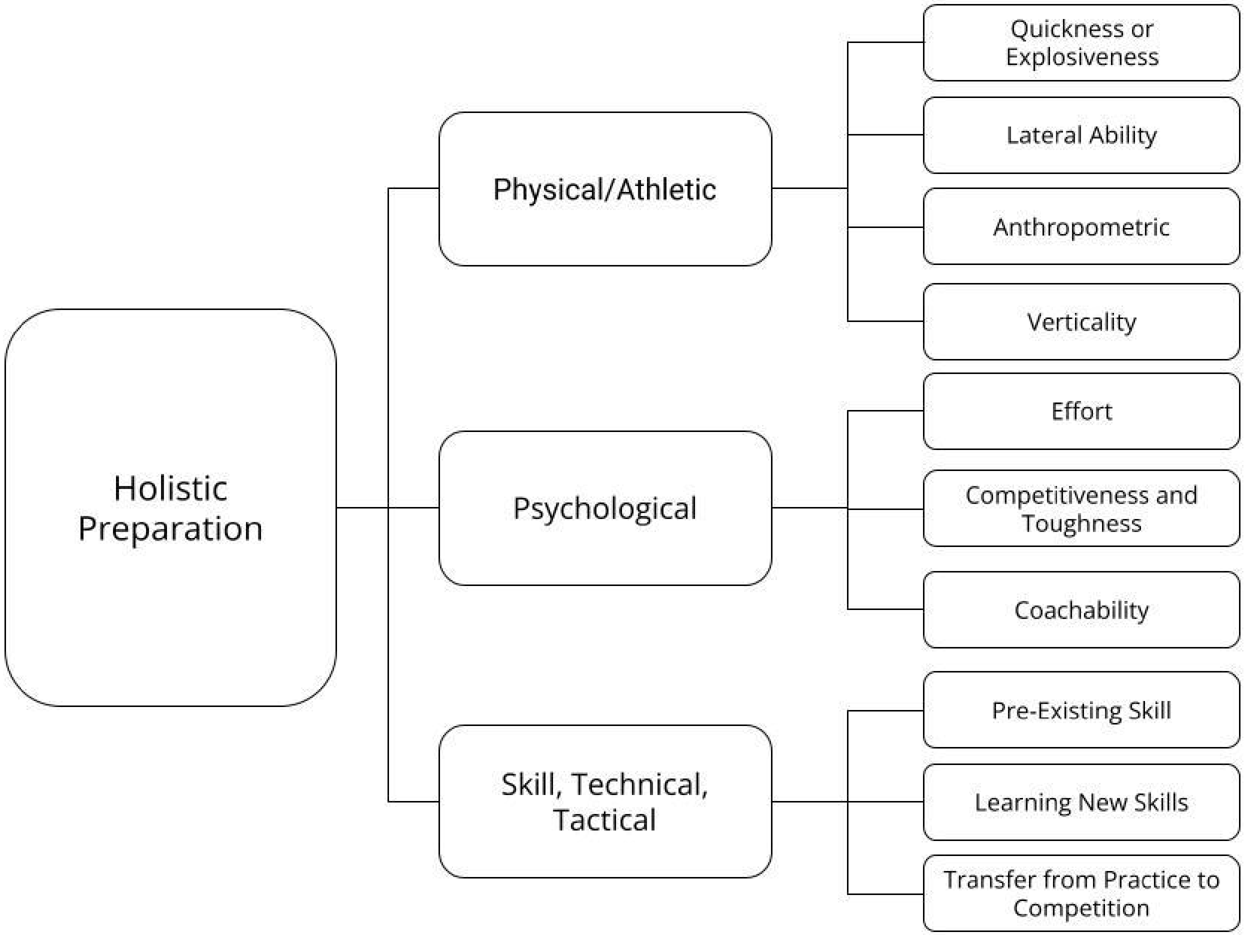
Holistic Preparation

The coaches' perceptions of performance in basketball highlighted three higher-order themes by which they assess their athletes. Despite the noted importance of *skill-based* assessment and *physical and athletic components*, all coaches discussed how crucial *psychological performance* was for their athletes, with one coach stating: *"I think the physical characteristic is second to the mental" (HC1).*

Physical and Athletic Factors

The coaches noted key *physical and athletic* factors they believe contribute to performance in basketball, whereby four sub-themes emerged. Of particular importance, the coaches discussed an athletes' *quickness or explosiveness* as an indicator of performance in basketball. A specific aspect of this highlighted by the coaches was *lateral ability* as a measure of offensive and defensive performance.

Figure 4.2 Thematic map of holistic performance in basketball



The coaches identified both trainable and non-modifiable components of basketball performance; anthropometric factors such as *"length"* (i.e., height and wingspan) and the concept of" verticality*"* (referring not only to jump height, but also "*how quickly they can get off of the floor, often in repetition" (AC2))* were both deemed important for basketball

Psychological Performance

Three sub-themes emerged within this theme, including the concept of *effort*. Though seemingly highly subjective in nature, the coaches described this using the term *"how hard"* an athlete is playing or working. Similarly, coaches posed the question *"how hard are they willing to work?" (AC1)* in association with performance.

This sub-theme is linked to a second sub-theme of *toughness*. Here, the coaches suggested that an athlete's performance and development may be reliant on whether *"they love the game" (HC3)* and *"can push themselves" (HC1)*. When discussing the concept of "*toughness*," one coach stated that *"physical toughness or mental toughness, in the end it's all the same…" (HC1)*. This accentuates the interplay between *psychological* and *physical* aspects of performance in basketball.

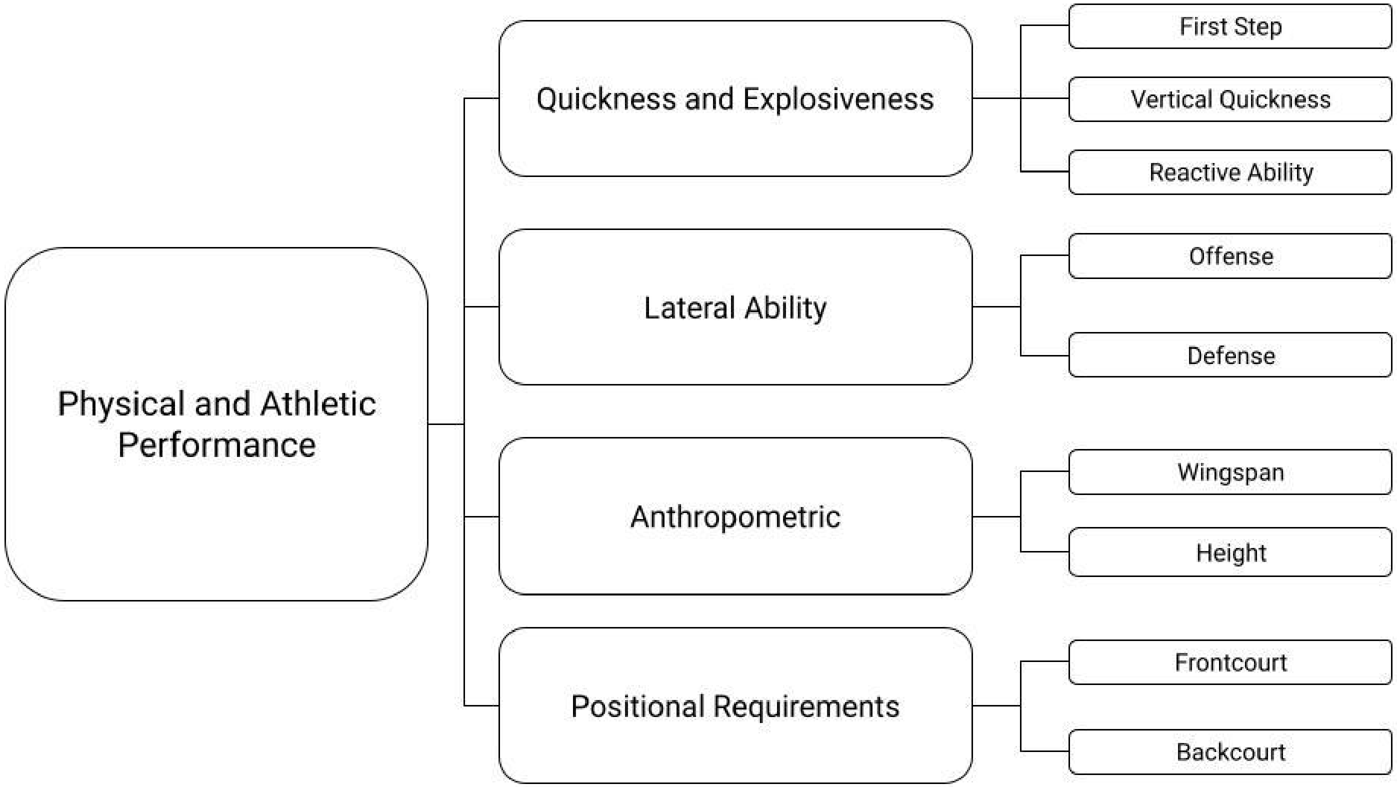
The third sub-theme discussed is *coachability*. Collectively, the coaches defined this as *"the ability to understand and learn how to put it into play" (AC1)* along with having the ability to *"reflect and ask the right questions" (AC1).* The coaches stated that athletes with a high level of coachability are *"those kids who are hungry to learn, … to get better" (HC2)*.

Skill, Technical and Tactical Ability

Intuitively, *skill* was noted as the other key factor of performance in basketball. Three sub-themes were identified within this theme: *Pre-existing Skill*, the *Ability to Learn New Skills*, and the *Transfer of Skill from Practice to Competition*. Particularly important to coaches was not skill execution in isolation, but *"how well they perform their skill, under pressure or at an elite level" (AC1)*. Regarding pre-existing skill, athletes were expected to have a certain baseline of fundamental skills: *"have the ability to shoot the ball, finishing with both sides of the body" (AC3)* and an underlying *"ability to execute fine motor skills" (AC2)*.

The ability to learn new skills overlaps with the previously mentioned *coachability* sub-theme of psychological performance. Coaches valued "*how quickly they learn" (AC2)* in addition to the general ability of players to pick up new skills. The coaches suggest that this ability to learn and pick up new skills aligns with the overarching goal of developing players, with one coach suggesting that if a player is given enough knowledge and skill "*to face any type of basketball situation, that's skill development" (AC3)*. Coaches specifically look at how an athlete transfers technical and tactical skills from practice to competition. This is deemed critical in *"getting players to be able to move up levels and be successful in adjusting…" (HC1)*.

Figure 4.3 Thematic map of Physical and Athletic Performance in basketball



Physical and Athletic Performance

Quickness and Explosiveness

A common term in sport, *explosiveness* was described by the coaches as *"fast twitch" (AC3)* and *"the ability to react, the ability to change direction … vertical or laterally" (AC1)*. Coaches noted that the first step of an athlete is a critical part of physical performance, and that a high level of *quickness* or *explosiveness* can compensate for *anthropometric* deficiencies. Collectively, coaches believe that this ability is transcendent of the level of sport, whereby *"at the next level, you see even no matter their size, they have to be fast twitch" (AC2)*.

Lateral Ability

A youth basketball player's ability to move *laterally* (i.e., side-to-side) was of high importance to the coaches interviewed in this study. While the coaches explained that lateral ability is important on offence to beat a defensive player (i.e. dribbling or cutting without the ball), the coaches also noted that strong lateral ability on defence is critical. With the increasing isolated nature of basketball offence (Demenius, 2020), players are often required to individually defend an opposing player. The coaches stated that the best players can *"stay in front of a guy… move their feet quickly" (AC4)*. When combined with anthropometric factors like height and wingspan, this was conceptualized as the ability to *"take up space" (AC2)*. When discussing how lateral movements fit into the game of basketball, the coaches stated that *"you go up and down, maybe for 3-4 seconds or a fast break, but as soon as there's a half court set, you're moving laterally most of the time" (AC3)*.

Anthropometric Factors

The coaches further noted the importance of some *anthropometric measures* in youth basketball. Most notably, the coaches discussed *wingspan* and *height* as performance indicators. The coaches focused on players who possess both factors, which allow such players to take up more space on defence. Regarding talent identification and player development, the coaches suggested that *"players that have a higher ceiling…are longer, are taller, are stronger" (AC1)*. The coaches also noted that *"length helps to account for quickness deficiencies" (AC2)*. The importance of these characteristics, according to the coaches, is not limited to the academy level. As one coach stated, *"length is being sought after by the best in the business" (AC2)*.

Positional Requirements

In relation to *physical and athletic* aspects of basketball performance, the coaches also discussed how *playing positions* may require specific traits or capacities. The coaches suggested that performance at all positions requires, to some extent, the characteristics mentioned above. However, they also stated that Frontcourt players specifically *"need to be tall" (AC5)* and that *"verticality is becoming something very important… your ability to jump in the air…" (AC4)*. For Backcourt players, the coaches believed that the more advantages a guard can have, the better, stating *"it's good to have a long guard… who can jump and run" (AC3)*, specifically *"have to be able to go fast" (HC3)*.

Measurement of Physical Output

Intensity

Among this cohort, *intensity* was referred to as *"how hard an athlete is working" (HC2, HC3, AC2, AC3, AC5)* and often used to collectively describe one's *speed* or *quickness.* When discussing *intensity*, the coaches didn't cite whether their perceptions were based on given instances during drills or from practice collectively, though one coach did speak to intensity's relevance to specific drills, stating that *"intensity tells you who's sitting out of drills too much" (AC2)*. As previously mentioned, from the coaches' perspective, the concept of intensity of exercise relates to the *psychological* concept of *effort*, with coaches looking to use intensity-related metrics to answer the question *"how do I know when they're giving 100%" (HC3)*.

Movement Characteristics

Of importance to the coaches was the monitoring or description of basketball-specific *movement patterns*. Most notably, the coaches indicated *lateral and vertical quickness*, the speed and angle of a *change of direction*, general *speed* capacity and the ability to change speed as characteristics of interest. These characteristics, collectively, help the coaches assess basketball-specific performance (e.g., as one coach put it, *"how quickly do they get from help to rotation" (AC2)* while on defence). Speaking to lateral quickness, one coach stated, *"laterals are a really important part… how do you measure that… how does it transfer to competition from practice?" (AC1)*, while another noted that *"...better lateral times… are going to be a better performer in a defensive containment drill" (AC3)*.

Endurance and Physical Fitness

In addition to the above physical attributes and characteristics, the coaches discussed other aspects including *endurance*, fatigability and the influence of the physical components on *skill execution*. When monitoring training, the coaches often want to know *"the threshold for physical fatigue becoming mental" (HC1)*, as it would help athletes avoid cognitive and technical mistakes. Further, one coach stated they would like to know *"what the player has in the tank.... Then I can manage that in a game situation" (HC2)*. Relatedly, another coach stated that *"endurance for me is the key... how long a player can go 80%" (AC4)*.

The Coach's Eye

The *coach's eye* is the sub-theme of coach perception of performance as a commonly used method of monitoring training. The interviews highlighted a heavy reliance on the coaches' perception, feel and experience for planning, modification and review of training practices. Regarding the planning of training, one coach stated that *"a lot will come from experience...understanding that any [drill] longer than 10-15 minutes, you're going to lose the player" (AC2)*. Another key point within this sub-theme was modifying training based on technical outcome, where coaches are required to *"decide to cut a drill or session short to avoid building bad habits or push through...play under fatigue" (HC1)*.

Figure 4.4 Thematic map of the Measurement of Physical Output in basketball

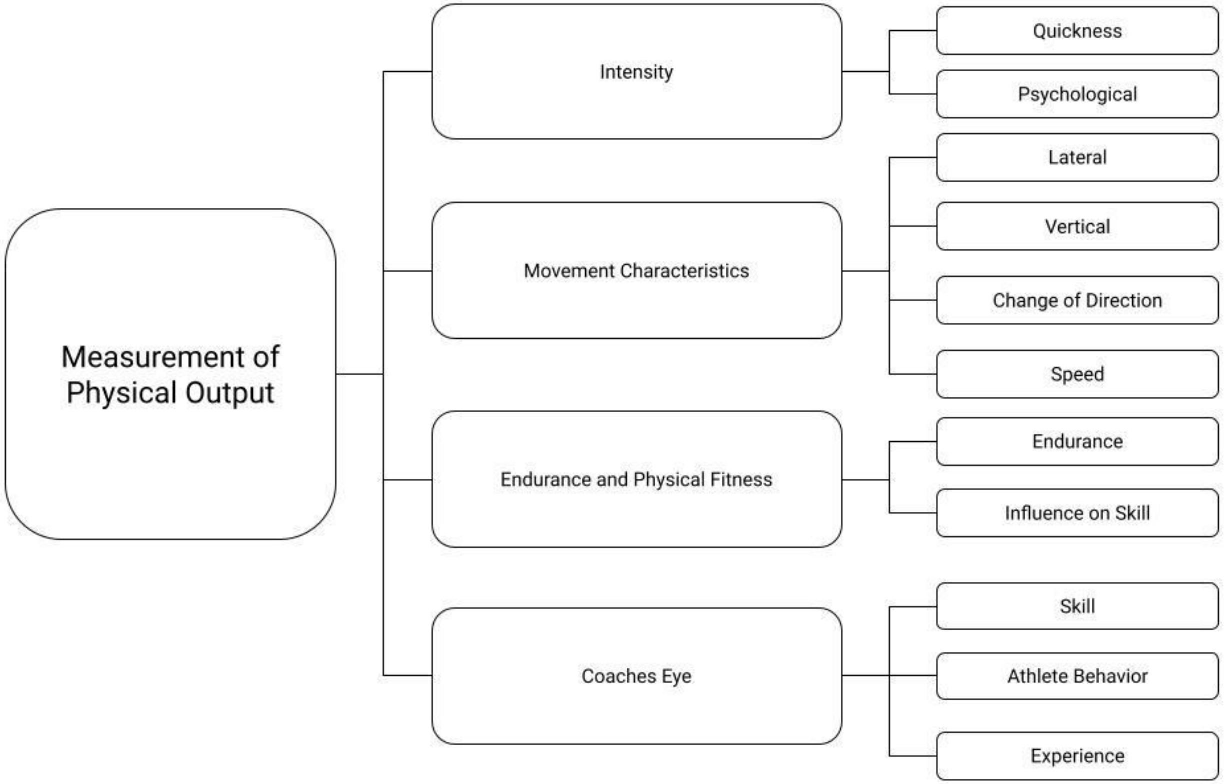
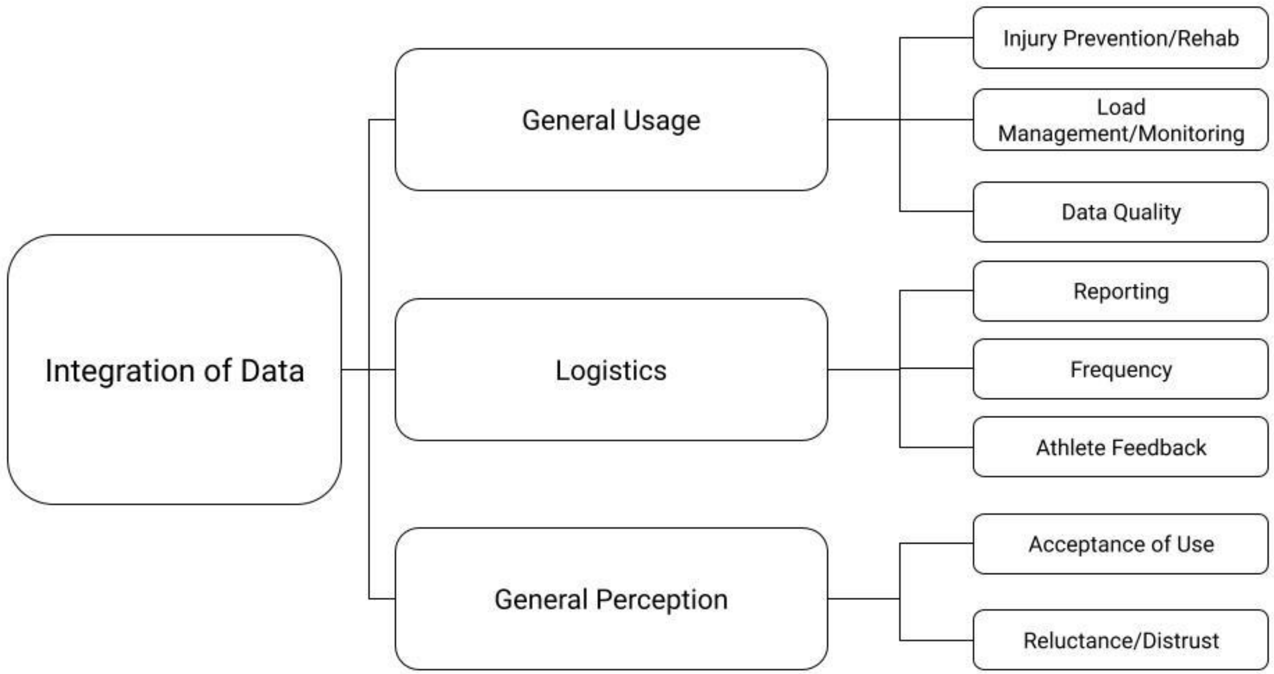


Figure 4.5 Thematic map of the Integration of Data in youth basketball academies.



Integration of Data

General Usage of Training Monitoring Data

The coaches identified several current use cases of training monitoring data gathered within their academy environment. For example, the coaches perceived training data as an aid to *injury prevention* and *rehab*. In addition, the coaches noted that such data help with week-to-week planning of training, with one coach stating, *"our weekly schedule has changed purely on how our workloads are going" (AC1)*. The coaches also showed interest in expanding the use of such data to inform substitutions during competition, although the coaches acknowledged that they may require additional education before they are able to fully utilise TL monitoring data.

Logistics

The cohort identified the importance of the logistics associated with obtaining and reporting data to ensure the effective application of such data within the coaches' training environment. While the coaches preferred reporting data to players at the individual level, the majority of such coaches also noted a preference in the combination of formal team meetings and informal conversations to convey the information. Indeed, one coach stated that *"a weekly chat needs to be had…the week in basketball is a long time… flightpath conversations are equally as important" (AC1).* Some coaches suggested that, in addition to a static report, an interactive report for those who want to explore the data further in their own time is beneficial. Regarding content, the coaches highlighted their desire for group- or team-based reporting, with individual athletes' emphasised on a case-by-case basis. For example, one coach stated a use case of an individual report could include *"reinforcing to the athletes that you're actually not working as hard as you thought" (AC2)*. Similarly, the coaches had a desire for live or instant feedback during training.

The coaches suggested that the formal reporting of TL data twice a week, as well as during a training session, was adequate for their needs.

General Perception of Technology and Monitoring in Basketball

The coaches reported two sub-themes for this theme, with some coaches being excited and passionate about the incorporation of technology and data-informed decision-making in their environment, while others stated that certain coaches may be reluctant to use it. For instance, the coaches who expressed support stated that *"the eye-test is part of it… data is also another" (AC3)*, that *"science is there to help you… it goes hand in hand with experience" (HC3)* and "(*the data) certainly usually backs up what you see as a coach" (HC1)*. Meanwhile, the coaches who expressed reluctance said that *"old school coaches, when we see a gadget… they're going to make the athletes soft" (AC5)* and *"it took me over 20 years to become a credible coach. How do I switch to a mode where this brand-new information is credible?*" *(AC6)*.

These quotes highlight what may be seen as an ideal high-performance training environment that blends the art and science of coaching, (i.e., *"... athlete centered, coach driven, scientifically and administratively supported") (HC1)*. As one coach put it, *"any data that can come to any coach, doesn't matter if you're youth, college or professional. Every coach is a coach. So, our job is to be knowledgeable. The more knowledge you have, it helps you to make better decisions" (HC3)*.

5.7 Discussion

To the authors' knowledge, this study is the first to explore coaches' perceptions of performance, development and TL monitoring in youth basketball. The findings indicate that this sample of youth basketball coaches perceive performance as a multi-dimensional construct, with psychological, physical, technical and tactical components all contributing to success on the court. Most pertinently, the coaches surveyed emphasised the role of psychological performance, often considering it of greater importance than physical characteristics. However, the interviews also revealed that physical and athletic performance are seen to be crucial for success in basketball, with particular importance placed upon 'explosive' movement capabilities. The analysis unveiled the complex interplay between objective measurement and subjective perception when monitoring training. Collectively, this study has provided a critical insight into how some basketball coaches may assess performance in a developmental environment and their perceptions of TL monitoring, which in turn provides key insights for performance practitioners to leverage when delivering sport science services to enhance developmental training of youth basketball players.

Regarding specific physical capacities and athletic ability, the coaches interviewed emphasised lateral movement ability for both defensive and offensive requirements. Lateral movement, particularly shuffling, accounts for 31% of a matches total movement, highlighting its importance in maintaining defensive position, reacting to offensive plays and creating space during offensive transitions (McInnes et al., 1995; Puente et al., 2017). Such movement is not only about quickness but also about sustained agility, allowing players to cover expansive court areas (Scanlan et al., 2011). The coaches also stressed the importance of speed and power in relation to anthropometric factors such as height and wingspan. According to these coaches, players who can combine these physical attributes with lateral speed have an enhanced ability to defend multiple positions and contest shots (Drinkwater et al., 2008; Ostojic et al., 2006).

Nonetheless, there is often a trade-off between these physical attributes and overall speed, necessitating individualised training programs that balance on-court drills with strength training tailored to a player's body composition (Joseph et al., 2021). Typically, faster and more agile players are more effective at both ends of the court, especially during high-intensity scenarios (Torres-Unda et al., 2016). As such, quantifying the volume and intensity of lateral movements in training could provide coaches with valuable insights into player TLs and performance. The integration of movement tracking into TL monitoring may provide coaches additional information that can be used to modify drills to meet specific match demands. Monitoring these metrics at the individual level may also allow coaches and performance staff to fine-tune player development, further enhancing both lateral quickness and overall ability to manage the physical demands of basketball.

The interconnection between the key performance indicators of basketball is critical, suggesting that holistic development is fundamental to player progression (Martindale et al., 2005). This conceptualisation aligns with broader practitioner-derived frameworks in basketball, where performance indicators have similarly been described as multidimensional, encompassing physical, technical, tactical, and psychological domains (Rogers et al., 2022). For instance, the most frequent psychological trait mentioned by the coaches interviewed for this study was effort (i.e., how hard players are willing to work to succeed). This may be related to on-court training and thus to physical workload, with the quantification of 'intensity' conceivably being a proxy measure. Relative measures of TL (e.g., TL $\cdot min^{-1}$) are typically used to quantify intensity in basketball (Scanlan et al., 2020), and may be valuable measures to educate coaches to help monitor training execution and performance. Nevertheless, the results of this study suggest that elite youth basketball coaches have a desire to quantify the intangibles of basketball, and thus further education may be required to define what measurement ability and precision exists. Youth basketball athletes are expected to have strong foundational/fundamental skills, though coaches believe mastery of these skills are honed under competitive conditions. As such, a means of planning, executing and reviewing these scenarios in the form of TL monitoring is likely beneficial for youth basketball coaches. Previous literature highlights the varying physical demands imposed by small-sided games and modified drills (e.g., court size and number of players) (O'Grady et al., 2020).

Acceleration and deceleration ability, including lateral and vertical change of direction, was identified by the coaches interviewed as a discriminator of athlete performance. These movement characteristics are directly linked to basketball-specific tasks, including defensive rotations and navigating offensive schemes. Sport-specific agility and movement measurements are complex (Sheppard & Young, 2006), and the coaches echoed this with concerns of how to accurately quantify such measurements in basketball. Acceleration and deceleration ability are often assessed by subjective means (Vázquez-Guerrero et al., 2018), thus limiting the precision of movement analysis. Interestingly, the results of this study report that elite youth basketball coaches still heavily rely on the *coach's eye* for evaluation of training and performance. Combining their experience, intuition and observation, coaches often make key decisions about TLs, drill duration and technical corrections without assistance or guidance from technology (Weston, 2018). Such methods are deeply rooted in coaching culture (Decabooter et al., 2024), and means of integrating modern data-informed decision-making protocols with experiential knowledge in basketball remains to be reported in the literature. This may be due to the relative infancy of valid and reliable technology in basketball (Russell, McLean, Impellizzeri et al., 2021), or as reported in this paper the hesitancy of some coaches to use these protocols in their environment. While this study reports that some coaches were excited by and accepting of data-informed approaches to support their program, others were sceptical of technology and questioned its legitimacy, suggesting it may undermine their experience and credibility. As such, sports scientists likely need to prioritise not only the selection of valid and reliable technologies and statistical approaches in basketball, but also engagement with coaching staff to ensure that data is used as a complement of their experience and judgement rather than as a substitute.

In addition to informing their own responsibilities, the coaches interviewed suggested that specific TL data may directly help their athletes' development by providing feedback on specific metrics that are aligned with the athletes' individual development goals. For example, live feedback during drills to encourage increased high-intensity efforts on defence quantified by change of direction or sprint metrics may assist the coaches in enforcing these habits with their athletes (Inoue et al., 2022). Previous research indicates that augmented feedback is likely to improve the performance and learning of gross motor and sport-specific skills (Petancevski et al., 2022). The coaches interviewed also have sought guidance from physical performance data during competition to inform substitution selection and timing. While such substitutions are based more on avoiding cognitive and technical declines due to fatigue rather than on TL management, TL data could act as augmented, in-match feedback for coaches.

This study provides novel insights into elite youth basketball coaches' perceptions of performance and TL monitoring, though the study is not without limitations. The thoughts of the coaches in the study are their own and based on their individual experiences, such that some answers reflect their unique environments. For that reason, and in conjunction with a small sample size the results may not be generalizable to all coaches or basketball training environments, or even all youth coaches or youth basketball training environments. In addition, it is difficult to develop a consensus definition on performance in sport due to its subjective nature and differing perspectives/priorities between domains; for instance, strength and conditioning coaches may bias towards performance in the physical domain when assessing basketball performance. Future research may look to expand this exploration by interviewing coaches from a variety of collegiate and professional basketball environments while also expanding upon this network of youth coaches, and engaging practitioners from varying performance domains such as strength and conditioning. It should be noted that pre-existing physical capacities and capabilities are likely strongly considered in the selection process for academies, thus development of psychological ability may seem like a priority for coaches to address. Future research should also explore athletes' perspectives of performance and development, as well as the degree of alignment between coach and athlete perceptions, to better understand the synergy required for effective holistic development.

5.8 Conclusion

Elite youth basketball coaches assess performance through a multidimensional lens, valuing psychological attributes such as effort and coachability alongside physical qualities like lateral quickness and explosiveness. While some coaches embrace data-informed approaches to guide training and injury prevention, others remain sceptical about its practical impact, emphasizing the importance of coaching intuition. The integration of TL monitoring varies, influenced by logistical constraints and differing levels of engagement with technology. These findings highlight the need for contextualized, actionable data that aligns with coaching philosophies and developmental priorities. Future research should explore strategies to enhance coach engagement with monitoring tools, ensuring they complement rather than replace traditional coaching expertise. By bridging subjective observation with objective performance data, sport scientists and coaches can work together to refine training methodologies, ultimately improving player development and decision-making in elite youth basketball.

Chapter 6: Study 4

Does the Intent Match the Output: Aligning Development Goals with Training Load in Youth Basketball

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6.1 Executive Summary

The fourth study addresses the final aim: to evaluate the alignment between coaches' intended training objectives and the measured TL outcomes of drills. Now that Study 3 has established how coaches interpret and apply TL data within their training philosophies and daily decision-making, this study examines whether those intended objectives are reflected in the physical demands experienced by athletes. Using drill-level analyses of external TL, it tests the extent to which coaching intentions translate into measurable outputs. In doing so, Study 4 completes the progression of the thesis, from describing internal and external TL patterns, to understanding coaching perspectives, to evaluating the relationship between planning, delivery, and athlete TLs in youth basketball.

6.2 Abstract

This study investigated the alignment between external TL metrics and coach-prescribed development goals in an elite youth basketball setting. External TL data from training drills were collected over two years from 25 elite male youth basketball players in a full-time residential academy. At the start of each term, coaches developed and assigned Individual Developmental Goals (IDGs) for each player. Using inductive thematic analysis, these IDGs were retrospectively grouped into four overarching Development Goal Categories (defensive, offensive, skill, physical) and 16 Specific Goal Types (e.g., cutting, shooting, load tolerance). Separately, external load metrics were recorded during all on-court training sessions using Catapult Vector S7 devices. To align IDGs with external load metrics, two multinomial logistic regression models were developed to classify (1) Development Goal Category and (2) Specific Goal Type (SGTs) using per-minute external load metrics. Both models achieved 66% classification accuracy (Kappa = 0.60). Key associated variables, such as high-intensity deceleration counts, vertical PlayerLoad, and high-speed running distances, were retained in both models following stepwise selection. Model performance was strong, with large reductions in AIC (ΔAIC = 1224.1 and 2540.7, respectively), demonstrating that coach-assigned IDGs were associated with distinct external load profiles. Additionally, accumulated training time differed significantly across Specific Goal Types, reflecting systematic variation in emphasis across the season. These findings demonstrate some ability of external TL metrics to reflect coach-assigned development goals to aid training design and physical demand alignment in youth basketball.

6.3 Introduction

In basketball, player development is a complex, multi-dimensional process requiring the coordinated advancement of technical skills, tactical understanding, and physical capacities (Ziv & Lidor, 2009). Within high-performance (McKay et al., 2022) youth academies, basketball coaches frequently tailor individual development plans that guide the selection of drills, session structures, and seasonal training blocks (Leite & Sampaio, 2012) aiming to develop the physical requirements of elite cohorts (Bartlett & Murray, 2025). These coaching plans emphasise specific goals, including improving defensive footwork, enhancing offensive decision-making, refining ball-handling, or building physical endurance. Despite this individualised and goal-driven approach to training design, performance support practices often operate in parallel, monitoring physical output through wearable technology without explicit consideration of coaching intent of the specific drills (Fox et al., 2017; Leite & Sampaio, 2012).

This disconnect between coach-led design and physical output monitoring presents a significant challenge in basketball and sport more broadly. Although external TL metrics provide valuable insights into the physical demands of basketball, they are frequently reported in isolation, without alignment to the technical or tactical objectives they are intended to support (Portes et al., 2019; Svilar & Jukić, 2018). Consequently, coaches often receive limited feedback on whether their chosen drills are eliciting the desired physical responses, while performance support staff may lack sufficient sport-specific context to interpret whether elevated or reduced TLs are appropriate. This may be particularly evident in basketball environments where drill-level intentions are not routinely shared or tagged (Fox et al., 2017), as per Study 3. As a result, physical and technical aspects of training are often evaluated separately, rather than in an integrated manner to evaluate whether the physical outputs of training align with intended purposes. Understanding this alignment has implications for coaching efficiency, managing exercise prescription and targeted TL, as well as individualised development programming.

Previous research has advanced understanding of the physical demands of basketball across contexts such as competition (García et al., 2020), training camps (Arede et al., 2021), and longitudinal exposure (as outlined in Study 1 and 2). However, few studies have examined how physical demands vary as a function of specific developmental goals, despite the increasing emphasis on individualised planning within youth sport development models (Leite & Sampaio, 2012; Pichardo et al., 2018). Verifying whether training elicits the intended physical responses is critical to ensuring delivery of a targeted developmental stimulus. For instance, drills designed to improve cutting or reactive defence are likely to produce different external TLs than those focused on decision-making in half-court offence or low-intensity technical repetition. Coaches frequently manipulate space (court size), speed (intensity of play), and player numbers (e.g., small-sided versus full-team drills) to control the physical and tactical demands imposed on athletes (Conte et al., 2017; Vázquez-Guerrero et al., 2018). Yet despite these distinctions, limited evidence links quantifiable physical outputs to coach-assigned development goals, particularly within structured academy environments. Within these training-specific approaches, a large proportion of training is often classified as “Situational” or “Live Play” (Russell, McLean, Stolp et al., 2021), comprising small-sided games or open format segments that may lack specific tagging to individualised goals despite their developmental relevance. The challenge, therefore, is twofold; first, to classify and structure the diverse training drills used in elite basketball based on their intended purpose; and second, to determine whether external TL metrics meaningfully reflect these goals. Initial evidence suggests that basketball coaches value TL monitoring practices but remain sceptical of its relevance to technical training outcomes (as outlined in Study 3). Without demonstrating that physical output maps onto developmental aims, TL data may continue to be perceived as an adjacent rather than integrated part of training design.

To address this gap, this study examined whether coach-prescribed development goals aligned with the physical demands of the drills used to achieve them. Through thematic analysis and classification modelling, we evaluated whether per-minute external TL metrics could meaningfully differentiate drills based on their technical, tactical, or physical focus. By testing this alignment, the study offers a novel, data-driven approach to integrating performance support and coaching practice, providing a framework for selecting drills that elicit appropriate stimuli and interpreting physical load data through the lens of development goals, advancing an integrated model of training planning in youth basketball.

6.4 Methods

Participants

Data was collected from 25 highly trained male youth basketball players (age = 17.1 ± 1 years, height = 201.4 ± 9.6 cm, mass = 89.5 ± 13.0 kg) enrolled in a full-time, academy program in Australia over two training years (24 months). The academy provides a full-time residential basketball development program alongside athletes' academic commitments. Upon completing the program, these players are typically recruited to Division 1 National Collegiate Athletic Association (NCAA) schools or professional teams (e.g., Australia's National Basketball League or NBA G-League).

Study Overview

This study adopted a multi-method design (Tenenbaum & Driscoll, 2005) to report basketball drills according to coach-prescribed developmental goals and evaluate how external TL metrics align with specific coaching objectives. To do so, individualised development goals (IDGs) were prescribed at the beginning of each training block based on the player's technical, tactical and physical developmental needs. Separately, external TL data were collected during on-court, coach-led training sessions throughout the 2021 and 2022 training seasons (Figure 6.1). A typical training week within the structured training environment of the youth basketball academy involved 12-16 coach-led hours on-court, 4-5 hours of strength and conditioning and 1-2 hours of injury prevention each week, along with structured recovery sessions 2-3 times per week (as outlined in Study 1 and 2). On-court sessions include shooting, team or individual practice, volume shooting (standardized drills to track shooting performance) and scrimmages. In addition, athletes are encouraged to engage in self-led skills training (e.g., shooting and ball handling) daily. Data was collected with permission from relevant governing bodies. Ethical approval was granted by the Institutional Human Research Ethics Committee (ETH25-10553).

Procedures

Individual Development Goals

Individual development goals were prescribed by a panel of five coaching staff members (basketball coaching experience = 21 ± 13 years; range: 4 - 30 years). Each coach was certified by the World Association of Basketball Coaches (WABC) with varying years of experience at youth, collegiate, professional and international levels of basketball.

IDGs were developed at the beginning of each training term (approximately every 8 weeks), where coaching staff had a formal meeting to assess the current status, progress to date and future direction of each athlete. This process allowed the tailoring of technical, tactical and physical development goals geared towards the long-term development of each athlete. In addition to athlete-specific needs, coaches' broader developmental philosophy and term-based training priorities informed the selection and emphasis of goals.

Thematic Analysis

An inductive thematic analysis was conducted on the IDG data at the conclusion of data collection, following Braun and Clarke's six-stage process (Braun & Clarke, 2006). The authors first familiarized themselves with the data by reading and noting preliminary ideas. Initial codes were then generated across the entire data set, which were iteratively refined into higher-order and sub-themes. These themes were reviewed and defined in alignment with the study's objectives.

A secondary reflexive process was undertaken to categorise external TL data based on the thematic structure of the development goals. The appended drill tags, recorded contemporaneously by the researcher using OpenField based on session plans, were systematically reviewed and aligned with the IDG themes established through prior inductive thematic analysis of coach-assigned goals. This ensured consistency between drill classification and the IDG objectives set by coaches. Drills were then categorised according to the dominant sub-theme they addressed, allowing for a structured mapping of external TL data to specific developmental objectives. In cases where a drill aligned with multiple themes, its classification was determined based on the primary focus outlined in the session plan.

These themes were organised into two hierarchical levels: (1) Development Goal Categories (n=4; Physical, Skill, Offensive and Defence) representing broad domains of focus, and (2) Specific Goal Types (n=16; (e.g., Cutting, Shooting, Load Tolerance.), which were nested within these categories to capture more detailed technical or tactical intentions (Figure 6.2). This hierarchical structure was used in subsequent analyses to evaluate alignment between physical output and coaching intent.

External Training Load

External TL data were collected from all coach-led, on-court sessions using Local Positioning System (LPS) devices (Catapult Vector S7, Catapult Sports, Melbourne, Australia), in accordance with the NBA/NBPA wearables safety guidelines (National Basketball Association, 2017). Each athlete wore the same device in a fitted vest positioned between the scapulae to minimise inter-device variability (McLean et al., 2018). Players were classified as Backcourt (n = 7) or Frontcourt (n = 18) based on established positional groupings (Russell, McLean, Impellizzeri et al., 2021). TL was organised by academic term blocks (T1–T4), each spanning 8–11 weeks, with breaks between terms and longer gaps across years.

LPS units sampled position at 10 Hz and included a triaxial accelerometer, gyroscope, and magnetometer (100 Hz). These systems are validated for indoor basketball and commonly used in team sport TL monitoring. Training sessions were live coded by the researcher using Catapults' proprietary software (Openfield Console, v3.7, Catapult Sports, Melbourne, Australia), based on coaching plans and standardized drill tags describing the context and purpose of each drill. Openfield includes tagging options that allow users to attach metadata to each activity segment. These tags provide customizable, drill-level contextual and subjective information, thereby enhancing the richness and interpretability of the training dataset. Data collection began at the start of each drill and excluded rest periods or coach instruction. Following each session, data were cleaned to isolate drill-specific activity and exported to CSV files for analysis. A complete list of reported external TL metrics is shown in Table 6.1. All selected variables were validated for use by the National Basketball Players Association (National Basketball Association, 2017). A broader set of external load metrics was included in this study relative to previous descriptive analyses (e.g., Study 2), as the objective was to evaluate classification performance across development goal categories using predictive modelling. Accordingly, multiple derivatives and banded variables were retained as potential predictors prior to stepwise selection. To enable alignment with individual development goals, only drills with clearly tagged objectives were retained for goal classification. Drills without identifiable developmental focus (e.g., some 'Situational' segments) were coded separately.

Data Analysis

All analyses were conducted using R Studio (Version 4.2, R Core Team). To contextualize how coach-prescribed IDGs were distributed over time, we calculated the frequency and relative proportion of drills assigned to each Development Goal Category and Specific Goal Type across academic terms. Drill counts were grouped by player, term, and IDG, and proportions were calculated accordingly. Descriptive statistics (mean ± SD) for all per-minute external load variables were calculated at the drill level and summarised by development goal category and specific goal type

To examine whether physical output could distinguish between development goal themes, we fitted two multinomial logistic regression models. These models used per-minute external TL variables, averaged at the drill level, as predictors. The outcome variables were (1) Development Goal Category (4 levels) and (2) Specific Goal Type (19 levels), based on the primary coaching objective associated with each drill. In total, 192 drill-level observations were included, each representing a single instance of a coach-led drill tagged to a specific goal.

Figure 0.1 Diagrammatic representation of the study design

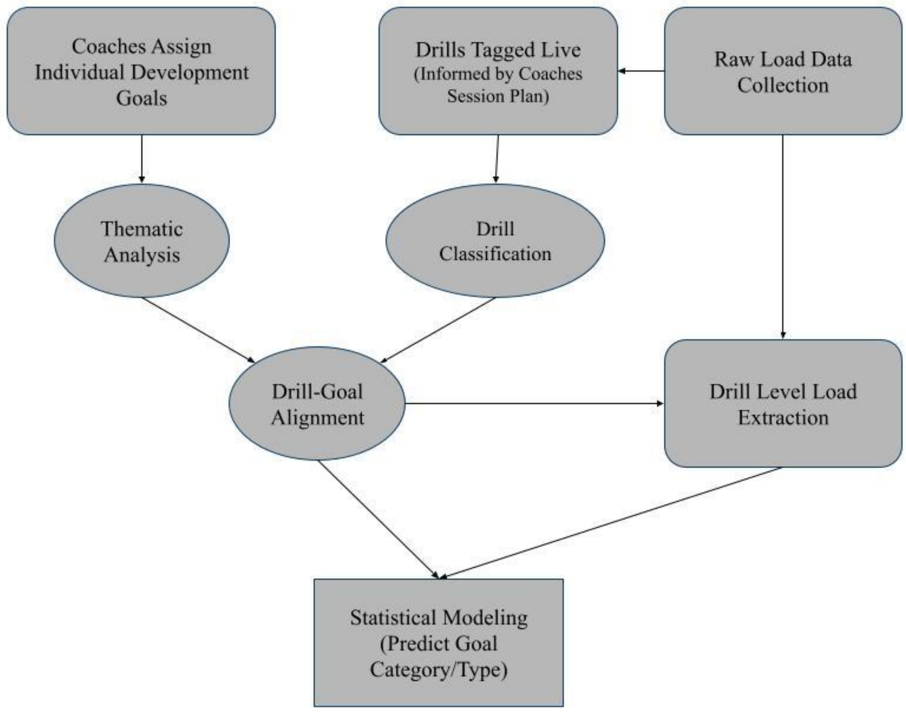


Table 0.1 External Training Load Parameters (All Per Minute) Obtained from the Catapult ClearSky LPS.

Parameter	Units of Measure	Definition
PlayerLoad (PL) and derivatives (1D, 2D)	AU	PL: The sum of accelerations across all axes of the triaxial accelerometer. 1D: accumulated acceleration in a single movement plane—vertical (jumping/landing), lateral (side-to-side), or sagittal (forward/backward). 2D: accumulated acceleration in two movement planes—typically lateral and sagittal.
PlayerLoad Accumulated in Bands	AU	The sum of accelerations across all axes of the triaxial accelerometer within the specified band. Band 1: 0-1 AU Band 2: 1-2 AU Band 3: 2-3 AU Band 4: 3-4 AU Band 5: 4-5 AU Band 6: >5 AU
Distance	Metres	The total distance covered.
Deceleration Efforts (Bands 1-3)	Count	The total number of deceleration efforts counted in the specified band. Band 1: -2 to -3 m/s Band 2: -3 to -4 m/s Band 3: <-4 m/s
Distance Covered in Velocity Thresholds (Bands 1-6)	Metres	The total distance covered in the specified band. Band 1: 0-1 m/s Band 2: 1-3 m/s Band 3: 3-4.5 m/s Band 4: 4.5-6 m/s Band 5: 6-7 m/s Band 6: >7 m/s
Jumps (Low, Medium, High)	Count	Vertical jumping actions detected via the inertial sensor and categorised based on magnitude. High: >40cm Medium: 20-40cm Low: <20cm

Outcome variables were treated as unordered factors, with "situational play" set as the reference level. To evaluate model performance and avoid overfitting, we used a stratified training/testing split approach. Datasets were randomly split into training (70%) and testing (30%) subsets using stratified sampling to preserve class balance across outcome levels. Full models were fit using the *multinom* function from the *nnet* package. Multinomial logistic regression was selected due to the categorical, non-ordinal nature of the outcome variables (Development Goal Category and Specific Goal Type), enabling classification across multiple nominal classes. Stepwise model selection was performed using the Akaike Information Criterion (AIC)-based *stepAIC* function from the *MASS* package to identify the most parsimonious predictor and interpretable subset of predictors. Variance inflation factors (VIF) were examined to assess multicollinearity; predictor(s) with VIF > 5 were flagged for concern and removed prior to model interpretation.

Model fit was evaluated using changes in AIC, and classification performance was assessed through classification accuracy and Cohen's Kappa on the held-out test set. Accuracy confidence intervals were estimated using binomial proportions. In parallel, Two-way ANOVAs were conducted to examine differences in the percentage of training time spent across Development Goal Categories and Specific Goal Types, as a function of Term. Post hoc comparisons were performed using Tukey's HSD where appropriate. Odds ratios (ORs) with 95% confidence intervals were reported for all predictors, though p-values were interpreted cautiously due to the exploratory classification focus of the models. Table 6.4 provides descriptive statistics of external TL metrics by goal category and types.

6.5 Results

Thematic analysis of the dataset yielded 20 sub-themes grouped within four overarching Development Goal Categories: 1) Defensive-Focus, 2) Offensive-Focus, 3) Skill-Focus, and 4) Physical-Focus (Figure 6.2).

Time Allocation Across Goal Categories and Goal Types

At the category level, a significant main effect of Development Goal Category was observed ($F(4, 415) = 1279.0$, $p < .001$), indicating significant difference in the total time accumulated across training categories. Situational play accounted for the greatest proportion of total training time (~50%) (Figure 6.3A). All structured training categories received significantly less total time than situational play ($p<0.01$). There was no main effect of Term ($p = 0.90$), and the Development Goal Category x Term interaction was not significant ($p>0.05$). At the Specific Goal Type level, a significant main effect of Specific Goal Type ($F(15, 1082) = 1787.75$, $p < .001$) confirmed substantial variation in how training time was distributed across specific development goal types (Figure 6.3B). Situational play accounted for the largest proportion of training time ($p<0.001$) (Figure 6.4). Although the main effect of Term was not significant ($p = .37$), a significant Specific Goal Type × Term interaction ($F(42, 1082) = 3.32$, $p < .001$) revealed differing training priorities across the season.

Classifying Developmental Goals from Physical Output

Stepwise multinomial logistic regression was used to examine whether per-minute physical output metrics could classify coach-prescribed IDGs. The Development Goal Category model (Table 6.2) demonstrated substantial improvement in model fit following stepwise selection (AIC reduced from 3917.7 to 2693.6, ΔAIC = 1224.1). Classification accuracy on the test set was 66.0% (95% CI: 61.9–69.9%), with a Cohen's Kappa of 0.60, indicating substantial agreement between classified and actual categories. Class-level sensitivity ranged from 35.0% (cutting) to 87.5% (endurance). Positive classification values were also high for some classes, including 100% for endurance and 96.9% for shooting. Although no single predictor reached statistical significance ($p < .05$), several interpretable metrics, including velocity bands, deceleration counts, and PL intensity bands, aligned meaningfully with Development Goal Categories.

The Specific Goal Type model (Table 6.3) also improved substantially with stepwise selection (AIC reduced from 5444.9 to 2904.2), yielding comparable classification accuracy (66.1%) and Kappa (0.60). Predictor sets varied across goal types, reflecting distinct physical output profiles. For example, cutting drills were associated with higher PL 1D Vertical $\cdot\text{min}^{-1}$ (OR = 3.82) and lower low intensity jump count $\cdot\text{min}^{-1}$ (OR = 0.37). TL tolerance drills were characterised by elevated values across multiple physical output metrics, including a markedly higher PL 1D Vertical $\cdot\text{min}^{-1}$ (OR = 424), indicating substantially greater vertical load.

Figure 0.2 Hierarchical structure of Development Goal Categories and Specific Goal Types identified across the academy training dataset

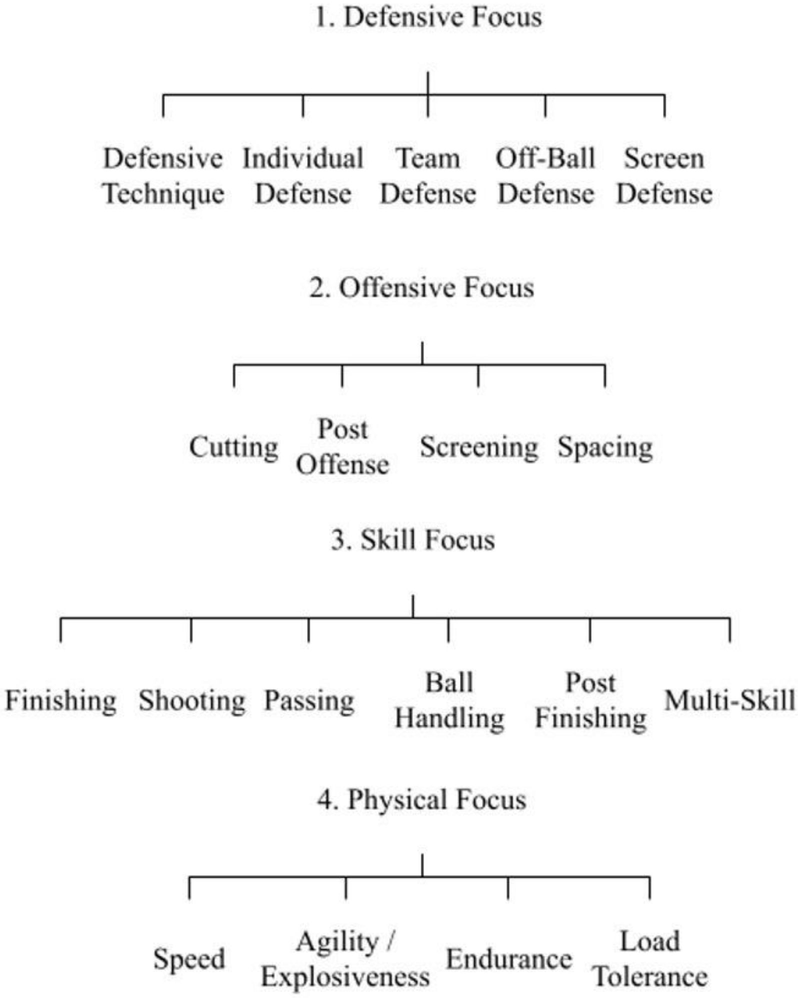


Figure 0.3 Distribution of total training time across Development Goal Categories (A) and by Term (B)

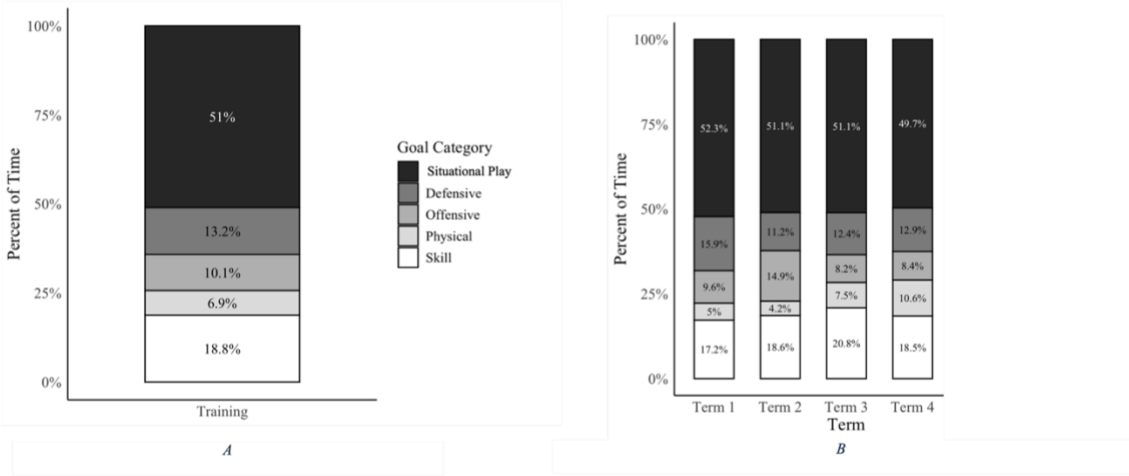


Figure 0.4 Distribution of total training time across Specific Goal Types

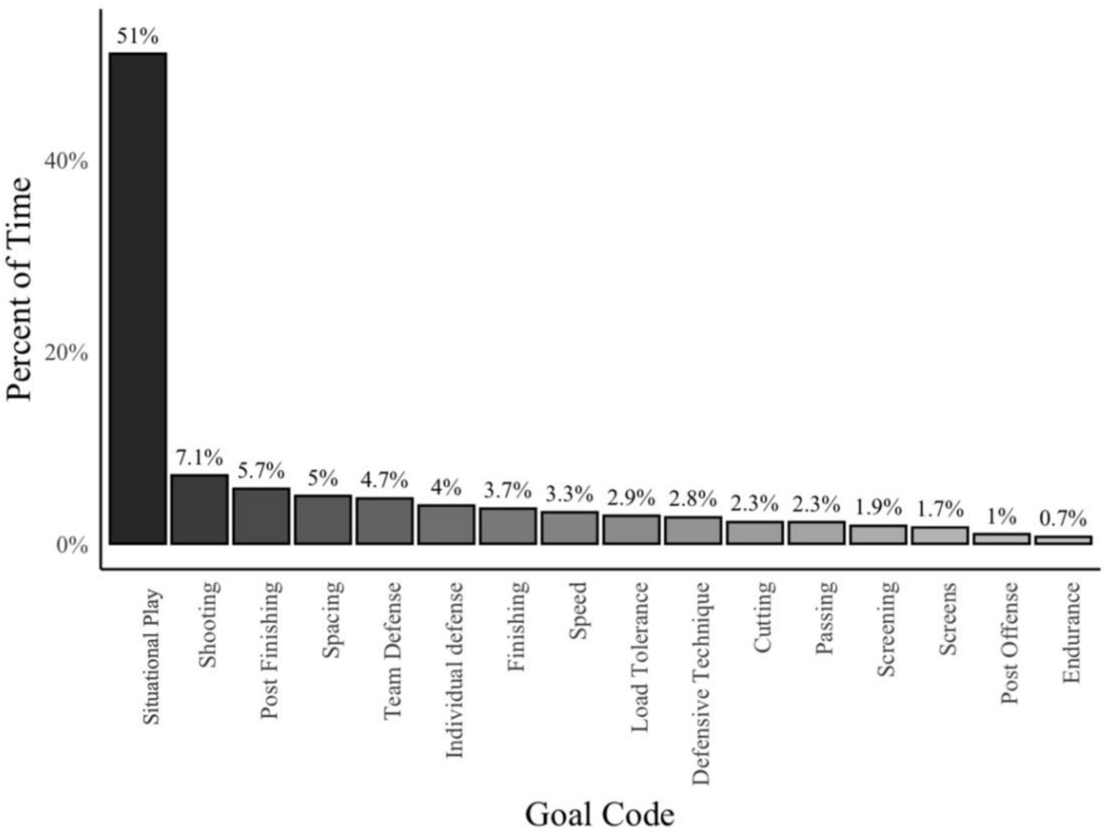


Table 0.2 Top Three Significant (p<0.05) Predictors for Goal Category

Category	Predictor	OR	Standard Error	Z-Statistic	p	OR Confidence Interval - Lower	OR Confidence Interval - Upper
Defensive	Deceleration Band 3	195754.4	3.42	3.56	0.00	239.69	159870607.75
	Deceleration Band 2	22.7	1.10	2.84	0.00	2.64	195.54
	Deceleration Band 1	13.2	0.56	4.59	0.00	4.38	39.55
Offensive	Deceleration Band 3	9275.4	3.14	2.91	0.00	19.63	4383280.74
	Velocity Band 6 Distance	15.0	1.12	2.41	0.02	1.65	135.56
	Deceleration Band 1	6.1	0.54	3.35	0.00	2.12	17.80
Physical	Deceleration Band 3	25796.5	3.48	2.92	0.00	28.26	23546030.55
	Velocity Band 6 Distance	53.6	1.14	3.48	0.00	5.70	503.52
	PlayerLoad 1D Vertical	52.1	0.80	4.97	0.00	10.96	247.41
Skill	Deceleration Band 1	22.5	0.54	5.81	0.00	7.87	64.32
	High Jump Count	8.5	0.30	7.08	0.00	4.70	15.40
	Medium Jump Count	6.0	0.21	8.55	0.00	4.00	9.10

Notes: Odds ratios (OR): > 1 indicate greater odds of a drill being classified into the given Development Goal Category based on the predictor; OR < 1 indicates lower odds (Hosmer et al., 2013). Standard Error: Standard error of the log odds coefficient; reflects estimation uncertainty. Z-Statistic: Test statistic for whether the log odds coefficient differs from zero.

Table 0.3 Top Three Significant (p<0.05) Predictors for Goal Type

Type	Predictor	OR	Standard Error	Z-Statistic	p	Confidence Interval - Lower	Confidence Interval - Upper
Cutting	Deceleration Band 2	33.08	1.29	2.71	0.01	2.64	413.90
	Deceleration Band 1	26.22	0.87	3.74	0.00	4.72	145.50
	Velocity Band 5 Distance	2.80	0.33	3.08	0.00	1.45	5.40
Defensive Technique	Deceleration Band 1	196.99	0.85	6.20	0.00	37.11	1045.62
	PlayerLoad Band 2	4.34	0.60	2.45	0.01	1.34	14.05
	Medium Jump Count	<0.01	0.97	-5.66	0.00	0.00	0.03
Endurance	Deceleration Band 2	21.85	1.32	2.33	0.02	1.63	292.89
	Velocity Band 6 Distance	11.83	1.14	2.17	0.03	1.27	110.13
	Velocity Band 5 Distance	3.55	0.34	3.70	0.00	1.81	6.95
Finishing	Hight Jump Count	100.94	0.65	7.08	0.00	28.12	362.35
	Medium Jump Count	9.69	0.39	5.88	0.00	4.54	20.66
	Velocity Band 5 Distance	4.77	0.39	4.00	0.00	2.22	10.26
Individual Defence	PlayerLoad Band 3	41.87	0.74	5.07	0.00	9.88	177.43
	Deceleration Band 1	16.53	0.91	3.09	0.00	2.78	98.17
	Velocity Band 5 Distance	0.13	0.97	-2.12	0.03	0.02	0.85
Load Tolerance	PlayerLoad 1D Vertical	423.76	1.40	4.34	0.00	27.51	6526.86
	Velocity Band 6 Distance	11.99	1.15	2.17	0.03	1.27	113.12
	Velocity Band 5 Distance	3.32	0.40	3.02	0.00	1.52	7.24
Passing	Deceleration Band 1	352.02	0.75	7.85	0.00	81.36	1523.02
	PlayerLoad 1D Vertical	7.52	0.75	2.71	0.01	1.74	32.44
	Velocity Band 5 Distance	2.42	0.38	2.35	0.02	1.16	5.06
Post Finishing	Deceleration Band 1	39.95	1.52	2.43	0.02	2.04	783.03
	Hight Jump Count	32.29	0.57	6.12	0.00	10.61	98.25
	Velocity Band 5 Distance	3.96	0.51	2.72	0.01	1.47	10.67

Type	Predictor	OR	Standard Error	Z-Statistic	p	Confidence Interval - Lower	Confidence Interval - Upper
Post Offence	Deceleration Band 1	94.92	1.13	4.03	0.00	10.35	870.57
	PlayerLoad Band 3	8.83	0.98	2.23	0.03	1.30	60.01
	PlayerLoad Band 3	5.79	0.70	2.52	0.01	1.48	22.63
Post Offence	Deceleration Band 1	94.92	1.13	4.03	0.00	10.35	870.57
	PlayerLoad Band 3	8.83	0.98	2.23	0.03	1.30	60.01
	PlayerLoad Band 3	5.79	0.70	2.52	0.01	1.48	22.63
Screens	Deceleration Band 1	1020.35	1.11	6.26	0.00	116.49	8937.07
	Deceleration Band 2	259.36	1.91	2.91	0.00	6.14	10952.46
	Low Jump Count	4.35	0.58	2.51	0.01	1.38	13.68
Shooting	Medium Jump Count	10.04	0.48	4.78	0.00	3.90	25.84
	PlayerLoad Band 3	0.00	2.92	-2.04	0.04	0.00	0.79
	Hight Jump Count	0.01	2.03	-2.44	0.01	0.00	0.38
Spacing	Deceleration Band 2	42.97	1.49	2.53	0.01	2.33	792.98
	Deceleration Band 1	33.99	0.96	3.66	0.00	5.13	225.06
	PlayerLoad 1D Vertical	13.62	1.05	2.48	0.01	1.72	107.68
Speed	Deceleration Band 1	24.75	0.90	3.58	0.00	4.27	143.42
	Deceleration Band 2	14.04	1.31	2.02	0.04	1.08	183.23
	Velocity Band 6 Distance	12.59	1.13	2.25	0.02	1.39	114.21
Team Defence	Deceleration Band 2	1233.94	1.67	4.26	0.00	46.76	32561.66
	Deceleration Band 1	130.22	1.10	4.43	0.00	15.12	1121.82
	PlayerLoad 1D Vertical	16.05	0.90	3.08	0.00	2.75	93.68

Notes: Odds ratios (OR): > 1 indicate greater odds of a drill being classified into the given Development Goal Category based on the predictor; OR < 1 indicates lower odds (Hosmer et al., 2013). Standard Error: Standard error of the log odds coefficient; reflects estimation uncertainty. Z-Statistic: Test statistic for whether the log odds coefficient differs from zero.

Table 0.4 Descriptives (mean ± SD) of external training load metrics by goal category and goal type

Goal Category	Goal Type	PlayerLoad (AU ·min⁻¹)	PL 1D Vertical (AU min⁻¹)	PL 1D Lateral (AU min⁻¹)	Decel Band 2 (min⁻¹)	Decel Band 3 (min⁻¹)	Vel Band 5 Dist (m min⁻¹)	Vel Band 6 Dist (m min⁻¹)	Meterage (m min⁻¹)	Medium Jump Count (min⁻¹)	High Jump Count (min⁻¹)
Defensive		6.07 ± 1.21	3.76 ± 0.78	2.77 ± 0.53	0.20 ± 0.13	0.03 ± 0.04	0.11 ± 0.26	0.01 ± 0.03	45.14 ± 10.42	0.42 ± 0.27	0.32 ± 0.28
	Defensive Technique	5.37 ± 1.03	3.20 ± 0.60	2.60 ± 0.49	0.11 ± 0.11	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	40.02 ± 9.47	0.14 ± 0.14	0.11 ± 0.13
	Individual Defence	6.64 ± 1.14	4.13 ± 0.73	3.01 ± 0.48	0.20 ± 0.12	0.03 ± 0.05	0.02 ± 0.10	0.00 ± 0.00	46.75 ± 11.92	0.61 ± 0.23	0.57 ± 0.24
	Screens	5.52 ± 1.02	3.58 ± 0.67	2.42 ± 0.48	0.26 ± 0.13	0.05 ± 0.05	0.00 ± 0.00	0.00 ± 0.00	47.31 ± 7.31	0.45 ± 0.23	0.14 ± 0.18
	Team Defence	6.06 ± 1.13	3.80 ± 0.73	2.68 ± 0.52	0.25 ± 0.10	0.04 ± 0.03	0.39 ± 0.38	0.04 ± 0.06	47.05 ± 8.13	0.38 ± 0.18	0.17 ± 0.10
Offensive		6.12 ± 1.42	3.91 ± 0.92	2.68 ± 0.67	0.28 ± 0.16	0.07 ± 0.14	0.89 ± 1.62	0.05 ± 0.12	51.66 ± 14.09	0.35 ± 0.27	0.25 ± 0.29
	Cutting	7.03 ± 1.75	4.54 ± 1.10	3.06 ± 0.86	0.42 ± 0.15	0.17 ± 0.26	2.21 ± 2.42	0.05 ± 0.12	61.18 ± 17.37	0.45 ± 0.42	0.30 ± 0.34
	Post Offence	6.43 ± 0.82	3.79 ± 0.43	2.91 ± 0.64	0.06 ± 0.10	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	40.92 ± 14.47	0.46 ± 0.17	0.48 ± 0.46
	Screening	6.40 ± 1.19	4.10 ± 0.90	2.83 ± 0.40	0.27 ± 0.10	0.02 ± 0.04	0.40 ± 1.14	0.00 ± 0.00	52.14 ± 12.27	0.44 ± 0.24	0.25 ± 0.21
	Spacing	5.17 ± 1.02	3.42 ± 0.74	2.22 ± 0.44	0.29 ± 0.12	0.05 ± 0.03	0.68 ± 1.03	0.09 ± 0.18	49.73 ± 8.56	0.18 ± 0.08	0.12 ± 0.06
Physical		8.80 ± 5.48	5.53 ± 3.44	3.72 ± 2.02	0.80 ± 1.13	0.69 ± 1.09	5.75 ± 9.52	2.19 ± 4.58	77.91 ± 53.91	0.24 ± 0.33	0.07 ± 0.10
	Agility.Explosiveness	4.85 ± 1.17	2.94 ± 0.77	2.30 ± 0.48	0.04 ± 0.04	0.00 ± 0.01	0.01 ± 0.01	0.00 ± 0.01	35.01 ± 15.55	0.43 ± 0.52	0.04 ± 0.06
	Endurance	17.75 ± 2.31	11.13 ± 1.49	6.89 ± 1.29	2.55 ± 0.91	2.50 ± 0.43	17.66 ± 13.11	7.03 ± 7.35	166.29 ± 12.13	0.01 ± 0.04	0.00 ± 0.00
	Load Tolerance	5.84 ± 1.51	3.87 ± 0.98	2.60 ± 0.76	0.08 ± 0.07	0.02 ± 0.03	2.22 ± 0.96	1.35 ± 1.45	46.06 ± 5.27	0.11 ± 0.17	0.00 ± 0.01
	Speed	6.67 ± 0.60	4.19 ± 0.41	3.02 ± 0.32	0.45 ± 0.17	0.20 ± 0.15	3.16 ± 1.99	0.66 ± 0.69	61.98 ± 8.09	0.33 ± 0.14	0.20 ± 0.08
Skill		7.94 ± 1.56	5.06 ± 1.24	3.28 ± 0.59	0.15 ± 0.10	0.02 ± 0.02	0.10 ± 0.23	0.01 ± 0.02	58.78 ± 13.62	2.30 ± 1.43	0.59 ± 0.68
	Ball-Handling	6.70 ± 0.34	3.49 ± 0.27	3.51 ± 0.31	0.06 ± 0.03	0.00 ± 0.01	0.00 ± 0.00	0.00 ± 0.00	33.44 ± 4.18	0.42 ± 0.46	0.14 ± 0.20
	Finishing	7.65 ± 0.62	4.77 ± 0.74	2.93 ± 0.47	0.10 ± 0.09	0.00 ± 0.01	0.09 ± 0.21	0.00 ± 0.00	60.19 ± 7.96	2.49 ± 0.72	1.56 ± 0.69
	Multi-skill	6.73 ± 1.61	4.22 ± 1.10	3.04 ± 0.73	0.04 ± 0.06	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	46.05 ± 26.84	0.87 ± 0.47	0.84 ± 0.29
	Passing	8.22 ± 0.39	5.09 ± 0.44	3.56 ± 0.19	0.15 ± 0.08	0.03 ± 0.05	0.13 ± 0.18	0.00 ± 0.00	56.16 ± 11.35	0.35 ± 0.32	0.26 ± 0.17
	Post Finishing	5.02 ± 1.02	3.08 ± 0.56	2.30 ± 0.49	0.02 ± 0.01	0.01 ± 0.01	0.00 ± 0.00	0.00 ± 0.00	46.36 ± 4.54	1.04 ± 0.42	1.21 ± 0.59
	Shooting	8.99 ± 0.92	5.96 ± 0.78	3.58 ± 0.34	0.21 ± 0.08	0.02 ± 0.02	0.13 ± 0.29	0.02 ± 0.02	66.83 ± 7.52	3.48 ± 0.74	0.18 ± 0.20
Situational Play		7.18 ± 1.19	4.55 ± 0.78	3.20 ± 0.52	0.27 ± 0.11	0.04 ± 0.03	0.16 ± 0.12	0.01 ± 0.04	57.53 ± 9.44	0.42 ± 0.15	0.22 ± 0.11

6.6 Discussion

This study sought to determine whether external TL metrics could distinguish between coach-prescribed development goals in a high-performance youth basketball setting. The findings showed that per-minute TL variables, especially deceleration, vertical PL, and velocity band distances, aligned with specific Development Goal Categories and Specific Goal Types. Notably, both models showed strong performance, with classification accuracy of 66% and substantial agreement (Kappa = 0.60), indicating that drills prescribed for different development goals tend to elicit distinct physical output profiles. While this does not confirm alignment with coaching intent, it suggests that goal-oriented drill design may result in identifiable external load patterns related to movement demands and intensity characteristics.

Physical output metrics successfully differentiated Development Goal Categories in this study, with defensive and physical drills showing consistently higher mechanical load and intensity values compared to skill-based or offensive drills. These results align with established assumptions in coaching and performance support that defensive and physical drills impose greater mechanical demands (Conte et al., 2017; Fox et al., 2017; Schelling & Torres-Ronda, 2016), while the demands of skill-based and tactical drills vary depending on structure (Ibanez et al., 2020)

Deceleration bands emerged as the most consistent predictors across categories and types, underscoring their relevance to basketball's repeated high-intensity movement profile (Svilar et al., 2018). Defensive drills were strongly characterised by elevated Deceleration Band 3 values (OR ≈ 195,000), indicating that high-intensity deceleration actions were a prominent feature. Notably, Deceleration Band 3 also contributed meaningfully to the classification of offensive and physical goal categories, suggesting that high-intensity braking demands are shared across multiple drill types. Although deceleration metrics were also retained in the model for physical drills the combination of high PL 1D Vertical (OR = 52.08) and Velocity Band 6 Distance (OR = 53.58) most clearly differentiated this category. These findings align with previous research showing that external TL profiles differ based on drill type, with variations in intensity, locomotor output, and mechanical load across formats such as small-sided games, technical drills, and full-court scrimmages (Russell, McLean, Stolp et al., 2021; Svilar & Jukić, 2018). However, this study extends that work by demonstrating that TL profiles are not just a function of drill design but can be associated with coach-assigned development goals, offering a potential framework for aligning physical performance monitoring with individualised training objectives in elite youth sport.

The classification accuracy of Specific Goal Type further highlights the feasibility of distinguishing not just broad training themes, but also specific technical or tactical foci, based on physical demands. For instance, cutting drills were primarily characterized by elevated Deceleration Band 1 (-2 - -3m/s; OR = 26.22) and Band 2 (-3 - -4m/s; OR = 33.08), alongside increased Velocity Band 5 distance (5.0-5.99m/s; OR = 2.80), while TL tolerance drills showed high values in PL 1D Vertical (OR = 423.76). Endurance drills were distinguished by higher distances covered in Velocity Band 6 (≥6.0 m/s; OR = 11.83) and Band 5 (5.0–5.99 m/s; OR = 3.55), consistent with drills involving sustained high-speed running or repeated movement across large areas of the court (Vazquez-Guerrero et al., 2020). These velocity profiles suggest that endurance drills likely included more continuous transitions between offensive and defensive roles, or covered greater spatial zones compared to other goal types. This aligns with previous research showing that drill design variables, such as court size, player number and task constraints, significantly influence external TL characteristics (Conte et al., 2017; Klusemann et al., 2012; Schelling & Torres-Ronda, 2016). Future studies could more systematically evaluate how spatial constraints and tactical context influence the physical demands of endurance-focused drills in basketball. Similarly, finishing drills were characterised by increased high intensity jump counts (OR = 100.94), aligning with the vertical demands of rebounding or contested scoring (Ben Abdelkrim, Castagna et al., 2010). This level of specificity supports the utility of external metrics not just in global TL monitoring, but in verifying drill integrity relative to its developmental aim.

Interestingly, while the classification models demonstrate alignment between physical outputs and coach-prescribed IDGs at the drill level, discrepancies were observed when examining how time was distributed across these Development Goal Categories. Our results suggest that coaches consistently prescribed development goals with a balanced and stable distribution across terms, reflecting intentional and structured planning. However, actual implementation, measured as time spent in goal-specific drills, revealed greater variability and divergence from intended proportions. This mismatch suggests that despite clear coaching intentions, practical constraints such as athlete readiness, changing training priorities, or situational adjustments significantly influence how training time is ultimately allocated (Study 3). Consequently, even with strong classification alignment in drill design, actual practice implementation may vary, underscoring the complexity of aligning planned training intent with real-world training delivery (Edwards et al., 2018). This highlights the importance of continually integrating coaching intentions with TL monitoring to optimise developmental outcomes. Now that specific metrics have been identified as differentiators between development goals, live monitoring can enhance this integration by providing real-time feedback on whether drills are eliciting the intended stimulus, allowing for immediate, data-informed adjustments to training.

Time allocation analyses revealed that situational play accounted for the largest share of total training time across the season, comprising over 50% of all recorded minutes. However, each structured Development Goal Category; skill, physical, offensive, and defensive, received significantly different amounts of time (all $p < .001$), indicating clear differentiation in how structured drills were emphasised. Skill-based drills were prioritised most within this group, receiving significantly more time than physical and offensive drills. This aligns with findings in highly trained youth basketball showing an increase in technical and tactical drill volume during later-season periods. While there was no main effect of Term on overall training time, a significant Development Goal Category × Term interaction ($p < .001$) indicated meaningful shifts in training priorities across the season. These changes may reflect strategic periodisation, in which early-term emphasis on physical development gives way to more skill-based training as athletes progress toward competition. This approach aligns with contemporary models of skill training periodisation, which advocate for structured progression of skill complexity and contextual interference to optimise learning and performance in youth athletes (Otte et al., 2019). At the Specific Goal Type level, similar patterns were observed: large between-type differences in time allocation and a significant Specific Goal Type × Term interaction suggested evolving developmental emphasis. Notably, post finishing and shooting drills received increased time in later terms, while certain defensive drills declined, reflecting seasonally adjusted development priorities.

A noteworthy finding was that over 50% of total training time was spent in sessions categorised as ‘situational play.’ However, this label likely reflects the use of unspecified or open-format drills, such as small-sided games or situational play, designed to test the integration of skills developed through goal-based training, rather than a lack of structure per se (Perdima et al., 2024). These segments may serve important pedagogical purposes by facilitating decision-making, contextual learning, player autonomy, and the application of newly acquired skills in dynamic match-like environments (Bennett et al., 2018). Nonetheless, the generic tagging of situational play limits the ability to attribute specific physical demands or developmental aims, posing challenges for monitoring alignment with individual development plans. While this study shows that drills with clearly defined goals can be differentiated based on TL output, open-format or generically tagged segments remain difficult to interpret. Integrating clearer tagging or metadata around drill intent during these periods would improve interpretability and support more targeted TL tracking.

Although prior studies have called for alignment in coaching intent and TL monitoring output (Edwards et al., 2018; Fox et al., 2017), they have lacked the individualised, goal-driven structure and modelling approach applied here. As such, this study offers a model for other academy and high-performance settings seeking to integrate performance data with player development planning. Whilst our study offers novel insights, several limitations warrant consideration. First, only on-court, coach-led sessions were monitored; off-court activities such as strength training, recovery, and injury prevention, which likely supported physical development, were not captured. Drill classification was based on primary intent and may not fully reflect the multidimensional nature of some activities, for instance defensive drills typically require competing against an offence and, in turn, offensive drills oftentimes require playing against defence. As the study was conducted within a single elite youth academy, generalizability may be limited. Additionally, the observational design precludes causal inference between development goals and physical outputs. Skill progression was not assessed, so it remains unclear whether drill demands translated into improved performance. Similarly, contextual data such as competition schedules that can influence training plans were not able to be accounted for. Finally, short self-led sessions before or after training were not recorded, which may have contributed minor additional volume not reflected in the dataset. Despite these limitations, the study provides a practical, data-driven approach to aligning training intent with physical demand in highly trained youth basketball.

These findings support several strategies to improve alignment between training design and physical performance monitoring in elite basketball. Coaches may use expected TL profiles to evaluate whether drills are eliciting the intended physical demands, allowing them to refine session content to better match development goals. For instance, if a cutting drill is expected to yield high deceleration loads, observed deviations may signal poor drill fidelity or reduced engagement. This approach also addresses coaching priorities identified in existing literature (Study 3), where lateral movement was frequently cited as a key performance determinant, especially for defensive effectiveness. Furthermore, this model may help coaches organise and structure their practices to maximise the desired effectiveness/outcome of the drill. Specifically, deviations indicative of fatigue or reduced engagement could be identified, allowing sessions to be restructured to achieve the desired outcomes.

These findings support integrating drill selection within a broader physical periodisation framework. The distinct load profiles identified across Development Goal Categories highlight how drill design can be strategically scheduled to align technical and physical training aims. Coaches can use expected drill-level load profiles to both verify whether drills elicit their intended demands and to guide when specific skills should be emphasised given athletes' current physical readiness. For example, higher-load drills (e.g., deceleration-dominant defensive work) may be best programmed during phases targeting adaptation, whereas lower-load, technique-focused drills are appropriate during recovery or deload microcycles. Such alignment promotes balanced technical progression and physical development across the training cycle, supporting existing models of load management and skill periodisation in team sport settings (Edwards et al., 2018; Otte e et al., 2019).

Our results confirm that defensive drills were uniquely classified by high-intensity deceleration, aligning with coach emphasis on lateral quickness and change of direction. This suggests an opportunity to use movement-based metrics, such as deceleration load or PL 1D (lateral), to quantify traits coaches already value but currently assess subjectively. Moreover, several metrics were consistently associated with multiple Development Goal Categories, including PL $\cdot\mathrm{min}^{-1}$ and Velocity Band 5–6 distances. These may serve as a core set of monitoring variables, with additional context-specific metrics (e.g., deceleration load for defence, vertical load for TL tolerance) layered in based on session intent. Future monitoring systems or dashboards could adopt this tiered structure, tracking universal TL markers while emphasizing metrics specific to the developmental goal of each drill. Finally, this integration supports improved periodisation by enabling staff to identify high- and low-TL sessions across a term. Linking drill types to expected outputs also facilitates clearer communication between coaching and performance staff, particularly if embedded within educational tools or real-time dashboards. Such practices answer recent calls to contextualize TL data within technical-tactical aims and development priorities, rather than treating it as standalone information.

6.7 Conclusion

External TL metrics collected via wearable technology can meaningfully reflect coach-prescribed IDGs in youth basketball. Through thematic analysis and classification modelling, this study demonstrated that distinct TL profiles align with different technical, tactical, and physical drill intentions. These findings support a more integrated approach to training design and monitoring, promoting shared understanding between coaching and performance staff. Future research should explore how these relationships vary across levels of competition and athlete maturity, and whether ongoing feedback based on goal alignment leads to improved developmental outcomes and performance over time.

Chapter 7: Discussion

7.1 Executive Summary

The preceding chapters presented four interrelated studies examining internal and external TLs, coaching perspectives, and the alignment between intended and delivered training within a high-performance youth basketball academy. This discussion chapter synthesises those findings, highlighting their collective implications for understanding TL monitoring as both a measurement process and a coaching tool within youth athlete development pathways.

7.2 Introduction

TL monitoring is commonly used in high-performance youth basketball environments (Fox et al., 2017; Fox, Scanlan, Sargent et al., 2020). Internal TL measures (sRPE) along with external TL (derived from wearable technology) are frequently used to inform decisions on athlete readiness, periodisation, and training structure (Fox, Scanlan, Sargent et al., 2020; McLean et al., 2019; Russell, McLean, Impellizzeri et al., 2021). However, in practice these tools are often used in a reactive manner, primarily for short-term decision making (i.e. risk management for injury prevention), rather than being proactively applied to support progressive athlete development, especially in academy basketball settings (Fox, Scanlan, Sargent et al., 2020; Murray, 2017; Russell, McLean, Impellizzeri et al., 2021). This thesis addresses this gap by examining longitudinal TL exposures (Studies 1–2), coaching conceptions and decision processes related to TL (Study 3), and the alignment between intended and delivered drill-level stimuli in practice (Study 4) within a high-performance youth basketball academy.

Athlete development within basketball academy environments is non-linear and context-dependent, shaped by periodisation, biological maturation, and environmental factors (Bergeron et al., 2015; DiFiori et al., 2018). However, interpreting TL data without reference to the broader training context or coaching aims may limit its value for embedded planning and evaluating athlete development (Impellizzeri et al., 2019; Svilar & Jukić, 2018). While performance staff are well-positioned to quantify mechanical, perceptual, and physiological demands, they often have less visibility of session-specific coaching objectives and decision rationales. Indeed, sport science personnel may not be exposed to the nuances of coaches' intent or their tactical priorities, given their role centres on physical metrics and planning (Bartlett & Drust, 2021; Reade et al., 2008). This disconnection can be driven by epistemic differences (what counts as 'evidence' for coaches vs performance staff), time pressures and workflow fit, and implicit knowledge structures that are difficult to externalise (Abraham et al., 2006; Partington & Cushion, 2013; Saw et al., 2016; Taylor & Garratt, 2013). Consequently, misalignment can emerge between intended developmental outcomes and how TL data are interpreted or applied. Such risks have been noted in previous work, which underscores that TL metrics must be contextualised to development goals to avoid misinterpretation (Edwards et al., 2018; Fox et al., 2017).

This thesis addresses these issues through four interconnected studies. Studies 1 and 2 quantify internal and external TLs across terms and years by playing positions to provide a comprehensive overview of the physical demands across an athlete development pathway. Study 3 explores coaches' perspectives on conceptualising performance and athlete development, including their views on the role of TL monitoring tools in practice. Study 4 then examines the degree to which objective TL data align with coaches stated developmental goals, using classification modelling to assess differences between drill design and measurable TL characteristics. Collectively, these studies provide an integrated perspective on how TL monitoring interacts with coaching context and developmental planning in a high-performance youth basketball environment.

7.3 Acute and Multi-year Training Load Trends

7.3.1 Multi-Year Trends (Macrocycles)

In the current thesis, internal TL, as measured by sRPE, showed incremental progression between Years 1 and 2 within the academy pathway (Study 1). Specifically, second-year athletes recorded approximately 10% higher weekly sRPE than their first-year counterparts, reflecting an increase in training volume through more and longer sessions, with a smaller contribution from higher perceived intensity. Such observations are consistent with TL progression strategies reported in other high-performance youth programs, including rugby league academies (McLaren et al., 2018) and elite European basketball systems (Ferioli et al., 2018). This progressive loading pattern is consistent with youth development guidelines recommending gradual increases in TL to facilitate physiological adaptation and build resilience (Bergeron et al., 2015; Lloyd et al., 2016).

The yearly increase in internal TL may also reflect broader developmental priorities within the academy, such as fostering psychological resilience and competitive preparedness, elements frequently emphasised in structured youth basketball settings (Calleja-González et al., 2016; DiFiori et al., 2018). Notably, Study 1 derived sRPE exclusively from on-court, coach-led basketball sessions (tactical, technical, and team-based), allowing the observed trends to reflect basketball-specific preparatory demands rather than mixed conditioning and other forms of training. While sRPE is well established in youth sport monitoring, its application has typically been confined to single coach-led, on-court sessions (Cruz et al., 2018; Lupo et al., 2017) and is rarely used longitudinally across multiple years in academy cohorts. This enhances interpretability for practice design but limits generalisation to non-court conditioning contexts (Foster et al., 2017; Sansone et al., 2020).

While longitudinal data in basketball remain limited, comparable multi-year academy studies in European settings have reported similar trends in initial physical workload increases followed by stabilisation or tactical refinement (Delextrat & Cohen, 2009; Ferioli et al., 2018). However, unlike some European programs that progressively increased both external and internal TLs across successive years (Ferioli et al., 2020), the current data suggest a divergence in this pattern beyond the Year 1 to 2 transition. While internal TL (sRPE; session and weekly totals) increased across training years (Study 1), external TL metrics did not follow the same trajectory (Study 2). This divergence is consistent with reports that drill architecture and session intent can reshape mechanical demands independent of time-based exposure (Sansone et al., 2023; Schelling & Torres-Ronda, 2016). Complementary explanations include maturation-related responses (DiFiori et al., 2018; Lloyd et al., 2016), calendar/scheduling effects (Reina Román et al., 2019; Williams et al., 2022), and measurement reactivity to monitoring protocols (Impellizzeri et al., 2019). In Study 2, a higher proportion of low-intensity technical/tactical sessions in later years (e.g., walk-throughs) increased total time without proportional increases in PL or HSR, aligning with the notion that format and intent, rather than duration alone, drive external TL (Sansone et al., 2023).

In Study 2, weekly exposure time increased from Year 1 to Year 3, yet group-level external TL (e.g., PL, distance, $PL \cdot min^{-1}$) showed no clear between-year differences, indicating that additional time did not translate into higher mechanical workload at the mean level. Comparable trends, characterised by greater total time on task but stable per-minute external TL, have been reported when technical and tactical content expands relative to conditioning (Sansone et al., 2023). The most plausible explanation is a front-loaded conditioning/adaptation phase followed by maintenance and greater technical/tactical integration (DiFiori et al., 2018; Lloyd et al., 2016). This sequencing aligns with reports from elite European youth programs (Calleja-González et al., 2016), though age/maturation, staff philosophy, and calendar density likely affect its manifestation or expression in a program. While few studies have monitored external TL across multiple training years in youth basketball, the present findings are consistent with program structures reported in elite academies, where initial physical benchmarks are often reached early and subsequently maintained (Delextrat & Cohen, 2009; Ferioli et al., 2018). Observational data from Study 2 support this interpretation, showing that Year 3 players engaged in a higher volume of low-intensity technical and tactical sessions (e.g., walk-throughs), which extended overall training duration without materially increasing mechanical workload. This suggests a shift in training focus toward qualitative refinement rather than volume progression, likely reflecting a transition in training priorities, from building physical capacity in earlier phases to increasingly prioritising technical and tactical skill development as athletes mature.

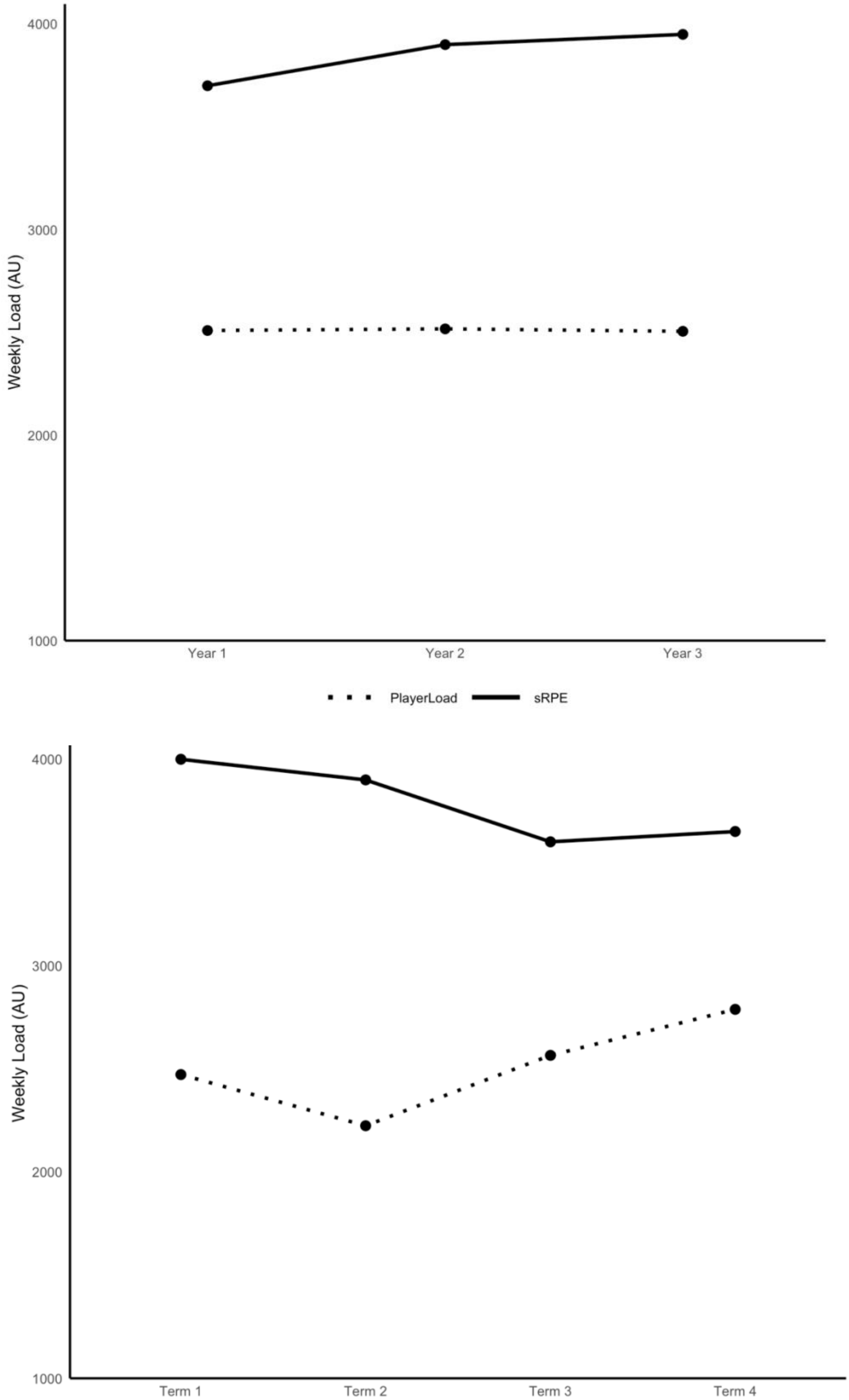
The observed divergence between internal and external TL trends (Figure 7.1) illustrate the complex, non-linear nature of training adaptation in youth sport. The current thesis findings indicate that increased training duration alone does not uniformly yield higher external TL, especially in structured settings where session design emphasises content over volume (Gabbett, 2016; Impellizzeri et al., 2019). Rather than continually increasing mechanical workload, later years of the program appear to prioritise technical and tactical development, with relative stabilisation of external TL. This sequencing is consistent with phased approaches in youth high-performance systems, front-loading broad physical qualities, then emphasising skill specificity and tactical complexity (Calleja-González et al., 2016; DiFiori et al., 2018). Whether this reflects an age-related coaching construct (i.e., a threshold level of physical capacity enabling higher-order skill/tactical work) or shifts in staff philosophy and scheduling constraints cannot be determined here; both are plausible and likely interact. From a practical standpoint, these findings may reflect a deliberate transition from initial physical development to later emphasis on task-specific intensity and skill refinement, rather than continued volume escalation (Balyi & Hamilton, 2004; Gabbett, 2016). However, the extent to which this represents intentional periodisation as opposed to emergent patterns in training design remains unclear. Further research is warranted to examine whether these TL trends are consistent across various basketball development systems or specific to the structure of this academy.

7.3.2 Seasonal Variations (Mesocycles)

TLs varied across the academy's four academic terms, showing within-season fluctuations consistent with mesocycle-level periodisation, whereby TL is varied systematically across blocks to manage fatigue and promote adaptation (Malone et al., 2015; Salazar et al., 2025). In Study 1, weekly internal TL (sRPE) was highest during the competitive season (Terms 1 and 2) and reduced in Terms 3 and 4 which represent the offseason and preseason. This pattern aligns with previous literature in youth basketball, where in-season phases are associated with increased training intensity, typically reflected in higher RPEs and greater relative effort, due to the proximity of competition demands (Brunelli et al., 2014; Conte et al., 2018). In contrast, preseason and off-season periods often prioritise recovery and general physical preparation, usually involving longer durations but lower relative intensity (Delextrat & Cohen, 2009; Ferioli et al., 2018). These fluctuations suggest that training emphasis shifted across terms, though the extent to which these changes were deliberately programmed cannot be confirmed by the present retrospective methodology.

In Study 2, external TL data (total distance and PL) were higher in Terms 3 and 4 (offseason and preseason) compared to Term 1 (competitive season), suggesting increased mechanical work during non-competitive periods. Relative intensity (PL $\cdot min^{-1}$) was highest in Term 4, which coincided with the onset of preseason training, typically involving intensified conditioning and sport-specific activities (Curtis et al., 2025; Holmberg, 2010). This divergence between internal and external TL patterns supports previous observations that these metrics reflect different components of training stress (Impellizzeri et al., 2019; Saw et al., 2016). Specifically, internal TL captures the athlete's subjective perception of effort (Scantlebury et al., 2018), while external TL reflects the objective mechanical work performed (Impellizzeri et al., 2023). As noted, relative intensity was greatest during Term 4, potentially reflecting a focus on high-tempo drills and conditioning consistent with early preseason programming reported in other youth basketball contexts (Gabbett, 2016; Sansone et al., 2020).

Figure 0.1 Internal (Study 1) and External (Study 2) Training Load Trends by Year and Term



During competition phases, practices may have been shorter and more cognitively demanding, which could explain elevated RPEs despite lower external TL metrics (Foster et al., 2001; Manzi et al., 2010). These trends may reflect differential emphases across phases, with higher perceptual intensity during in-season tactical sessions, and higher mechanical demands during off-season conditioning blocks, though this interpretation remains speculative.

By way of comparison, the alternating patterns of internal and external TL are consistent with mesocycle periodisation principles, which advocate cycling training stress to optimise adaptation and manage fatigue (Kiely, 2010; Soligard et al., 2016). European academies likewise vary TL across terms, building volume and intensity during development phases and tapering during competition, to balance growth and performance (Calleja-González et al., 2016). The present research shows a similar term-linked pattern, with higher loads in later terms (off-season phases) reflecting a comparable developmental emphasis.

These findings reinforce the need to interpret TL data within the context of seasonal planning and coach's developmental intent. While internal TLs declined in the off-season, the concurrent increase in external TL may reflect a shift toward physical capacity development. Similarly, elevated RPEs during competition phases may reflect the combined psychological and tactical demands of typical match preparation periods (Foster et al., 2001; Manzi et al., 2010). The contrast between perceptual and mechanical loads has been previously described in team sport literature and may reflect intentional design or natural variation across the season (Gabbett, 2016; Manzi et al., 2010). While causality cannot be confirmed, these patterns are consistent with strategies that balance short-term competition and long-term development (Gabbett, 2016; Granacher et al., 2016; Lloyd et al., 2016; Manzi et al., 2010; Tenforde et al., 2022).

7.3.3 Weekly and Session-Based Dynamics (Microcycles)

Findings from Study 2 showed week-to-week fluctuations in external TL metrics, including total distance and PL. Although Study 2 did not directly quantify competition frequency, these results may reflect differences in training emphasis across the calendar. For example, preparatory weeks without immediate competitive demands may permit longer session durations or greater conditioning exposure, whereas weeks closer to competition may involve comparatively reduced total external TL and greater tactical focus. These fluctuations also highlight how basketball-specific movement patterns, such as repeated short sprints, rapid decelerations, and jumps (Ben Abdelkrim et al., 2007; Scanlan, Tucker et al., 2014), can produce substantial mechanical demands even within limited session durations.

Elevated relative intensity was particularly evident in Term 4 (preseason), where training content included high-intensity conditioning drills. These sessions coincided with the onset of the annual training cycle and may have reflected an increased focus on physical preparation at that time. Given the observed week-to-week variability in internal TL, microcycle-level monitoring is warranted to manage recovery and adjust training in line with competition frequency. This may be particularly relevant in applied settings during tournament and travel-dense periods, where recovery windows narrow and contextual stressors such as disrupted sleep, nutrition, and routines compound physiological strain

(Fuster et al., 2021; Garcia et al., 2022; Svilar & Jukić, 2018). However, such factors were not directly measured within Study 2 and are presented here as plausible contextual considerations rather than tested mechanisms. When combined with mesocycle and macrocycle planning, this granular view allows practitioners to identify atypical loading weeks and tailor recovery or stimulus accordingly.

Collectively, these microcycle-level trends reinforce the value of monitoring weekly variation in external TL when supporting youth athlete development. For example, this data showed elevated TL during preparatory phases and comparatively reduced loads during other phases, consistent with broader periodisation principles. Although Study 2 did not directly assess planning rationale, the observed week-to-week variation is consistent with proposed models of TL management that aim to balance performance and fatigue across the competitive calendar (Gabbett, 2016; Soligard et al., 2016). While these short-term trends align with known periodisation practices, it is inferred that coaches' microcycle adjustments (e.g. flagging an atypical load spike and providing extra recovery) may help manage the performance–fatigue balance in real time. However, this linkage is speculative, as it was not directly tested in the current thesis. These findings contribute to the broader thesis aim of characterising how structured TL variation may support sustainable performance and progression in youth basketball settings.

7.3.4 Position-Specific Training Load Considerations

Player position is a relevant factor in TL analysis, as different positional roles in basketball are associated with distinct physical and movement demands during both training and competition (Puente et al., 2017; Scanlan, Wen et al., 2014; Svilar et al., 2018). In line with academy structures and recent reviews of TL monitoring practices (Russell, McLean, Impellizzeri et al., 2021), positional groups in the current study were categorised as Backcourt (guards) and Frontcourt (forwards and centres), reflecting typical role-based classifications used in youth basketball development settings. The similarity in internal TL between Backcourt and Frontcourt players might reflect a strategy by coaches to standardise the athletes' training experience, ensuring all players perceive similar effort levels during sessions. Alternatively, this pattern may reflect team-based training structures in academies, mixed-positional drills oriented to shared tactical outcomes, which can attenuate positional differences in perceived load (Bonal et al., 2020; Calleja-González et al., 2016; Klusemann et al., 2012; Russell, McLean, Impellizzeri et al., 2021) Indeed, youth basketball academies often emphasise holistic athlete development, including psychological robustness and competitive readiness, across all positional groups (Calleja-González et al., 2016; DiFiori et al., 2018). During this stage, players are encouraged to explore multiple positional roles, developing a broad technical and tactical foundation that underpins later specialisation and long-term adaptability (Calleja-González et al., 2016; DiFiori et al., 2018). However, similar internal TL values should be interpreted cautiously, as they may mask underlying differences in mechanical or technical demands across roles. This is supported by Study 2, which demonstrated that similar internal TLs were accompanied by clear positional differences in external TL.

Specifically, external TL data from Study 2 revealed substantial and consistent positional differences between Backcourt and Frontcourt groups, particularly highlighting higher mechanical demands for Backcourt players. Guards demonstrated significantly greater external TL metrics, including increased distance covered $\cdot min^{-1}$, PL $\cdot min^{-1}$, and more frequent high-intensity decelerations compared to their Frontcourt counterparts. These findings concur with evidence from basketball match-play research, which report that guards typically exhibit greater agility demands, extensive court coverage, rapid directional changes, and higher-intensity movement patterns relative to forwards and centres (Ben Abdelkrim et al., 2007; Puente et al., 2017; Svilar et al., 2018; Vázquez-Guerrero et al., 2018). Consequently, when drills are delivered uniformly across positions, Backcourt players may accumulate higher external TLs due to greater movement requirements associated with their positional role (Svilar et al., 2018; Vázquez-Guerrero et al., 2018). Conversely, Frontcourt players engage in more static or vertically oriented tasks, such as rebounding and close-range defensive positioning, generating lower cumulative distance and PL metrics (Puente et al., 2017; Salazar et al., 2020; Scanlan et al., 2012; Svilar et al., 2018).

These findings suggest that position-specific monitoring may be beneficial in refining training prescription and managing accumulated TL more effectively, particularly during periods of high training volume or intensity (Scanlan et al., 2012; Svilar et al., 2018). Positional differences in external TL were stable across years and terms, indicating role-specific physical demands (Backcourt vs Frontcourt) that persist despite athlete development and seasonal phase. Two evidence-based interpretations remain: 1) role-congruent development (e.g., guards sustain higher accelerations$\cdot min^{-1}$ and decelerations$\cdot min^{-1}$; Frontcourt sustain higher jump/contact counts) consistent with elite-youth positional profiles (Pino-Ortega et al., 2019); and 2) practice design and role assignment that systematically reproduce these external TL signatures across seasons

(Sansone et al., 2023). These results indicate stable positional exposure patterns, but causality cannot be determined without interventions that manipulate roles or drill assignments.

In summary, findings from Studies 1 and 2 report that TLs within high-performance youth basketball are dynamic and context-dependent, varying substantially across macrocycles, mesocycles, microcycles and positional roles. The combination of similar internal TL and divergent external TL across positions highlights the limitations of relying on single-source metrics and supports the utility of a multidimensional approach to monitoring. Rather than indiscriminate increases in volume, Study 1 and 2 data suggest training exposure was modulated through varied intensity and session structure, though it is unclear to what extent this was deliberately individualised across positions. These quantitative insights provide a foundation for the subsequent exploration of qualitative dimensions, specifically, coaches' perceptions, philosophies and practical strategies for athlete development and monitoring. The following segment examines how these quantitative monitoring findings align with coaches' developmental philosophies and objectives, offering a more comprehensive understanding of TL management within this academy.

7.4 Coaches' Perspectives on Athlete Development and Training Load Monitoring

7.4.1 Holistic Development and Psychological Attributes

Understanding coaches' perspectives on athlete development is critical to interpreting how training environments are constructed, evaluated, and adapted (Bartlett & Drust, 2021; Partington & Cushion, 2013; Taylor & Garratt, 2013). Study 3 demonstrated that coaches conceptualised development as inherently multidimensional, integrating physical, technical, tactical and psychological domains within the academy. When considered alongside the quantitative findings from Studies 1 and 2, this holistic philosophy helps contextualise why TL patterns varied primarily by training term rather than by playing position, reflecting phase-based developmental priorities rather than positional specialisation. Thus, observed TL variation appears consistent with coaches' stated emphasis on long-term athlete progression over isolated physical metrics. (Bergeron et al., 2015; DiFiori et al., 2018; Lloyd et al., 2016)Coaches' preference for evaluating performance through observable changes in decision-making and execution under pressure further contextualises the TL findings. While internal and external load metrics quantified physical stimulus across terms (Studies 1 and 2), coaches interpreted these demands through perceived influence on skill execution and psychological resilience. (Bergeron et al., 2015). In summary, these findings suggest that TL variation was not viewed as an end in itself, but as a means to facilitate technical and tactical adaptation across developmental phases.

This developmental philosophy also shaped how coaches interpreted and applied TL monitoring data. Although coaches recognised the value of internal and external TL metrics, they consistently emphasised that numerical outputs alone could not capture the full scope of athlete development. TL monitoring data were viewed as complimentary to experiential judgement rather than determinative, reinforcing the continued centrality of subjective observation within training decisions. When considered alongside the quantitative findings from Studies 1, 2 and 4, this stance helps explain why TL metrics reflected structured variation across terms and development goals, yet were not treated as isolated indicators of performance. Rather, TL data were implicitly positioned as contextual tools to support technical refinement, tactical progression and psychological resilience across developmental phases. This integrative perspective aligns with contemporary athlete development models that view monitoring tools as supportive aids rather than prescriptive systems, helping to balance training decisions across developmental, tactical, and physiological domains (Impellizzeri et al., 2019; Lloyd et al., 2016). Accordingly, effect TL integration in youth academies appears to depend less on expanding metric sophistication and more on enhancing shared interpretation between coaches and performance practitioners. Strengthening this dialogue may allow TL information to shift from retrospective description toward prospective training design, improving alignment between developmental intent and physical stimulus.

7.4.2 Context-Specific Physical Development Priorities

Coaches in Study 3 prioritised basketball-specific physical attributes and functional performance outcomes over general physiological indicators. Comparable trends are evident in other sports, where task-relevant execution under environmental and tactical constraints are similarly privileged in decision-making, from strength-based disciplines and athletics to team-sport coaching guided by constraints-led frameworks (Cotterill & Discombe, 2016; Renshaw et al., 2019; Travassos et al., 2013). Rather than focusing on traditional measures of fitness or capacity, coaches consistently prioritised qualities that transferred directly to match-play tasks. Lateral quickness, encompassing rapid changes of direction and defensive slide speed, was frequently identified as a key physical performance attribute, especially for perimeter players (i.e., guards) (Svilar et al., 2018; Vázquez-Guerrero et al., 2018). These observations are consistent with match analysis research highlighting the unique movement demands of perimeter players, including their high-frequency agility-based actions (Ben Abdelkrim et al., 2007; Puente et al., 2017). As one coach explained, key traits included *"the ability to react, the ability to change direction… vertically or laterally,"* reinforcing the sport-specific lens through which physical development was viewed. This aligns with literature advocating for role-specific conditioning in team sport settings, where physical attributes are evaluated based on their impact within competitive contexts (Gamble, 2013; Impellizzeri et al., 2005).

Coaches also clearly distinguished between general measures of power or speed and the application of those qualities in match situations. For example, vertical jump capacity was valued not in isolation, but for its utility in basketball actions such as contesting rebounds, shot blocking, and scoring under pressure (Puente et al., 2017; Ziv & Lidor, 2009). Similarly, repeated-acceleration ability was prioritised for transition play and defensive recovery, with coaches reiterating execution *"under pressure or at an elite level"* over isolated sprint metrics. Methodologically, this suggests value in context-aware quantification, such as tagging accelerations to phase of play, court location or match-state. Technology providers could enhance applicability by further integrating tactical tags and event-linked windows so that reported TLs more directly reflect role-specific demands and coaching intentions. For instance, tagging specific drills or play sequences within the data would allow coaches to see not just how much load was accumulated, but in what context (e.g., fast break vs. half-court offence), thereby making the metrics more representative of actual match situations. Such integration is likely most effective when developed collaboratively with performance analysts and video or strategy staff, whose contextual expertise can ensure team-specific accuracy and relevance. By anchoring TL outputs to real basketball actions, tactical tagging improves the ecological validity of the data. This reflects broader critiques in applied sport science that caution against over-reliance on decontextualised physical metrics, instead supporting assessment strategies that prioritise ecological validity and relevance to sport-specific actions (Impellizzeri et al., 2005; Jeffries et al., 2022).

These principles were also reflected in the academy's training design and monitoring practices. Coaches described favouring conditioning drills that simulated matchplay demands over generic endurance or resistance-based exercises. One coach noted that *"endurance for me is the key… how long a player can go 80%,"* reflecting an interest in sustaining higher submaximal intensities during extended tactical or defensive sequences. This approach mirrors findings in the basketball literature, where maintaining performance quality under cumulative fatigue is considered a key differentiator of competitive readiness (Petway et al., 2020; Scanlan et al., 2012; Stojanović et al., 2018). By prioritising physical capacities with clear functional value, such as maintaining lateral speed during repeated defensive rotations, the coaches reinforced the academy's holistic framework, integrating physical training with tactical intent. This context-sensitive approach echoes previous research claims that physical development in youth sport should be guided by sport-specific demands, rather than generic fitness benchmarks (Gamble, 2013; Granacher et al., 2016).

7.4.3 Attitudes Toward Training Load Monitoring

Coaches interviewed in Study 3 expressed a measured stance toward TL monitoring, valuing TL data while maintaining a strong emphasis on experiential judgement. This position is consistent with prior research, which suggests that the successful integration of sport science depends on complementing, rather than displacing, coaches' practical knowledge (Bishop, 2008; Taylor & Garratt, 2013). Coaches acknowledged the value of TL data, particularly in areas such as injury prevention and quantifying session intensity, but consistently emphasised that such information should inform, not dictate, training decisions. The "coach's eye" was described as paramount, reflecting broader concerns in the literature that practitioner-led interpretation remains central to effective athlete monitoring (Gamble, 2013; Saw et al., 2016).

A key concern raised by coaches was the potential for monitoring systems to overlook behavioural or qualitative elements of training, such as work ethic, teamwork, or technical intent. Several participants were sceptical of metrics that failed to reflect these attributes, particularly if such tools were used to judge or constrain athlete development. These views echo earlier critiques of prescriptive monitoring systems that risk undermining character-building and coaching autonomy (Partington & Cushion, 2013; Taylor & Garratt, 2013). Coaches cautioned against context-free interpretation of TL values, reinforcing the need for interpretive frameworks that integrate (i) intended drill function (constraints, bout structure, advantage states), (ii) delivered internal–external outputs within common windows (session means and worst-case periods), and (iii) role-relevant competition benchmarks (Piñar et al., 2022). Further reservations were expressed around how TL monitoring might influence athlete behaviour. Coaches warned that players could become overly reliant on feedback or hesitant to push beyond thresholds, potentially diminishing resilience or autonomy, concerns previously noted in applied sport psychology literature (Collins & MacNamara, 2012; Langdon et al., 2015). These concerns are not unique to this setting; similar issues have been raised in other high-performance environments, where monitoring is sometimes perceived as reducing athletes to data points rather than supporting their holistic development (Gearity & Murray, 2011).

Despite these caveats, coaches also acknowledged the value of TL data when employed as a communication and decision-support tool. TL metrics were described as particularly useful for facilitating discussions with athletes regarding recovery, TL management, and performance trends, provided the data were presented in an accessible and context-specific manner. This emphasis on usability and contextual relevance is consistent with previous literature, which identifies simplicity and interpretability as key determinants of monitoring tool adoption in applied settings (Martindale & Nash, 2013; McCall et al., 2018). Coaches often operate under limited time and varied expertise, so monitoring outputs must be straightforward to interpret. Overly complex or abstract metrics (e.g. elaborate composite scores or ratios with little intuitive meaning) tend to be ignored, whereas simple indicators relevant to basketball-specific contexts (such as the number of high-intensity efforts, distance covered, or jump counts in a session) enable coaches to confidently incorporate data into their decision-making processes (Martindale & Nash, 2013; McCall et al., 2018).

Overall, Study 3 reinforces the view that effective TL monitoring must operate within the practical realities of coaching, respecting the value of lived expertise while offering relevant, flexible insights. This balance reflects contemporary thinking in applied sport science, which advocates for monitoring systems that are embedded in collaborative processes and oriented toward developmental rather than prescriptive goals (Bartlett & Drust, 2021; Eisenmann, 2017). Coaches' engagement with data was conditional on alignment with their beliefs, competitive aims, and daily workflows, underscoring the importance of co-design, shared language, and timely feedback loops to embed monitoring into practice. Prior work similarly shows that adoption depends on perceived relevance, trust, and actionability, with engagement driven less by technological capacity than by alignment with coaching context and communication structures (Brewer et al., 2025; Martindale & Nash, 2013).

7.4.4 Effective Communication of Monitoring Data to Coaches

Study 3 identified practical requirements for integrating TL data into day-to-day decisions. Coaches emphasised presentation and context: they preferred reports that link metrics to observable training events (e.g., explaining TL spikes via added sessions or increased drill intensity), while noting that the empirical importance of spikes remains debated (Impellizzeri et al., 2019; Windt & Gabbett, 2017). They highlighted the value of simple, regular touchpoints (e.g., a brief weekly review) and immediately actionable summaries, consistent with contemporary recommendations (McCall et al., 2018). Coaches favoured relative, individualised views, comparing current TLs to personal baselines to flag atypical trends, aligning with published guidance on individualised monitoring and change detection (Bourdon et al., 2017; Malone et al., 2017; McLaren et al., 2018). They also described how objective data complemented their experiential judgement, viewing monitoring as a supportive tool rather than a directive one (Jeffries et al., 2022).

These preferences imply that effective integration depends on matching data displays and language to coaches' models of player development and session design. Accordingly, clear specification of intended drill aims (e.g., conditioning-dominant vs skills/tactics-dominant), pre-agreed evaluation metrics (e.g., PL·min^{-1} for density; accelerations/decelerations·min^{-1} for change-of-pace; jump counts for plyometric exposure), and brief post-session reviews of intended vs delivered outputs provide an actionable feedback loop for decision-making (Russell, McLean, Impellizzeri et al., 2021; Sansone et al., 2023). When embedded routinely, such streamlined feedback cycles can contribute to holistic athlete development (Bourdon et al., 2017; Phibbs et al., 2017). Some coaches expressed reservations about extensive data use, preferring observational judgement (e.g., *"Old school coaches… when we see a gadget… they're going to make athletes soft."*). This illustrates the need for flexible monitoring practices that accommodate varied levels of engagement with data and technology rather than enforcing a single approach. From a practical perspective, such flexibility could extend to communication, as performance staff can adapt how they present insights (e.g. visual dashboards, brief summaries, or face-to-face discussions) to match coaching staff preferences and technological comfort. In other words, effective communication is part of a flexible monitoring approach, ensuring that rapport with coaching staff is built and key information is conveyed in an accessible way to all stakeholders.

In summary, Study 3 provided critical evidence regarding coaches' preferences for tailored, context-rich, and actionable monitoring data directly informing daily decision-making. These qualitative insights complement earlier quantitative analyses by demonstrating that effective TL monitoring in youth basketball requires deliberate, coach-oriented data presentation strategies. This tailored approach enhances the practical value and usability of TL data, clearly aligning monitoring practices with the academy's holistic athlete-centred developmental philosophy.

7.5 Aligning Coaching Intentions with Training Loads

Aligning coaching intentions with objective TL outcomes is a critical step in determining whether monitoring practices can meaningfully support athlete development, rather than operate in parallel to coaching (Impellizzeri et al., 2019; Jeffries et al., 2022). As shown in Study 3, coaches were more likely to value TL data when it aligned with their session goals and developmental foci. Informed by these findings, Study 4 investigated whether drill-level physical outputs corresponded with the IDGs set by coaches in the academy setting. Using classification modelling, the study examined whether external TL metrics could distinguish between drills based on their intended developmental emphasis, thereby testing the extent to which physical outputs reflect the designed purpose of training. This approach offers a novel method for evaluating the integration between training plans and TL monitoring data within the academy setting.

7.5.1 Linking Development Goals with Objective Metrics

Drills targeting different developmental goals (e.g., agility compared with conditioning) generated distinct external TL profiles, indicating that variations in drill design yield measurable differences in mechanical workload metrics (Fox, Conte et al., 2021; Klusemann et al., 2012). In Study 4, classification performance varied across drill families, demonstrating that the ability to distinguish between drill types reflected their underlying physical characteristics. For example, intended "conditioning-dominant" drills were characterised by higher PL·min^{-1} and greater accelerations·min^{-1} and decelerations·min^{-1} than "skill/tactics-dominant" drills, which showed lower PL·min^{-1} and reduced HSR distance. Agreement between intended emphasis and measured outputs was partial, whereby some IDG categories were reliably distinguished by PL·min^{-1} and accelerations·min^{-1}, whilst others overlapped. These patterns are consistent with evidence that manipulating drill constraints (duration, space, rules) systematically alters external TL (Klusemann et al., 2012; Sansone et al., 2020; Schelling & Torres-Ronda, 2016). Importantly, while these results demonstrate an element of TL differentiation based on coach programming, further investigation is required to determine whether TL metrics relate to skill progression and broader developmental outcomes, which were beyond the scope of the present thesis. Promising approaches include multi-year longitudinal tracking that follows athletes across transitions to senior levels and mixed methods designs pairing quantitative TL with coach/athlete ratings of skill acquisition and tactical decision-making.

Classification accuracy varied by developmental category (e.g., conditioning-dominant vs. skills/tactics-dominant), highlighting opportunities to refine drill design (constraint manipulation and dose targets) and to standardise activity labelling so that classification categories show greater alignment to the metrics that discriminate them (e.g., PL·min^{-1} for intensity; accelerations/decelerations for change-of-pace; jump counts for plyometric emphasis). This partial alignment presents opportunities for coaches and support staff to prospectively and collaboratively refine drill prescription characteristics to better clarify and represent developmental intentions. For example, drills targeting conditioning produced more consistent and predictable TL profiles than those focused on agility or decision-making, which typically involved higher counts of accelerations and decelerations $\cdot min^{-1}$, greater change-of-direction frequency, and shorter high-intensity worst-case windows relative to pattern drills (Fox, Conte et al., 2021; Reina Román et al., 2019; Schelling & Torres-Ronda, 2016).

Where external TL profiles converge across drills with different developmental aims, complementary indicators may clarify whether the intended emphasis was achieved. For instance, use of pre/post-session RPE (internal TL), decision-making tasks, or skill-execution proxies when the goal is perceptual–cognitive or technical progression (Fuster et al., 2021; Impellizzeri et al., 2019). Establishing brief, scheduled feedback loops (e.g., post-session review of intended vs. delivered using pre-agreed metrics) may improve alignment by iteratively refining drill constraints and TL targets (Impellizzeri et al., 2019; Sansone et al., 2023). Additionally, ongoing dialogue between coaches, performance staff, and athletes can help ensure that training design remains aligned with measurable objectives, supporting a more coherent relationship between planned content and observed physical output.

7.5.2 Challenges of Training Load Monitoring in Representing Developmental Outcomes

Study 4 showed that IDG-labelled drills exhibited separable external TL signatures, for example, conditioning-dominant drills presented higher $PL \cdot min^{-1}$ and $accelerations \cdot min^{-1}/decelerations \cdot min^{-1}$, whereas skills/tactics-dominant drills displayed lower $PL \cdot min^{-1}$ and low HSR distance, yet these mechanical indices did not fully index developmental objectives oriented toward technical execution or perceptual–cognitive demands (Jeffries et al., 2022). Drills with similar external TL characteristics often differed in their intended tactical or cognitive emphasis, complicating interpretation based solely on TL data. For example, scrimmages labelled by coaches as “transition-focused” typically showed high frequencies of accelerations and high-speed running (Fox, Conte et al., 2021; Svilar & Jukić, 2018; Vázquez-Guerrero, Fernández-Valdés, Gonçalves et al., 2019).

Furthermore, drills emphasising half-court execution or tactical rehearsal, although qualitatively distinct, sometimes produced similar external TL profiles, for example, comparable accelerations·min^{-1} and decelerations·min^{-1} and overlapping PL·min^{-1} values, limiting separability on mechanical indices alone. This overlap limited the ability to reliably distinguish certain drill types based solely on TL data (Petway et al., 2020; Reina Román et al., 2019; Sansone et al., 2020). Situational-play drills, with greater reactive decision-making, were the hardest to differentiate using standard external TL metrics. In these scenarios, PL·min^{-1} and accelerations·min^{-1} frequently overlapped with skills/tactics- based drills, and HSR distance remained low across both. This aligns with reports that perceptual–cognitive emphasis may not manifest as distinct mechanical signatures (Jeffries et al., 2022; Russell, McLean, Impellizzeri et al., 2021). These findings reinforce the challenge of inferring developmental emphasis from external TL alone: when drills share similar PL·min^{-1}, accelerations·min^{-1}/decelerations·min^{-1}, and low HSR distances, mechanical data cannot, by itself, index cognitive or technical intent. This highlights the importance of movement context, why an athlete performs a particular action, an issue raised by coaches in Study 3 who emphasised the functional purpose of movement over its raw quantity.

Addressing these limitations may require targeted increases in granularity, for example, refining drill taxonomies only where classification uncertainty is high or where intended emphases (e.g., conditioning-dominant vs. skills/tactics-dominant) recurrently overlap on external TL metrics. The aim is decision utility rather than depth for its own sake: added detail is justified when it improves intended–delivered alignment checks or clarifies metric–construct mapping (e.g., using PL·min^{-1} for density, accelerations/decelerations·min^{-1} for change-of-pace, jump counts for plyometric exposure), but not when it merely proliferates categories without demonstrable interpretive gain (Bourdon et al., 2017; Impellizzeri et al., 2019; Sansone et al., 2023). From a practical standpoint, short debriefs that combine coach context with metric checks can clarify whether drills delivered the intended stimulus; where external TL profiles converge, add qualitative inputs (e.g., coach observation, athlete feedback and/or video) (Bourdon et al., 2017; Mason et al., 2021).

7.5.3 Interpreting Convergence Between Training Load Outputs and Drill Intent

Study 4 showed partial discrimination between drill categories: conditioning-dominant drills had greater PL·min^{-1} and accel/decel·min^{-1} than skills/tactics-dominant drills; situational play showed the weakest discrimination on these metrics. This mirrors format-driven mechanical shifts reported previously (Klusemann et al., 2012; Schelling & Torres-Ronda, 2016). External TL captures the training dose but not the technical or perceptual–cognitive emphasis (Impellizzeri et al., 2019; Klusemann et al., 2012; Russell, McLean, Impellizzeri et al., 2021; Schelling & Torres-Ronda, 2016). Convergence between external TL profiles and drill intent should be examined rather than assumed; apply the aims→metric–construct→brief review process as outlined in 7.3.4 (Bourdon et al., 2017; Sansone et al., 2023). When external TL profiles converge across drills with different technical or tactical objectives, complementary indicators such as pre/post-session RPE, decision-making assessments, or technical-execution markers may clarify whether the intended emphasis was achieved (Fuster et al., 2021; Jeffries et al., 2022). In sum, short, decision-focused reporting centred on metrics that meaningfully discriminate drill categories, and on concise alignment checks, can improve interpretability without over-extending analysis.

7.5.4 Applying Study 4 Findings to Improve Monitoring-Coaching Integration

Misclassifications observed in Study 4 may relate to inconsistencies in drill structure, terminology or metric sensitivity, issues discussed earlier in this chapter. Rather than restating these findings, this section focuses on applied strategies that may improve the integration of monitoring and coaching practice. In some cases, enhancing specificity may involve rethinking how physical outputs are interpreted, shifting from broad, across-drill comparisons toward drill-specific benchmarks that better reflect the coach's intended stimulus. This approach aligns with perspectives captured in Study 3, where coaches emphasised that TL data are only meaningful when contextualised within the design and purpose of the drill itself. Study 4 showed that when drills lacked unique TL signatures, they were more susceptible to misclassification. Coaches can respond by adjusting drill constraints, such as intensity, duration, or spatial configurations (Conte et al., 2016; Klusemann et al., 2012), to produce clearer physical responses tied to the targeted quality. For instance, shorter, more reactive formats may help differentiate lateral quickness from aerobic conditioning, as they tend to elicit higher neuromuscular and change-of-direction loads with lower total volume (Reina Román et al., 2019; Svilar & Jukić, 2018). However, where qualities like tactical awareness or psychological resilience are central to a drill, and difficult to capture through accelerometer-based measures alone, supplemental tools such as video review or athlete self-report may be required. These adjustments are consistent with the principle of training specificity and reflect an effort to better align monitoring with complex developmental objectives (Fox, Conte et al., 2021; Reina Román et al., 2019).

The integration of monitoring also depends on how and when information is communicated. Coaches in Study 3 expressed a clear preference for TL data that was delivered in an interpretable, context-rich format, and aligned with their session objectives and timelines. Based on these insights, Study 4 motivates considering routine collaborative reviews to reflect on whether physical outputs aligned with planned goals. These debriefs are especially valuable for drill types that were misclassified by the model, providing an opportunity to reconcile expectations, refine drill designs, or re-evaluate which metrics best reflect the intended outcome. Embedding these discussions into regular planning cycles reinforces shared understanding of developmental aims and promotes more consistent alignment between prescribed objectives and measured outputs.

7.6 Summary

This chapter synthesised findings from four interrelated studies examining the role of TL monitoring within a high-performance youth basketball academy. Studies 1 and 2 quantified internal and external TLs across multiple timescales, revealing non-linear and context-dependent variations influenced by season, year, and playing position. These patterns suggested structured periodisation but also highlighted the limits of assuming uniform progression. Study 3 provided qualitative insight into coaches' philosophies, emphasising holistic development and a preference for monitoring tools that supported, rather than dictated, decision-making. Study 4 examined indicators of alignment between prescribed developmental goals and physical outputs. Drills with clear physical emphases often produced more distinct TL profiles, whereas complex or blended goals were misclassified more frequently. These misclassifications reflected broader challenges in aligning training intent with monitoring outputs and indicate a need for clearer terminology, improved drill design, and collaborative interpretation. Collectively, the findings suggest that monitoring is most effective when embedded within the developmental process as a context-sensitive, coach-informed practice rather than a standalone evaluative tool.

Together, these outcomes advance current understanding of how TL monitoring can operate as an integrated element of athlete development rather than an external measurement process. The synthesis links objective load data with coaching intent, offering an applied basis for connecting design, delivery, and athlete response within a single developmental framework. In doing so, it extends existing TL literature beyond descriptive or injury-focused paradigms and contributes new evidence on how monitoring can facilitate feedback, reflection, and alignment between planned and delivered training in youth sport. These insights underpin the practical recommendations outlined in Chapter 8.

Chapter 8: Summary and Practical Applications

8.1 Thesis Aims

Although TL monitoring is widely adopted in both elite senior and high-performance youth sport, its application in youth settings remains limited and largely reactive, primarily centred on injury prevention rather than developmental planning (Fox, Scanlan, Sargent et al., 2020; Murray, 2017). In academy environments, where practitioners must balance short-term competition with long-term development, a more holistic and integrated approach to monitoring may be required. To address this gap, this thesis examined how internal and external TL metrics align with coaching practice, training structure, and developmental objectives across a multi-year academy program.

A mixed-methods design was employed, comprising four interrelated studies. Studies 1 and 2 quantified internal and external TLs across annual, seasonal, and positional dimensions, illustrating how TL exposure evolved over time. Study 3 explored coaches' philosophies toward performance and monitoring, providing insight into how practitioners interpret and apply TL data in context. Study 4 then examined the alignment between drill-level physical outputs and coach-assigned developmental goals, using classification modelling to explore whether objective TL metrics reflect the intended purpose of training. Together, these studies provide a comprehensive evaluation of TL monitoring within a youth basketball academy, moving beyond traditional injury-risk frameworks to examine its role in supporting developmental planning. The findings offer new insight into how monitoring practices can be tailored to better reflect the developmental goals, contextual demands, and coaching processes within youth sports academies.

8.2 Key Findings

Key findings from each of the four studies are summarised below.

Study 1

- Internal TL (sRPE) increased by approximately 10% from Year 1 to Year 2, suggesting a planned progression in training demands across academy years.
- This increase was primarily driven by higher weekly session frequency and total training duration, with only moderate changes in perceived exertion.
- Year 3 athletes recorded further increases in sRPE compared to Year 1, though with greater variability, suggesting a less standardised TL profile at later stages.
- Internal TL values were comparable across positional groups, indicating uniformity in perceived session intensity regardless of role.
- Internal TL fluctuated across the year, with higher values recorded during competitive terms (1 and 2) and reductions observed in off-season terms (3 and 4), consistent with planned seasonal modulation.

Study 2

- External TL metrics (e.g., PL, distance) plateaued after Year 1 despite longer training durations, suggesting a shift in training focus from primarily building physical capacity toward greater emphasis on technical and tactical training content.
- Cumulative external TLs were higher during off-season periods (Terms 3 and 4) compared to in-season periods (Terms 1 and 2), suggesting a volume-based approach to preseason preparation.

- PL $\cdot\text{min}^{-1}$ peaked during pre-season (Term 4), indicating elevated session intensity during this preparatory phase.
- Weekly TL variation reflected structured microcycle planning, with higher training volumes during non-competition weeks and tapering during congested schedules.
- Backcourt players exhibited higher external TLs, particularly in decelerations, movement intensity, and PL $\cdot\text{min}^{-1}$, underscoring the importance of position-specific monitoring strategies.

Study 3

- Coaches articulated a holistic developmental philosophy, prioritising psychological resilience, technical proficiency, and decision-making under pressure in conjunction with physical preparation.
- Coaches reported using TL metrics as contextual guides rather than prescriptive thresholds, with decision-making largely informed by observational judgement and situational context.
- Monitoring practices were perceived as most effective when collaboratively interpreted and aligned with coaching aims; rigid or decontextualised data applications were met with resistance.
- Coaches favoured communication formats that incorporated visual trend data, individual comparisons over time, and informal dialogue embedded within daily routines.

- Caution was expressed regarding excessive reliance on monitoring, particularly where it was perceived to compromise coaching autonomy or diminish athlete ownership and resilience.

Study 4

- Drills assigned distinct developmental goals often produced differentiated external TL profiles, suggesting partial alignment between design and physical output.
- Classification modelling partially distinguished many drills. Accuracy varied by category, for example agility and decision-making drills were more prone to misclassification.
- Misalignment typically occurred in drills with overlapping objectives or where cognitive or tactical emphasis did not result in distinct external TL signatures.
- These inconsistencies highlight a gap between coaching intent and measurable outputs, particularly in open-ended or multi-component training tasks.

8.3 Practical Applications

Based on the research findings, several practical applications are proposed to enhance TL monitoring integration in youth basketball:

- Where possible, monitoring systems should track how TL evolves across years to ensure that early increases in exposure are followed by phases that support technical and tactical development.

- Backcourt players consistently exhibit higher external TLs, especially in decelerations and movement volume, necessitating position-specific TL adjustments and recovery strategies. In practice, this does not imply that high TLs are undesirable; rather, elevated loads can be used deliberately to target key performance areas, such as developing defensive resilience or repeated-effort capacity, provided they are planned, monitored, and supported by appropriate recovery.
- TL data should be interpreted at both individual and positional levels to avoid misleading conclusions based on team-level averages.
- Coaches may benefit from reviewing how weekly and seasonal TL trends align with their intended periodisation plans, ensuring training stress is distributed appropriately across phases.
- Monitoring TL data is most likely to be adopted by coaching staff when presented in a contextualised, athlete-specific, and visually accessible format.
- Drills that are repeatedly misclassified by models may signal mismatches between intended emphasis and physical expression, warranting review of drill content and expected TL profiles.
- Monitoring data should function as a reflective tool to support coaching decisions, not as a rigid framework dictating training structure.
- Incorporating monitoring into regular planning and review processes fosters alignment between intended developmental goals and observed training outcomes.

In summary, the work contributes new multi-year and drill-level evidence, integrates coach perspectives, and empirically tests the alignment of intended versus realised training demands, thereby strengthening the foundations of youth basketball monitoring. While these findings arise from a single academy context and should be generalised cautiously, the core principles identified in this thesis, such as the progressive increase in TL with maturity and the need to contextualise monitoring data, may be relevant to similar high-performance youth programs (Calleja-González et al., 2016). Yet practitioners should tailor implementations to their own environment's specific context and constraints.

8.4 Future Research

While this thesis advances understanding of TL integration in youth basketball, several areas warrant further investigation, such as:

- Monitoring approaches that capture cognitive and tactical demands should be developed for drills where external TL alone is insufficient.
- The modelling used in Study 4 could be refined by integrating additional data sources (e.g., video, spatial tracking, contextual tags) to improve classification of complex, perceptual-cognitive focused drills.
- Longitudinal tracking to examine whether intent–exposure alignment persists as athletes transition into senior competition, and how this relates to retention and performance outcomes through combined TL monitoring and career progression data.
- Dose-response relationships between drill design, external/internal TL and skill execution should be modelled to determine training features that most strongly influence technical and perceptual-cognitive outcomes.

- Coach-scientist collaboration processes should be studied to identify translation mechanisms (e.g., meeting structures, visualisations, light-touch indices) that improve adoption.
- Cross-site replication in different academies and age brackets should be undertaken to test generalisability and to quantify maturational and contextual moderators.
- Worst-case period analyses should be aligned with declared drill intentions to validate whether peak-demand segments reflect the targeted developmental emphasis.

Overall, this thesis offers an applied set of observations and tools for youth sport monitoring, one that emphasises precise measurement, contextual interpretation, and alignment with developmental goals. Within one academy, integrating multi-year data, coach perspectives, and intent-versus-outcome analyses illustrates possible ways to bridging the gap between TL metrics and long-term player development pathways. This contribution establishes a durable foundation for subsequent research, enabling future studies to build on an evidence-based, context-aware monitoring model. Likewise, this work provides clear practical guidance by offering coaches an actionable blueprint: measure TLs rigorously, interpret them in context, and align training with athletes' developmental objectives with the aim of enhancing performance and progression. These findings reflect one academy, a male youth cohort, and specific monitoring implementations; future multi-site studies are needed to evaluate generalisability.

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Appendices

Appendix 1- Ethics Approval Letter: Longitudinal Internal Training Load and Exposure in a High-Performance Basketball Academy

AIS Ethics

MINUTE: 9 NOVEMBER 2022

TO: Jonathon Lever

FROM: Michael Gillard, AIS Ethics Committee Secretary

SUBMISSION TITLE: Training Exposure and Internal Training Load in a High-Performance Basketball Academy: A Five-Year Analysis

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The AIS Ethics Committee (EC) have considered your research submission, titled above. Following your responses to the initial queries raised by the EC, the EC does not see any ethical reason why the project should not proceed as specified in your submission.

Ethics approval number: 20220901
Ethics approval expiry: 31 May 2023

As the Principal Researcher, please advise all researchers involved in the study of the EC approval and any conditions of approval stated above. Please also advise the EC immediately (via the Secretary) of:

- Any proposed changes to the research design
- Any adverse events that occur whilst carrying out your research study
- Premature termination of the project
- Project completion.

Researchers are responsible for submitting the required annual status reports and project completion reports to the EC Secretary. Details of report requirements can be found online at:

https://www.ais.gov.au/research-submissions

After approval expires, you will need to submit an extension request to continue the study if required. If you have any questions regarding this matter, please contact me.

Sincerely,

Production Note:
Signature removed prior to publication.

Michael Gillard
AIS Ethics Committee Secretary
ethics@ausport.gov.au

Appendix 2 - Ethics Ratification Letter: Longitudinal Internal Training Load and Exposure in a High-Performance Basketball Academy

Dear Applicant

Re: ETH22-7841 - "Longitudinal Internal Training Load and Exposure in a High-Performance Basketball Academy"

[External Ratification: AIS Ethics Committee Michael Gillard - AIS Ethics Committee Secretary ethics@ausport.gov.au HREC approval - 20220901 - 09/11/22 to 31/05/2023]

The UTS Human Research Ethics Executive Review Committee has reviewed the above-named application, and agreed that the application meets the requirements of the NHMRC National Statement on Ethical Conduct In Human Research (2007). I am pleased to inform you that your external ethics approval has been ratified.

This ratification is subject to the standard conditions outlined in your original letter of approval. You are reminded that this letter constitutes ethics approval only. This research project must also be undertaken in accordance with all UTS policies and guidelines including the Research Management Policy.

Your approval number is UTS HREC REF NO. ETH22-7841.

Approval will be for the period specified above and subject to the provision of evidence of continued support from the above-named Committee.

This research must be undertaken in compliance with the Australian Code for the Responsible Conduct of Research and National Statement on Ethical Conduct in Human Research.

You should consider this your official letter of approval. If you require a hardcopy please contact the Ethics Secretariat.

To access this application, please click here, a copy of your application has also been attached to this email.

We value your feedback on the online ethics process. If you would like to provide feedback please do so here.

If you have any queries about your ethics approval, or require any amendment to your research in the future, please don't hesitate to contact the Ethics Secretariat and quote
the ethics application number (e.g. ETH20-xxxx) in all correspondence.

Yours sincerely,
The Research Ethics Secretariat
on behalf of the UTS Human Research Ethics Executive Review Committee
C/- Research Office
University of Technology Sydney
Research.Ethics@uts.edu.au | Website
PO Box 123 Broadway NSW 2007
E13-6

Appendix 3 - Ethics Approval Letter: Quantifying the External Training Loads of High-Performance Youth Basketball Players: A Season-Long Analysis

Dear Applicant

Re: ETH22-7626 - "Quantifying the External Training Loads of High-Performance Youth Basketball Players: A Season-Long Analysis"

Thank you for your response to the Committee's comments for your project. The Committee agreed that this application now meets the requirements of the National Statement on Ethical Conduct in Human Research (2007) and has been approved on that basis. You are therefore authorised to commence activities as outlined in your application.

You are reminded that this letter constitutes ethics approval only. This research project must also be undertaken in accordance with all UTS policies and guidelines including the Research Management Policy.

Your approval number is UTS HREC REF NO. ETH22-7626.

Approval will be for a period of five (5) years from the date of this correspondence subject to the submission of annual progress reports.

The following standard conditions apply to your approval:

- Your approval number must be included in all participant material and advertisements. Any advertisements on Staff Connect without an approval number will be removed.
- The Principal Investigator will immediately report anything that might warrant review of ethical approval of the project to the Ethics Secretariat.
- The Principal Investigator will notify the Committee of any event that requires a modification to the protocol or other project documents, and submit any required amendments prior to implementation. Instructions on how to submit an amendment application can be found here.
- The Principal Investigator will promptly report adverse events to the Ethics Secretariat. An adverse event is any event (anticipated or otherwise) that has a negative impact on participants, researchers or the reputation of the University. Adverse events can also include privacy breaches, loss of data and damage to property.
- The Principal Investigator will report to the UTS HREC or UTS MREC annually and notify the Committee when the project is completed at all sites. The Principal Investigator will notify the Committee of any plan to extend the duration of the project past the approval period listed above.

- The Principal Investigator will obtain any additional approvals or authorisations as required (e.g. from other ethics committees, collaborating institutions, supporting organisations).
- The Principal Investigator will notify the Committee of his or her inability to continue as Principal Investigator including the name of and contact information for a replacement.

This research must be undertaken in compliance with the Australian Code for the Responsible Conduct of Research and National Statement on Ethical Conduct in Human Research.

You should consider this your official letter of approval. If you require a hardcopy please contact the Ethics Secretariat.

If you have any queries about your ethics approval, or require any amendments to your research in the future, please don't hesitate to contact the Ethics Secretariat and quote the ethics application number (e.g. ETH20-xxxx) in all correspondence.

Yours sincerely,
The Research Ethics Secretariat
On behalf of the UTS Human Research Ethics Committees
C/- Research Office
University of Technology Sydney
E: Research.Ethics@uts.edu.au
Ref: E38

Appendix 4 - Ethics Approval Letter: Revisiting the Playbook: Are Training Load Monitoring Practices Providing Academy Basketball Coaches What They Need?

Dear Applicant,

Re: ETH22-7619 - "Revisiting the Playbook: Are Training Load Monitoring Practices Providing Academy Basketball Coaches What They Need?"

Your local research office has reviewed your application and agreed that it now meets the requirements of the National Statement on Ethical Conduct in Human Research (2007) and has been approved on that basis. You are therefore authorised to commence activities as outlined in your application, subject to any conditions detailed in this document.

You are reminded that this letter constitutes ethics approval only. This research project must also be undertaken in accordance with all UTS policies and guidelines including the Research Management Policy.

Your approval number is UTS HREC REF NO. ETH22-7619

Approval will be for a period of five (5) years from the date of this correspondence subject to the submission of annual progress reports.

The following standard conditions apply to your approval:

- Your approval number must be included in all participant material and advertisements. Any advertisements on Staff Connect without an approval number will be removed.
- The Principal Investigator will immediately report anything that might warrant review of ethical approval of the project to the Ethics Secretariat.
- The Principal Investigator will notify the Committee of any event that requires a modification to the protocol or other project documents, and submit any required amendments prior to implementation. Instructions on how to submit an amendment application can be found here.
- The Principal Investigator will promptly report adverse events to the Ethics Secretariat. An adverse event is any event (anticipated or otherwise) that has a negative impact on participants, researchers or the reputation of the University. Adverse events can also include privacy breaches, loss of data and damage to property.
- The Principal Investigator will report to the UTS HREC or UTS MREC annually and notify the Committee when the project is completed at all sites. The Principal

Investigator will notify the Committee of any plan to extend the duration of the project past the approval period listed above.

· The Principal Investigator will obtain any additional approvals or authorisations as required (e.g. from other ethics committees, collaborating institutions, supporting organisations).

· The Principal Investigator will notify the Committee of his or her inability to continue as Principal Investigator including the name of and contact information for a replacement.

This research must be undertaken in compliance with the Australian Code for the Responsible Conduct of Research and National Statement on Ethical Conduct in Human Research.

You should consider this your official letter of approval.

If you have any queries about this approval, or require any amendments to your approval in future, please do not hesitate to contact your local research office or the Ethics Secretariat.

Ref: 12a

Appendix 5 – Ethics Approval Letter: Are External Training Loads Different Based on Coach-Prescribed Goals Between Drills in Youth Basketball?

Dear Applicant

Re: ETH25-10553 - "Are External Training Loads Different Based on Coach-Prescribed Goals Between Drills in Youth Basketball?"

Thank you for your response to the Committee's comments for your project. The Committee agreed that this application now meets the requirements of the National Statement on Ethical Conduct in Human Research (2018) and has been approved on that basis. You are therefore authorised to commence activities as outlined in your application.

You are reminded that this letter constitutes ethics approval only. This research project must also be undertaken in accordance with all UTS policies and guidelines including the Research Management Policy.

Your approval number is UTS HREC REF NO. ETH25-10553.

Approval will be for a period of five (5) years from the date of this correspondence subject to the submission of annual progress reports.

The following standard conditions apply to your approval:

- Your approval number must be included in all participant material and advertisements. Any advertisements on Staff Connect without an approval number will be removed.
- The Principal Investigator will immediately report anything that might warrant review of ethical approval of the project to the Ethics Secretariat.
- The Principal Investigator will notify the Committee of any event that requires a modification to the protocol or other project documents, and submit any required amendments prior to implementation. Instructions on how to submit an amendment application can be found here.
- The Principal Investigator will promptly report adverse events to the Ethics Secretariat. An adverse event is any event (anticipated or otherwise) that has a negative impact on participants, researchers or the reputation of the University. Adverse events can also include privacy breaches, loss of data and damage to property.
- The Principal Investigator will report to the UTS HREC or UTS MREC annually and notify the Committee when the project is completed at all sites. The Principal Investigator will notify the Committee of any plan to extend the duration of the project past the approval period listed above.
- The Principal Investigator will obtain any additional approvals or authorisations as required (e.g. from other ethics committees, collaborating institutions, supporting organisations).

- The Principal Investigator will notify the Committee of his or her inability to continue as Principal Investigator including the name of and contact information for a replacement.

This research must be undertaken in compliance with the Australian Code for the Responsible Conduct of Research and National Statement on Ethical Conduct in Human Research.
You should consider this your official letter of approval. If you require a hardcopy please contact the Ethics Secretariat.

If you have any queries about your ethics approval, or require any amendments to your research in the future, please don't hesitate to contact the Ethics Secretariat and quote the ethics application number (e.g., ETH24-xxxx) in all correspondence.

Yours sincerely,
The Research Ethics Secretariat
On behalf of the UTS Human Research Ethics Committees
C/- Research Office
University of Technology Sydney
E: Research.Ethics@uts.edu.au
Ref: E38

Appendix 6 - NBA Research Agreement Letter

Execution Version

RESEARCH AGREEMENT

THIS AGREEMENT (this "Agreement") is made, as of February ____, 2020, by and between University of Technology Sydney, located at 15 Broadway, Ultimo NSW 2007, Australia ("UTS") and NBA Properties, Inc. ("NBAP"), located at 645 Fifth Avenue, New York, New York 10022.

1. **UTS'S OBLIGATIONS**

A. UTS hereby agrees to perform the services described in Schedule A to this Agreement (the "Services"), subject to the terms and conditions set forth below and in Schedule A (or any other schedule or exhibit attached hereto).

B. UTS shall perform the Services in accordance with the date specifications set forth in Schedule A (or any other schedule or exhibit attached hereto). Unless otherwise indicated herein, all approvals to be made by NBAP hereunder must be in writing and shall be given or withheld in NBAP's sole discretion.

2. **RELATIONSHIP OF PARTIES**

UTS agrees to perform the Services as an independent contractor. Neither UTS nor any employee or student of UTS or other person retained by UTS shall be (a) considered under the provisions of this Agreement or otherwise, an employee, agent or partner of NBAP; or (b) eligible to participate in any welfare, retirement, or other plan, or receive any other benefits, provided or made available to NBAP's employees. UTS agrees that, as between the parties, all entities and individuals supplied or otherwise retained by UTS in connection with this Agreement ("UTS Personnel") will be the employees or contractors of UTS, and there shall be no employment, contractual or direct relationship between such UTS Personnel and NBAP. As such, UTS shall be responsible for all compensation and benefits that may be due to the UTS Personnel, including, without limitation, regular pay, overtime, worker's compensation, vacation, sick time, disability, pension and any other compensation or benefits that such individuals may be owed under any applicable law as a result of their performance of Services for and on behalf of UTS pursuant to this Agreement. UTS agrees to indemnify, defend and hold the NBAP Indemnitees (as defined below) harmless from and against any claims, losses, expenses (including reasonable attorneys' fees), judgments or liabilities of any kind or nature whatsoever (collectively, "Claims") which in any way arise from or are related to the performance by the UTS Personnel of any duties assigned to such individuals hereunder (including, without limitation, Claims for overtime, worker's compensation or any other benefits that may be associated with employment, as well as Claims against the NBAP Indemnitees that may be made by any governmental agency with respect to the employment status of the individuals supplied hereunder).

3. **COMPENSATION**

A. As full compensation for all Services rendered in accordance with the terms of this Agreement, NBAP shall pay to UTS the amounts set forth in Schedule A on the schedule set forth in Schedule A; provided, however, that such amounts may be subject to adjustment in accordance with the terms of this Agreement (including Schedule A).

B. UTS and UTS Personnel are not authorized to incur any expenses on behalf of NBAP without the prior written consent of NBAP. NBAP will not be responsible for,

Appendix 7 - Basketball Australia Data Consent Letter

BASKETBALL AUSTRALIA

Thursday, August 24, 2023

Re: Novel IMU Metrics Validation Research Project with Basketball Australia's Centre of Excellence

To whom it may concern.

This letter acknowledges our in-principal agreement pertaining to the PhD research project at UTS that will investigate the validity of novel wearable technology algorithms to detect and quantify basketball movement profile. As part of this research, the researchers will be granted access to the training environment at Basketball Australia's Centre of Excellence in the Australian Institute of Sport, Canberra to aid the data collection pertaining to this study. This data will include accelerometry measures from inertial measurement units alongside the video footage of the basketball movement assessment protocol. Please note that this data collection is subject to University Ethics as well as all researchers having relevant police and working with children checks.

Regards,

Production Note:
Signature removed
prior to publication.

Peter Lonergan

Director of High-Performance Coach Development

Basketball Australia

+61

Appendix 8 – Semi-Structured Interview Template (Study 3)

Part 1: Introductory Questions	
Questions	*Follow-Up Questions*
1. How long have you been involved in basketball? 2. What level(s) have you coached at? (i.e., Pro, semi-pro, college, amateur/junior) 3. What is your current coaching role?	1a) Describe your playing experience. 1b) Describe your coaching experience. 2a) How long did you coach at each level? 3a) What are your key responsibilities in this role?
Part 2: The Coaches Eye	
1. How would you define performance in basketball? 2. Thinking of basketball performance, what physical characteristics do you deem most important for individual success in basketball and why? 3. What strategies do you implement to develop and coach these characteristics during training?	1a) What makes a good player in the academy system? 2a) Do you believe these characteristics are equally important at all levels of competition or are there others that are more/less important? Why? 2b) Do these characteristics differ between practice and competition or are they the same? If so, how? 2c) Do these characteristics differ between positions? If so, how/why? 3a) Do you prioritise development of one or more of these characteristics over others? If so, which ones and why?
Part 3: Training and Drill Prescription	
1. When prescribing drills, how do you determine the planned duration? 2. Do you periodise on-court basketball training? If so, how? 3. What informs your opinion on, and implementation of physical training and development of your athletes? (i.e., people, technology, training/qualifications?)	1a) Are there any tools or people that help this process? 1b) Would accompanying physical performance measures help this? 2a) What is this based on? Why? 2b) How do you stay accountable to your planned periodisation? 3a) What aspects of this do you utilise? Why?

Part 4: Monitoring Athletic Output and Performance	
1. How would you measure or monitor physical performance in basketball training?	1a) Would some of these measures be more suitable for some playing positions than others?
2. While these metrics we discussed may be more individualised, what metrics would help you quantify team/squad performance?	2a) Which metrics would help you assess the quality of a drill or training session? 2b) Would some measures be more suitable for specific drills and not others? If so, why?
3. Thinking about your daily training environment, what metrics/measures would help you forecast and plan training?	3a) Would some measures be suitable for specific drills more than others? If so, why?
4. Thinking of your daily training environment, how would this information be best communicated to you and your coaching staff?	4a) How frequently would you like to receive this information? 4b) Would you prioritise information regarding the squad as a whole or individuals? Why? 4c) To what degree would you rely on such information to inform your training plans?