Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Medicine and Health Sciences
Department of Neuromedicine and Movement Science

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Quantifying External Load and Physical Capabilites in Elite U-16 and U-19 Male Football Players.

Do Elite Academy Players Train as Hard as They Play?

Master's thesis in Physical Activity and Health
Supervisor: Ulrik Wisløff
Co-supervisor: Arnt-Erik Tjønna
May 2022

NTNU
Kunnskap for en bedre verden

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Background

In modern football…

players has been shown to sprint **6-41%** longer distances and partake **4-26** more sprints in match compared to 10 years ago[13]

players uses **high-intense external load** from their worst-case match as **physical targets** to reach during training-week[2]

Methods

Observational cohort study

Subjects: U-16 and U-19 male football players

Catapult GPS system measuring external load in match and training in 2021-season. Measuring Physical capabilities at the end of season.

Aim and hypothesis

Purpose: This study quantifies match load, training load and physical capabilites in elite U-16 and U-19 players.

Main objective: Do elite academy players train as hard as they play?

Hypothesis: we expect that high-intensity running profiles will be higher in match compared to accumulated training load in both teams

Results

Quantification of match load, training load and physical capacity

External load	Match U-16	Match U-19	Diff	Training U-16	Training U-19
Total distance (m)	10767	11241	4%	21434	15325
HIR (m)	376	384	2%	275	279
Sprint (m)	116	140	19%	36	58
90%MV (m)	25	36	36%	1	7
Acceleration (nr)	98	115	16%	233	175
Deceleration (nr)	99	112	12%	213	152

Physiological test	U-16	U-19	Diff
VO_{2MAX} (ml/kg$^{0.75}$/min)	179.9	184.5	4%
Repeated sprint ability (s)	30.1	29.4	1%
30 m Sprint (m)	4.0	4.0	2%
Knee flexion (Nm)	90.6	102.3	9%
Knee Extension (Nm)	154.6	162.7	12%
Velocity (km/h)	30.8	30.9	2%

Do elite academy players train as hard as they play?

TMr of U-16 and U-19 shows

TMr >1	TMr <1
Total distance	High-Intensity-Running,
Acceleration	Sprint
Deceleration	90%MV

Conculusion: In line with hypothesis a mismatch between high-intensity running profiles in training-load and match was observed. Age and positional differnces in physical capacity and external match load was shown.

Information: Thresholds: High-Intesnsity-Running (19.8-25.2km/h), Sprint (>25.2 km/h), Acceleration and deceleration (± >2m/s^2);
Abbreviations: TMr= Training-Match-ratio (Accumulated training load/mean match load).

Refernces:

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List of commonly used abbreviations

GPS	⇒	Global Positioning System
CD	⇒	Central-defender
FB	⇒	Fullback
DM	⇒	Defensive-midfielder
CM	⇒	Central-midfielder
WM	⇒	Wide-midfielder
CF	⇒	Central-forward
U-16	⇒	Under 16 age group
U-19	⇒	Under 19 age group
HSR	⇒	High-Speed-Running
HIR	⇒	High-Intensity-Running
90%MV	⇒	90 % of maximal velocity
RSA	⇒	Repeated Sprint Ability
Δ	⇒	Absolute Mean Difference
cm	⇒	Centimeter
kg	⇒	Kilogram
m	⇒	Meter
s	⇒	Seconds
Nm	⇒	Newton Meter
ns	⇒	Not significant ($p>0.05$)

Abstract

Purpose: The aim was to quantify and compare external load, as well as physical capacities in male elite youth football players.

Methods: Thirty-six elite U-16 (n=18, 15.5years, 174.8cm, 68.8kg, 62.9ml/kg/min, 11.1fat%) and U-19 (n=18, 17.7years, 182cm, 74.4kg, 62.3ml/kg/min) outfield footballers were categorized into playing-positions: central-defender, fullback, defensive-midfielder, central-midfielder, wide-midfielder, central-forwards, wide-players, and central-players. The external load: total distance (m), High-speed-Running (HSR; m, 14.4–19.8km/h); High-Intensity-Running (HIR; m, 19.8–25.2km/h; Sprint distance (m, >25.2km/h); Number of sprints (number); distance >90% individual maximal velocity (>90%MV; m) acceleration (>2m/s^2), and deceleration (>-2m/s^2) was collected during matches and training-sessions with a 10Hz GPS system. External load in match and training and VO_{2MAX}, body composition, bilateral isokinetic knee strength, 30m sprint and 7x30m repeated sprint ability (RSA) were quantified and compared. The training-match ratio (TMr) was calculated in training-weeks with 1- and 2-matches for both teams. Linear mixed model was used in all comparisons.

Results: External match load varied between playing positions for both teams: total distance (0-16%), HSR (11-49%), HIR (22-76%), sprint distance (60-168%), number of sprints (100-168%), acceleration (3-29%), deceleration (8-52%) and >90%MV (81-167%). Mean U-19 player had more total distance (4%), acceleration (16%), deceleration (12%) and distance >90%MV (36%) compared to the mean U-16 player (all, p<0.05). Measured external load was lower in 2-match training-week compared to 1-match training-week (30-126%, p<0.05). Total distance, acceleration and deceleration was >1TMr, whilst HIR, sprint of distance and >90%MV was <1TMr in both training-weeks. Mean U-19 player had greater VO_{2MAX} (3%), knee strength (9%), and RSA (2%) compared to mean U-16 player. Wide-players was faster in maximal velocity (2%), 30m sprint (3%), RSA (1%) compared to central-players who performed better on VO_{2MAX} (4%) and knee strength (10%). Correlation between sprints in match and 30m sprint and RSA was observed in U-16(p<0.05).

Conclusion: Results highlights a mismatch between match load and accumulated training load in running-activities >19.8km/h. Also, positional differences in external match load were observed suggesting individual training specificity. The mean U-19 player had somewhat greater physical capacity, and number of sprints in game strongly correlates with RSA and 30m sprint.

Keywords: Youth football, match load, training load, physical capacity

Sammendrag

Hensikt: Hensikten var å kvantifisere og sammenligne ekstern belastning, i tillegg til fysisk kapasitet hos mannlige elite akademi fotballspillere.

Metode: Trettiseks elite G-16 (n=18, 15.5år, 174.8cm, 68.8kg, 62.9ml/kg/min) og G-19 (n=18, 17.7år, 182cm, 74.4kg, 62.3ml/kg/min, 9.9fett%) utespillere ble kategorisert i posisjoner: midtstopper, sideback, defensive-midtbane, sentral-midtbane, kantspillere, spiss, sentrale-spiller og laterale-spillere. Eksterne belastningen av total distanse (m), høy-hastighets-løp (HSR; m, 14.4-19.8km/t), høy-intensitets-løp (HIR; m, 19.8-25.2km/t), sprint distanse (m, >25.2km/t), antall sprinter (antall >25.2 km/t), distanse over 90% individuell makshastighet (>90%MV; m), akselerasjoner (>2m/s^2), retardasjoner (>-2m/s^2) ble samlet i kamper og treninger med et 10Hz GPS system. Ekstern kamp- og trenings-belastningen og VO_{2MAX}, kroppssammensetning, bilateral isokinetisk knestyrke, 30m sprint og 7x30m repetert sprint test (RSA) ble målt og sammenlignet. Trening-Kamp ratio (TMr) ble kalkulert i treningsuker med 1 og 2-kamper. Lineære blandet modell ble brukt i alle sammenligninger.

Resultat: Ekstern belastning varierte basert på posisjon i begge lag: total distanse (0-16%), HSR (11-49%), HIR (22-76%), sprint distanse (60-168%), antall sprinter (100-168%), akselerasjoner (3-29%), retardasjoner (8-52%) og >90%MV (81-167%). Gjennomsnittlig G-19 spiller hadde mer total distanse (4%), akselerasjon (16%), retardasjon (12%) og distanse >90%MV (36%) sammenlignet med den gjennomsnittlige G-16 spilleren (alle, $p<0.05$). Eksterne belastningen var lavere i 2-kamps-treningsuke sammenligner med en 1-kamps-treningsuke (30-126%, $p<0.05$). Total distanse, akselerasjon og retardasjon hadde >1TMr, i motsetning til HIR, sprint distanse og >90%MV med <1TMr i begge treningsukene. Gjennomsnittlig G-19 spilleren hadde noe bedre VO_{2MAX} (3%), knestyrke (9%) og RSA (2%) sammenlignet med den gjennomsnittlige G-16 spilleren. De laterale-spillerne var kjappere i maksimal hastighet (2%), 30m sprint (3%) og RSA (1%) sammenlignet med de sentrale-spillerne som hadde noe høyere VO_{2MAX} (4%) og knestyrke (10%). Vi observerte en sterk sammenheng mellom antall sprinter i kamp og RSA samt 30m sprint.

Konklusjon: Resultatene fremhever en skjevfordeling mellom kampbelastning og treningsbelastning i aktivitetssonene >19.8km/t. I tillegg fant vi posisjonelle forskjeller i kampbelastning, noe som fremhever viktigheten av trenings spesifisitet. Generelt hadde den gjennomsnittlige U-19 spiller bedre fysisk kapasitet, og antall sprinter i kamp korrelerer sterkt med resultater på RSA og 30m sprint.

Nøkkelord: Akademi fotball, kampbelastning, treningsbelastning, fysisk kapasitet

Introduction

In professional football the primary focus is to increase the chances of good results and winning matches (Larsen et al., 2020). Moreover, professional football clubs aim to develop talented players in a long-term strategy to enhance football-performance and to satisfy sponsors, media, and supporters (Larsen et al., 2020; Buchheit et al., 2010; Flatgård et al., 2020; Larsen et al., 2020). Football-performance is a multifactorial concept, characterized by team-cooperation between eleven players possessing a high-level of individual factors such as technical, tactical, psychological, and physiological attributes (Haugen et al., 2013; Hoff, 2002; Stolen et al., 2012).16/05/2022 04:40:00 Football has a multidirectional intermittent movement and intensity pattern requiring a well-developed aerobic and anaerobic energy systems enabling players to repeatedly perform intense actions throughout the relative extensive match duration (Bradley et al., 2009; Stolen et al., 2012; Vigh-Larsen et al., 2018). Subsequently, a talented young player with his own independent set of physical- and physiological characteristics must possess some degree of physiological, technical, tactical, psychological skills, or show exceptional potential in one to these increase the chances of future success (Buchheit, Mendez-Villanueva, et al., 2010; Flatgård et al., 2020; Fuhre et al., 2022; Larsen et al., 2020).

The physical-capabilities of the players is usually evaluated periodically trough fitness testing with the overall aim to mimic specific fitness requirements and classify anthropometric characteristics, aerobic capacity (VO_{2MAX}), sprint ability and lower limb strength of the players (Silva et al., 2011). Enhanced physical capabilities in endurance, repeated sprint ability (RSA) and sprint-speed might increase chances of future performance level emphasizing the importance of appropriate fitness testing (Gonaus et al., 2019). Although different methods have been used when assessing fitness characteristics of football players, testing of VO_{2MAX}, Repeated Sprint Ability (RSA), maximal sprint tests, and assessment of lower limb isokinetic strength have been proposed (Buchheit, Mendez-Villanueva, et al., 2010b; Chamari et al., 2005; Gonaus et al., 2019; Ingebrigtsen et al., 2012; Silva et al., 2011; Stolen et al., 2012). Appropriate fitness testing facilitates effective adjustments of training load and training interventions tailored to players individual strengths and weaknesses. Moreover, fitness testing allows monitoring of performance improvements and provides comparison-basis to normative values allowing for a more swift transition to future physical load and playing schedules (Gonaus et al., 2019). Training load is typically represented as external and internal load, defined respectively as the physical work done in training and matches (e.g., sprint distance ran), and the associated physiological response (e.g., heart rate response)(Akenhead & Nassis, 2016; Clemente et al., 2019).

The use of Global Positioning Systems (GPS) for tracking and monitoring the external load imposed on players during match scenarios and training has become a prominent tool in recent years (Akenhead & Nassis, 2016; Baptista et al., 2019). When developing youth players, the use of GPS monitoring can help quantify the physical demands of playing-positions and optimizing the individual training load to improve performance, rehabilitation or prevent injuries (Bradley et al., 2010; Buchheit et al., 2021; García et al., 2018; Ingebrigtsen et al., 2015; Stevens et al., 2017). Match running-performance has been shown to vary based on playing-position, tactical configuration, formation, match-score, and level of opposition (Bradley et al., 2010; Mohr et al., 2003; Rampinini et al., 2007; Riboli et al., 2020; Vigh-Larsen et al., 2018)., Although total distance has remained relatively stable at 9-13km, physical demands (external load) has evolved illustrated by quicker Australian academy players (1.2% faster 20m sprint time, 0.05s, between 2002-2015), and increased sprint distance and number of sprints in senior players in English Premier League (41%, 118m, and ↑26 sprints, at >25.2 km/h, between 2006-2012) and Spanish La Liga (6%, 32m and ↑4sprints, at >21 km/h, between 2012-2020) (Barnes et al., 2014; Gonaus et al., 2019; Lago-Peñas et al., 2022). The elite senior players generally perform 10-50 sprints resulting in a sprint distance between 100-700m (>25.2 km/h), which is more sprint distance (~103%) compared to elite youth players, where limited research has stated 70-185m in elite U-17 matches (Al Haddad et al., 2015; Ingebrigtsen et al., 2015; Pettersen & Brenn, 2019; Stolen et al., 2012). Moreover, elite youth-players have similar or even more accelerations and decelerations (70-170) during match when compared to senior players (Lago-Peñas et al., 2022; Pettersen & Brenn, 2019; Vigh-Larsen et al., 2018). Youth players have a maximal speed between 26-35 km/h, with wide-players generally demonstrating the highest velocities (Abbott et al., 2018; Al Haddad et al., 2015; Mendez-Villanueva et al., 2011; Pettersen & Brenn, 2019). Moreover, youth players has 1-3 sprints above 90% of their maximal velocity during match, but the distance traveled at this threshold is absent highlighting the need for further knowledge (Al Haddad et al., 2015; Mendez-Villanueva et al., 2011).

The previous and upcoming matches appear to be the factors most considered when implementing adjustments in training load (Akenhead & Nassis, 2016; Buchheit et al., 2021). The dominant objective within a training-week is injury prevention and performance enhancement, where the days in between matches (turnover length) is the most important factor for weekly programming and training load (Akenhead & Nassis, 2016; Buchheit et al., 2021). Recently, specific high-intensity targets (distance ran >19.8 km/h) based on match reference values has been used to plan the weekly external training load aiming to mimic or exceed the the external load encountered in an intended competitive match (Akenhead & Nassis, 2016; Buchheit et al., 2021). However, with multiple matches it seems to be difficult to replicate the high-intensity activities (e.g., sprint distance) associated with match-play during conventional senior training, evidenced by higher single match-loads compared to accumulated training-week (Clemente et al., 2019; Dalen et al., 2016; Morgans et al., 2018). Moreover, when trying to keep the entire squad healthy, fit, and competitive throughout the entire seasons, compensatory and supplementary work may be needed to reach the specific high intensity targets for all players independent of age, training- and injury history, playing time in match and positional role (Akenhead & Nassis, 2016). The observed increase in physical demands during matches in addition to the importance of straight-line sprinting in match-winning situations requires modern players to possess pronounced speed and capabilities to repeat high-intensity actions (Barnes et al., 2014; Dupont et al., 2010; Faude et al., 2012; García et al., 2018; Gonaus et al., 2019; Lago-Peñas et al., 2022). Moreover, this highlights the necessity for adequate position-specific individualized training in youth players to facilitate development of future physical load (Abbott et al., 2018; Baptista et al., 2019; Meylan et al., 2014; Pettersen & Brenn, 2019).

Therefore, the primary aim of the present study was to quantify and compare the match load with training load in training-weeks with 1 and 2-matches in elite U-16 and U-19 male footballers to possibly answer the question "do elite academy players train as hard as they play?" Secondary we sought to quantify the positional differences in match load and physical capabilities and to compare the latter with the number of sprints in match. We hypothesized that high-intensity activities during match will outperform the accumulated training load, and that there will be a difference in external load between U-16 and U-19 players and playing-positions. Further we expect wide-midfielder to possess most sprint distance, and number of sprints during match. In addition, we hypothesize that the number of sprints during match strongly correlates with RSA.

Methods

Subjects

Eighteen U-16 and eighteen U-19 outfield football players of the highest Norwegian youth category comprised the data in this study. Subject characteristics can be found in Table 1. Investigation has been collected in accordance with the requirements presented in the Declaration of Helsinki. All participants provided written consent for their inclusion in this study, with parental or guardian consent given if the subjects was under 18-years of age.

Table 1: Subject Characteristics

Team	Age	Height	Weight	VO_{2MAX}	Fat %
U-16	15.4 ± 0.5	174.8 ± 9.2	68.8 ± 9.3	62.9 ± 5.0	11.1 ± 3.8
U-19	17.7 ± 1.1	182.0 ± 8.9	74.4 ± 10.9	62.3 ± 5.0	9.9 ± 2.0

Data are presented as mean ± SD. Heigh (cm), Weight (kg), VO_{2MAX} (ml/kg^{1}/min), Fat (%)

Design

An observational cohort study was conducted with data from U-16 and U-19´s respective matches, training-sessions, and physical testing throughout the 2021-season football season (May-December).

External Match and Training Load

The investigated teams played a match every third day (U-16 National League, Norwegian Cup U16/U19, U-18 National League or PostNord League). The U-16 and U-19`s most competitive match-arena (U-16 National League and PostNord League) was included in match data this study. Both teams played in a 4-3-3 formation leading to the following playing-positions: fullbacks (FB), central-defenders (CD), defensive-midfielders (DM), central-midfielders (CM), wide-midfielders (WM) and central-forward (CF). Wide-players (FB+WM) and central-players (CD+DM+CM+CF) will be used in match load and physical test results. Goalkeepers were excluded from the data analysis. Training data was defined as the accumulated external load from one training-week (Monday–Sunday) characterized by the number of matches in that given week. This criterion led to two separate ways of presenting training data: 1-match training-week (mean 5 sessions) and 2-match training-week (mean 4 sessions).

Inclusion and exclusion criteria

Players were included in match-analysis if they played >60min in the same position whilst players that played >60min was extrapolated to calculate their full match estimate (e.g., Sprint distance: [100m/64min]×90=141m), as done previously (Stevens et al., 2017). Each participant only featured in one playing-position per match, however the very same player could be regarded in different positions across matches. At least 3 sessions were present to be regarded as a 1- or 2-match training-week. To be included in the final analysis of training data the sessions had to be completed by the whole team and players had to participating in the full session. Players that were injured, sick or due to other reasons did not partake in full seasons were excluded from that training-session.

Data Collection

External load was obtained by GPS (Catapult X7, Melbourne, Australia) with a sampling frequency of 10 Hz, which has been shown as a reliable and valid method for measuring constant and instantaneous velocities for linear and multidirectional movements (Varley et al., 2012; Castellano et al., 2012; Rampinini et al,.2015). Players wore their own vest (Vector Core Vest) and tracking device (Figure 1) which was tightly placed on between the shoulder blades during every session and match (Catapult Vector X7, 81mm x 43mm x 16mm). GPS validity preview and device specifications are provided in appendices (B and C). The GPS-data were downloaded and stored in NTNU databases following all activities and analyzed in Catapult Openfield Cloud Analytics (Openfield 3.3.1 Build #68050). External load will be described by the following variables: total distance (m); High-Speed-Running (HSR; m, 14.4–19.8km/h); High-Intensity-Running (HIR; m, 19.8–25.2km/h; Sprint distance (m, >25.2km/h); number of sprint (counts, >25.2km/h), acceleration (counts, >2m/s^2); and deceleration (counts, >-2m/s^2). These thresholds were in accordance with the literature (Bradley et al., 2009; Ingebrigtsen et al., 2015). In addition, distance above 90% of individual maximal velocity will be used (>90%MV; m). The maximal velocity was individualized based on the highest speed obtained during the season. The criteria fulfillment for the acceleration and deceleration count were: 1) acceleration reaches a minimum of 2m/s^2, 2) the player must stay above this minimum threshold for 0.6s, 3) the player must leave the acceleration band for a duration of the timeout window (1s) before the player can reach another count. The same criteria are evident for deceleration, only in reverse. These thresholds were standardized by Catapult Sports and in accordance with the literature (Vigh-Larsen et al., 2017).

All outlined external load markers will be used to quantify the load during match and training. The match load is presented as position-specific and team-level with observations in final analysis in Table 2. Training load is presented for team-level with observations in final analysis in Table 5. The relationship between match load and accumulated training load is presented as training match ratio (TMr; formula: Accumulated training load/match load=TMr) and described by total distance, HIR, distance in sprint and >90%MV, and the pooled mean of accelerations + decelerations. The included data on weekly training load was presented at team-level and was calculated by summing all external load markers fulfilling inclusion criteria, with mean sum representing the accumulated training load.

Figure 1: *Illustration of player with Catapult Vector X7 and Vector Core Vest and system (pc - software, vector dock, vest, receiver and combability with watch, tablet, and phone. Pictures from Catapult Vector Brochure Artwork.*

Physical testing

Players performed 7x30m repeated sprint ability, 30m sprint, VO_{2MAX}, body composition (height, weight, and fat percentage) and lower-limb bilateral isokinetic muscle strength (quadriceps and hamstring) at the end of the season (November - December). Since VO_{2MAX} of heavier players tend to be underestimated compared to lighter players when bodyweight is raised to the power of 1 (kg^1), scaled VO_{2MAX} ($ml/kg^{0.75}/min$) was used in analysis whilst VO_{2MAX} ($ml/kg^1/min$) is presented to describe the populations enabling comparisons with other research (Chamari et al., 2005). Participants had at least 48-hours between each test (Test-day 1, 2 and 3) and was told to abstain from strenuous exercise the day before and food intake two hours prior to testing. Test performance results are presented for wide- and central-players and for team-level, with observations in final analysis in Table 7. Although a complete position-specific overview of physical test would be beneficial, limited space resulted in the outlined positional-distinction. Detailed description of test-protocols, equipment and illustrations can be found in Appendix A.

Statistical Analysis

Statistical analysis was performed with SPSS Inc (version 27.0, Chicago, III, USA). Results are presented as mean ± standard deviation (SD), if not otherwise stated in the text. Statistical analysis for match load was performed between each position within the team (e.g., U-16 central-defender vs U-16 fullback), and across teams for similar positions (e.g., U-16 fullback vs U-19 fullback). Statistical analysis in training load was performed between each training-week within the team (e.g., U-16 1-match training-week vs U-16 2-match training-week). Statistical analysis in physical testing was performed between wide- and central-players within the team (e.g., U-16 central-players vs U-16 wide-players), and mean values across teams (e.g., mean value VO_{2MAX} in U-16 vs mean value VO_{2MAX} in U-19). Absolute mean difference (Δ) was used when comparing match load between teams, and when comparing physical test results across teams. A linear mixed model was used to adjust for repeated measurements. The linear mixed model had subject ID as random factor, position or team as fixed factor, and all external load markers as dependent variables. When looking at external match load and physical testing the fixed factor was set as positions whilst the fixed factor was team for external training load. Relationship between the number of sprints in match and the physical testing was established using the Pearson-s Correlations Coefficient (r) and Standard Error of Estimates (S.E.E.) is presented in brackets. Pearson's r was classified as weak (<0.1), modest (0.1-0.3), moderate (0.3-0.5), strong (0.5-0.8) or very strong (0.8-1.0). The level of significance was set to $p<0.05$.

Results

External Match Load in U-16 and U-19

Table 2: Number of match observations and total positional observations included in final analysis

	Observations	
	U-16	**U-19**
Included matches	11	25
Central-defenders	15 (4)	29 (4)
Fullbacks	13 (6)	25 (4)
Defensive-midfielders	12 (4)	8 (2)
Central-midfielders	15 (5)	19 (5)
Wide-midfielders	19 (5)	25 (5)
Central-forwards	9 (2)	17 (3)

Data are presented as number of match observations and the total of all positional observations (separate players).

Positional-specific external match load for U-16

Total distance and High-Speed-Running

The final analyzed match data and distribution of observations can be found in Table 2. Detailed overview of external match load for U-16 can be found in Table 3. Defensive-midfielders covered more total distance than fullbacks (7%), central-defenders (15%), and wide-midfielders (7%), whilst central-defenders had lower total distance compared to all other positions (all, p<0.05). Central-midfielder covered more total distance than the fullbacks (9%), central-defenders (16%), and wide-midfielders (8%, all, p<0.05). Fullbacks (31%) and central-midfielders (26%) had more High-Speed-Running (HSR, 14.4-19.8 km/h, m) compared to defensive-midfielders (both, p<0.05). Central-defender had lower HSR compared to central-midfielders (36%) and center-forwards (28%) (both, p<0.05).

High-Intense-Running and sprint distance

Central-forwards covered more High-Intense-Running (HIR, 19.8-25.2km/h, m), than wide-midfielders (4%), central-midfielders (3%), fullbacks (13%), central-defenders (44%), and defensive-midfielders (64%) (all, p<0.05). Defensive-midfielders (60%) and central-defenders (39%) had lower HIR distances compared to all other positions (p<0.05). Wide-midfielders had more sprint distance (>25.2 km/h, m) than central-forwards (13%, ns), central-midfielders (61%, p<0.05), fullbacks (72%, p<0.05), central-defenders (121%, p<0.05), defensive-midfielders (153%, p<0.05). Central-defenders had lower sprint distance than defensive-midfielders (60%, ns) and all other positions (62-121%, all, p<0.05).

Number of sprints and distance >90%maximal velocity

Wide-midfielders had more sprints than defensive-midfielders, central-midfielders, fullbacks, and central-defenders, whilst defensive-midfielders had fewer number of sprints compared to central-forwards, central-midfielders, fullbacks, and wide-midfielders (all, p<0.05). Wide-midfielder covered more distance >90%MV (m) compared to fullbacks (14%, ns), central-midfielders (58%, ns), central-defenders (58%, ns), central-forwards (62%, p<0.05) and defensive-midfielders (161%, p<0.05). Wide-midfielders (133%) and fullbacks (156%) had more distance >90%MV compared to defensive-midfielders (p<0.05).

Accelerations and decelerations

Central-forwards had more accelerations compared to central-midfielders (3%, ns), wide-midfielders (18%, p<0.05), defensive-midfielders (24%, p<0.05), fullbacks (25%, p<0.05), and central-defenders (29%, p<0.05). Similarly, central-forwards had more decelerations compared to central-midfielders (14%), wide-midfielders (38%), defensive-midfielders (35%), fullbacks (40%), and central-defenders (52%) (all, p<0.05). Apart from the central-forwards, central-midfielders had more accelerations and decelerations compared to all other positions (p<0.05). Central-defenders had fewer decelerations compared to all other positions (p<0.05), and fewer accelerations compared to central-midfielders and central-forwards (p<0.05).

Positional-specific external match load for U-19

Total distance and High-Speed-Running

The detailed overview of external match load for U-19 can be found in Table 3. The highest total distance was observed by defensive-midfielders and central-midfielders covering more total distance than central-defenders (11%), central-forwards (11%) and fullbacks (6%) (all, p<0.05). Central-forwards and central-defenders had lower total distance compared to all positions (p<0.05) apart from each other (ns). Central-midfielders covered more HSR than wide-midfielders (12%), fullbacks (20%), defensive-midfielders (25%), central-forwards (35%), and central-defenders (49%) (all, p<0.05). Wide-midfielder covered more HSR than central-defenders (40%), and central-forwards (23%), but less than the central-midfielders (12%) (all, p<0.05). Wide-midfielders and fullbacks had more HSR than central-defenders (36% and 30%), and central-forwards (15% and 24%) (all, p<0.05). HSR of central-forwards was higher than central-defenders (14%, ns) and lower compared to all other positions (15-35%, p<0.05).

High-Intensity-Running and sprint distance

Wide-midfielder had more HIR than fullbacks (11%, ns), central-midfielders (15%, p<0.05), central-forwards (26%, p<0.05), central-defenders (50%, p<0.05), and defensive-midfielders (79%, p<0.05). Fullbacks had more HIR compared to central-defenders (41%), defensive-midfielders (67%), and central-forwards (17%) (all, p<0.05). Defensive-midfielders had lower HIR than all other positions (29-76%, p<0.05). Wide-midfielders and fullbacks had similar sprint distance (3%, ns) and more sprint distance than central-forwards (48% and 45%), central-defenders (74% and 71%), central-midfielders (91% and 88%), and defensive-midfielders (168% and 167%) (all, p<0.05). Defensive-midfielder had lower sprint distance than all other positions (123-168%), whilst central-defenders had lower sprint distance compared to fullbacks (71%), and wide-midfielders (74%) (all, p<0.05).

Number of sprints and distance >90%maximal velocity

Wide-midfielders had more sprints than central-forwards, central-midfielders, defensive-midfielders, and central-defenders, whilst defensive-midfielder had fewer sprints compared to all other positions (all, p<0.05). Fullbacks had higher distance >90%MV than central-forwards (33%), wide-midfielders (47%, p<0.05), central-defenders (77%, p<0.05), central-midfielders (107%, p<0.05), and defensive-midfielders (155%, p<0.05). Wide-midfielders had more distance >90%MV than defensive-midfielders (131%) and central-midfielders (69%) (both, p<0.05). Defensive-midfielders had lower distance >90%MV than central-midfielders (81%, ns) and all other positions (111-155%, p<0.05).

Accelerations and decelerations

Wide-midfielders had more accelerations than central-midfielder (3%, ns), defensive-midfielders (14%, p<0.05), central-defenders (16%, p<0.05), fullbacks (23%, p<0.05), and central-forwards (26%, p<0.05). Central-midfielders had more accelerations than defensive-midfielders (11%), fullbacks (20%), central-defenders (13%), and central-forwards (23%) (all, p<0.05). Central-forwards had lower accelerations than fullbacks (11%, ns) and compared to all other positions (19-26%, p<0.05). Central-midfielders had more decelerations than wide-midfielder (4%, ns), defensive-midfielders (5%, ns), fullbacks (21%, p<0.05), central-defenders (25%, p<0.05), and central-forwards (33%, p<0.05). Wide-midfielders had more deceleration than fullbacks (17%), central-defenders (21%), and central-forwards (29%) (all, p<0.05). Defensive-midfielders had more decelerations than central-forwards (28%) and central-defenders (20%) (both, p<0.05). Central-defenders had fewer decelerations than fullbacks (4%, ns) and compared to all other positions (8-25%, p<0.05).

Table 3: Quantification of position-specific external match load in U-16 and U-19 elite youth male footballers

	Variable	Mean ± SD		P<0.05		Range	
		U-16	U-19	U-16	U-19	U-16	U-19
CD	**Total distance**	9830 ± 599	10566 ± 527	*‡ β*	*bcde β*	8883-11013	8928-11520
	HSR	429 ± 60	408 ± 75	*df*	*‡*	294-515	278-603
	HIR	288 ± 94	284 ± 62	*ac*	*‡*	105-392	165-416
	Sprint	52 ± 43	100 ± 41	*acef β*	*bce β*	0-131	39-184
	>90%MV	21 ± 25	28 ± 25	*c*	*bcef*	0-80	0-96
	Acceleration	87 ± 14	111 ± 14	*df β*	*bdef β*	68-112	87-146
	Deceleration	80 ± 8	100 ± 12	*‡ β*	*cdef β*	66-91	74-123
	Nr of Sprints	6 ± 2	5 ± 3	*bdef β*	*bce β*	0-8	0-18
FB	**Total distance**	10556 ± 789	11207 ± 486	*acd β*	*‡ β*	8991-11693	10473-12207
	HSR	652 ± 474	550 ± 110		*adf*	281-1861	395-791
	HIR	396 ± 111	429 ± 93	*adef*	*acf*	220-589	248-626
	Sprint Distance	99 ± 41	211 ± 143	*bdef β*	*acdf β*	30-183	10-538
	>90%MV	33 ± 28	63 ± 45	*c β*	*acde β*	0-81	0-162
	Acceleration	91 ± 15	103 ± 11	*df β*	*acde β*	66-114	73-125
	Deceleration	91 ± 15	104 ± 12	*adf β*	*def β*	59-126	84-128
	Nr of Sprints	3 ± 3	10 ± 6	*ace β*	*ace β*	1-9	0-24
DM	**Total distance**	11338 ± 811	11839 ± 706	*abe*	*abf*	10074-12588	10834-13218
	HSR	477 ± 123	524 ± 100	*d*	*ad*	309-722	363-666
	HIR	231 ± 95	213 ± 73	*bdef*	*‡*	108-390	128-376
	Sprint Distance	28 ± 23	19 ± 21	*bdef*	*‡*	0-82	0-44
	>90%MV	4 ± 8	8 ± 9	*abde*	*abef*	0-25	0-36
	Acceleration	92 ± 11	113 ± 11	*df β*	*bdef β*	73-111	94-123
	Deceleration	95 ± 17	122 ± 18	*adf β*	*af β*	67-120	87-142
	Nr of Sprints	1 ± 1	1 ± 1	*bdef β*	*‡ β*	0-3	0-1
CM	**Total distance**	11530 ± 710	11763 ± 894	*abe*	*Abf*	10124-12522	10258-14271
	HSR	618 ± 152	675 ± 158	*ac*	*‡*	276-809	383-974
	HIR	434 ± 75	406 ± 114	*ac*	*Ace*	323-604	201-668
	Sprint Distance	112 ± 52	82 ± 46	*ace*	*Bcef*	33-210	0-169
	>90%MV	21 ± 24	19 ± 20	*ce*	*be*	0-82	0-72
	Acceleration	113 ± 11	126 ±19	*abce β*	*abcf β*	100-140	86-172
	Deceleration	122 ± 10	128 ± 22	*‡ β*	*abf β*	98-132	86-173
	Nr of Sprints	3 ± 1	5 ± 3	*ace*	*bce*	2-9	0-13
WM	**Total distance**	10659 ± 912	11568 ± 686	*acd β*	*af β*	9139-12432	9445-12478
	HSR	575 ± 506	599 ± 99		*adf*	296-2604	421-767
	HIR	434 ± 181	473 ± 126	*ac*	*acdf*	269-1047	89-714
	Sprint Distance	210 ± 73	218 ± 117	*abcd*	*cdef*	67-321	25-466
	>90%MV	20 ± 34	45 ± 53		*c*	0-90	0-196
	Acceleration	98 ± 19	130 ± 15	*df β*	*abcf β*	67-131	108-162
	Deceleration	93 ± 16	123 ± 24	*adf β*	*abf β*	68-121	80-173
	Nr of Sprints	11 ± 5	11 ± 5	*abcd*	*acdf*	4-24	3-22
CF	**Total distance**	10971 ± 996	10566 ± 609	*a*	*bcde*	8823-12194	9471-11669
	HSR	569 ± 93	472 ± 98	*a β*	*abdf β*	474-792	357-699
	HIR	449 ± 91	363 ± 104	*ac β*	*abce β*	314-624	196-549
	Sprint Distance	184 ± 101	133 ± 70	*abc*	*bcde*	62-380	14-250
	>90%MV	25 ± 27	36 ± 38	*β*	*β*	0-98	0-196
	Acceleration	117 ± 10	100 ± 13	*abce β*	*acde β*	103-137	69-129
	Deceleration	136 ± 19	92 ± 12	*‡ β*	*‡ β*	101-170	65-109
	Nr of Sprints	9 ± 5	7 ± 4	*ac*	*ce*	1-18	1-13

Data presented as mean ± SD and range, minimal-maximal value. *Significance is presented as comparisons between positions within team, and similar positions across teams. Total distance, High-Speed-Running, High-Intensity-Running, sprint distance and >90%MV are in meters, acceleration, deceleration and number of sprints are counts. Abbreviations: CD=Central-defender; FB=Fullback; DM=Defensive-midfielder; CM=Central-midfielder; WM=Wide-midfielder; CF=Central-forward; >90%MV=distance >90% max velocity; Nr of Sprints=Number of sprints; a=significant vs CD; b=significant vs FB; c=significant vs DM; d=significant vs CM; e=significant vs WM; f=significant vs CF; ‡=significant vs all positions;* β=significant vs similar position from other team

Comparison of external match load between U-16 and U-19

The mean external match load for U-16 and U-19 is displayed in Table 4. Similar HSR was observed between the teams, however, the mean U-19 player covered more total distance (4%), acceleration (16%), deceleration (12%) and distance >90%MV (36%) than the mean U-16 player (all, p<0.05). The U-19 player had more HIR (2%, ns), sprint distance (19%, ns), number of sprints (16%, ns) than the mean U-16 player. The HSR, HIR and sprint distance contributed to 4%, 2% and 0.5% (U-16) and 6%, 4% and 2% (U-19) of the total distance, respectively.

U-19 fullbacks had more total distance (6%, Δ650m, p<0.05), HIR (8%, Δ33m, ns), sprint distance (72%, Δ112m, p<0.05), acceleration (13%, Δ12counts, p<0.05), decelerations (14%, Δ13counts, p<0.05), distance >90%MV (62%, Δ30m, p<0.05) and number of sprints (108%, 4Δ, p<0.05) compared to U-16 fullbacks. U-16 fullbacks had 13% higher HSR (Δ75m, ns) compared to U-19 fullback. U-19 central-defender had higher total distance (7%, Δ736m), sprint distance (63%, Δ48m), acceleration (25%, Δ24counts), decelerations (24%, Δ20counts), and number of sprints (18%, 3Δ) (all, p<0.05). U-16 central-defenders had higher HSR (45%, Δ21m, ns) compared to U-19 central defenders, but similar distance >90%MV and HIR was observed. U-19 defensive-midfielders had higher total distance (4%, Δ501m, ns), sprint distance (37%, Δ9m, ns), acceleration (20%, Δ21counts, p<0.05), deceleration (25%, Δ27 counts, p<0.05), distance >90%MV (79%, Δ5m) and number of sprints (0%, 1Δ, p<0.05), whilst HSR (9%, Δ47m) and HIR (8%, Δ18m, ns) was higher for the U-16 defensive midfielders.

U-19 central-midfielders has higher total distance (2%, Δ232m, ns), HSR (9%, Δ57m, ns), acceleration (13%, Δ13 counts, p<0.05) and deceleration (11%, Δ11 counts, p<0.05) and number of sprints (50%, Δ2, ns), whilst U-16 central-midfielders has higher HIR (7%, Δ28m, ns) and sprint distance (32%, Δ30m, ns) with similar distance >90%MV. U-19 wide-midfielders has a higher total distance (8%, Δ99m, p<0.05), HSR (4%, Δ25m, ns), HIR (9%, Δ39m, ns), sprint distance (4%, Δ8m, ns), acceleration (28%, Δ32 counts, p<0.05), decelerations (28%, Δ32 counts, p<0.05), and similar number of sprints and distance >90%MV. U-19 central-forwards had lower total distance (4%, Δ405m, ns), HSR (19%, Δ98m, p<0.05), HIR (21%, Δ86m, p<0.05), sprint distance (32%, Δ51m, ns), acceleration (16%, Δ17counts, p<0.05), deceleration (38%, Δ43counts, p<0.05) and number of sprints (25%, Δ2, ns), whilst U-19 central-forwards has more distance >90%MV (77%, Δ25m, ns).

Table 4: Mean values of external match load in U-16 and U-19 elite youth male footballers

Variable	Mean ± SD		P<0.05		(Range)	
	U-16	U-19	U-16	U-19	U-16	U-19
Total distance	10767 ± 957	11241 ± 827	*β*	*β*	8823-12587	8928-14270
HSR	555 ± 332	551 ± 147			276-2604	278-974
HIR	376 ± 140	384 ± 125			105-1047	89-714
Sprint Distance	116 ± 86	140 ± 110			0-380	0-538
>90%MV	25 ± 27	36 ± 38	*β*	*β*	0-98	0-196
Acceleration	98 ± 18	115 ± 19	*β*	*β*	66-140	69-172
Deceleration	99 ± 22	112 ± 22	*β*	*β*	59-170	65-173
Number of Sprints	6 ± 5	7 ± 5			0-24	0-24

Data are presented as mean ± SD and range minimal-maximal value. Significance reported between teams. Total distance, High-Speed-Running, High-Intensity-Running, sprint distance and >90%MV are presented in meters and acceleration, deceleration and number of sprints are counts: β= significant vs other team.

External Training Load in U-16 and U-19

Table 5: Number of training sessions, weeks and total observations included in final training load analysis.

	1-match training-week		2-match training-week		Total files	
	U-16	U-19	U-16	U-19	U-16	U-19
Sessions	14	19	7	26	32	56
Weeks	3	5	2	8	8	15
Observations	27	41	31	76	73	142

Data are presented as number of included sessions, weeks, and observations in training data. Abbreviations: n=number of training-weeks in 1-Match and 2-Match training-weeks.

Quantification of external training load in U-16 and U-19

The final analyzed training data can be found in Table 5. The quantification of external load in 1 and 2-match training-weeks for the U-16 and U-19 are displayed in Table 6. For U-16 the external load in 1-match training-weeks was higher compared to 2-match training-weeks in total distance (39%), HIR (73 %), sprint distance (126%) accelerations (30%) and deceleration (32%) (all, $p<0.05$). For U-19 the external load in 1-match training-weeks was higher compared to 2-match training-weeks in total distance (28%), HIR (65%), sprint distance (75%), acceleration (41%), deceleration (47%) ($p<0.05$). Apart from distance >90%MV, all external load markers were lower in 2-match- compared to the 1-match training-weeks($p<0.05$).

Table 6: Quantification of External Training-Load

	Week	Mean ± SD		P<0.05		Range	
		U-16	U-19	U-16	U-19	U-16	U-19
Exposure time	**1Match**	05:26 ± 00:20	04:50 ± 00:50				
	2Match	05:11 ± 01:31	04:46 ± 00:45				
Total distance	**1Match**	25605 ± 4725	17504 ± 5190	‡	‡	18188-33693	9107-28079
	2Match	17262 ± 2519	13145 ± 3091	‡	‡	12724-21237	8906-19940
High-Intensity Running	**1Match**	375 ± 135	369 ± 200	‡	‡	184-691	49-857
	2Match	175 ± 98	189 ± 108	‡	‡	65-467	34-604
Sprint distance	**1Match**	70 ± 51	79 ± 93	‡	‡	10-223	0-410
	2Match	16 ± 34	36 ± 40	‡	‡	0-149	0-162
Acceleration	**1Match**	268 ± 59	210 ± 88	‡	‡	186-418	73-418
	2Match	198 ± 32	139 ± 56	‡	‡	126-249	54-280
Deceleration	**1Match**	247 ± 59	187 ± 77	‡	‡	137-401	60-375
	2Match	179 ± 39	116 ± 52	‡	‡	124-265	26-276
Distance >90%MV	**1Match**	1 ± 6	10 ± 19			0-29	0-92
	2Match	1 ± 4	4 ± 9			0-17	0-41

Data are presented as mean ± SD, range, minimal-maximal value. Significance comparison of training-week within team. Exposure time is given in h: min, total distance, High-Intensity-Running, sprint distance, >90%MV in meters and acceleration and deceleration as counts. Abbreviations: 1Match= 1-match training-week; 2Match= 2-match training-week; ‡=Significant vs different training-week. ‡= significant vs other training-week in same team.

Quantification of Training-Match-ratio in U-16 and U-19

The Training-Match-ratio (TMr) is displayed in Figure 3. The accumulated training load of total distance, acceleration, and deceleration was higher in 1-match training-weeks and 2-match training-weeks compared to the respective match reference for both teams (both, TMr >1). Accumulated training load of HIR was lower in 2-match training-weeks (TMr 0.5), whilst 1-match training-weeks was equal to match reference value for U-16 (TMr 1). For the U-19 the accumulated training load of HIR was lower in 1-match training-weeks (TMr 0.9) and 2-match training-weeks (TMr 0.5). The accumulated training distance in sprint and >90%MV was lower compared to match reference value for both teams (all, TMr <1).

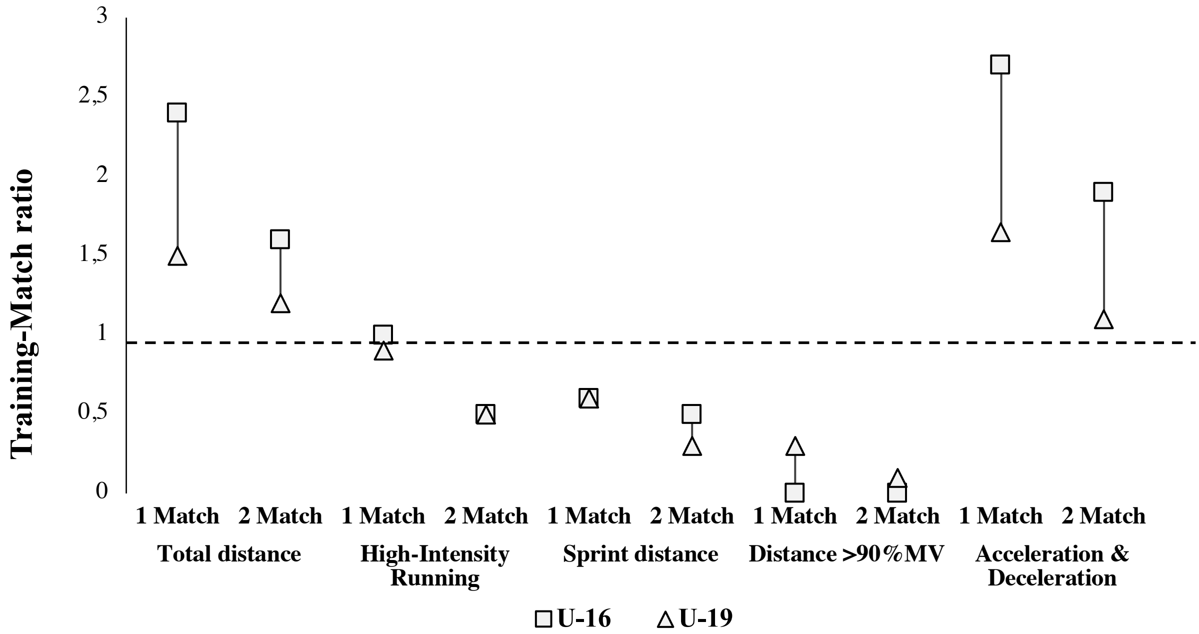


Figure 3: *Training-Match ratio of external load in training weeks with 1 and 2-matches. Acceleration & Deceleration= pooled mean; distance >90%MV=distance >90% max velocity; 1 Match=training-week with 1 match; 2 Match= training-week with 2 matches; Dotted line=mean match reference.*

Physical testing

Table 7: Number of observations included in final physical testing

	Wide-players		**Central-Players**		**Total files**	
	U-16	**U-19**	**U-16**	**U-19**	**U-16**	**U-19**
VO_{2MAX} ($ml/kg^{0.75}/min$)	9	3	8	9	17	14
Repeated sprint ability (s)	5	4	4	10	9	14
30m Sprint (s)	7	4	4	10	11	14
Knee Flexion (Nm)	7	5	7	7	14	12
Knee Extension (Nm)	7	5	7	7	14	12
Maximal velocity (km/h)	9	5	10	11	19	16

Data are presented as number of separate player observations included in physical test final analyzed data. Total files are presented as number of separate player observations. Abbreviations: VO_{2MAX}*=Maximal oxygen uptake; RSA=Repeated Sprint Ability; Knee Flexion=Isokinetic strenght of hamstrings; Knee Extension=Isokinetic strenght of quadriceps.*

Quantification of physical test results and maximal velocity in U-16 and U-19

The final analyzed physical data can be found in Table 7 above. The quantification of physical tests and maximal velocity in U-16 and U-19 are displayed in Table 8 below. In U-19 the wide-players were faster in 30m sprint (3%, $p<0.05$) compared to central-players. Similar results were observed between the mean U-16 and U-19 players in VO_{2MAX} (3%), 30m sprint (0%) and RSA (2%), however the mean U-19 player had higher knee flexion (12%) and knee extension (5%), compared to the mean U-16 players (all, ns). Although the results were similar, U-16 central-players had somewhat higher results in VO_{2MAX} (3%), knee flexion (2%), knee extension (4%), and slower 30m sprint (2%) and RSA (2%) compared to U-16 wide-players (all, ns). U-19 wide-players had lower VO_{2MAX} (6%), knee flexion (15%), knee extension (19%) (all, ns). U-19 players were marginal faster (0-3%) than the U-16 players in all positions apart from the central-forwards were the U-16 players were faster (5%, all, ns). Wide-midfielder was faster than other positions in both teams (ns).

Table 8 Quantification of physical test results for central and wide-players in U-16 and U-19.

		Mean ± SD U-16	Mean ± SD U-19	Δ Mean difference	Range U-16	Range U-19
VO2MAX ($ml/kg^{0.75}/min$)	**Wide**	182.6 ± 12.4	177.4 ± 15.1	5.2	157.5 – 197.4	160.4 – 193.9
	Central	176.8 ± 16.5	188.5 ± 10.6	6.8	154.1 – 202.9	170.8 – 204.2
	Mean	179.9 ± 14.3	184.5 ± 13.2	4.7	154.1 – 202.9	160.4 - 204.2
Repeated sprint ability (s)	**Wide**	29.8 ± 1.0	29.4 ± 0.3	0.3	28.4 – 31.1	29.1 – 29.7
	Central	30.4 ± 1.8	29.5 ± 0.6	1.0	28.4 – 32.6	28.8 – 30.5
	Mean	30.1 ± 1.4	29.4 ±0.5	0.6	28.4 – 32.6	28.8 – 30.5
30m Sprint (s)	**Wide**	4.0 ± 0.1	3.9 ± 0.0	0.1	3.9 – 4.2	3.9 – 4.0
	Central	4.1 ± 0.3	4.0 ± 0.1	0.1	3.9 – 4.5	3.9 - 4.2
	Mean	4.0 ± 0.2	4.0 ± 0.1	0.0	3.9 – 4.5	3.9 – 4.2
Knee Flexion (Nm)	**Wide**	91.5 ± 18.9	93.8 ± 8.3	2.3	72.2 – 114.4	80.6 – 102.5
	Central	89.8 ± 20.1	108.5 ± 25.0	12.1	63.7 – 114.4	72.5 – 134.9
	Mean	90.6 ± 18.7	102.3 ± 20.6	11.7	63.7 – 114.4	72.5 – 134.9
Knee Extension (Nm)	**Wide**	158.0 ± 23.0	144.7 ± 7.3	13.3	128.9 – 192.2	140.7 – 157.5
	Central	151.2 ± 34.8	175.6 ± 37.8	19.4	92.8 – 192.2	122.1 – 216.4
	Mean	154.6 ± 28.6	162.7 ± 32.4	8.1	92.8 – 192.2	122.1 – 216.4
Maximal velocity (km/h)	**CD**	31.4 ± 2.3	31.6 ± 0.7	0.2	28.8 – 32.7	31.3 – 32.4
	FB	30.1 ± 2.0	30.9 ± 0.1	0.7	27.9 – 32.7	30.8 – 31.0
	DM	29.1 ± 2.9	30.0 ± 1.7	0.9	27.2 – 32.4	28.8 – 31.2
	CM	30.3 ± 1.3	30.3 ± 0.7	0.1	29.3 – 31.2	29.6 – 31.2
	WM	31.6 ± 1.8	31.8 ± 1.9	0.2	28.8 – 33.7	30.7 – 34.0
	CF	32.0 ± 0.0	30.6 ± 1.4	1.4	32.0 - 32.0	29.6 – 31.6
	Wide	31.0 ± 1.9	31.5 ± 1.4	0.5	27.9 - 33.7	30.7 – 34.0
	Central	30.6 ± 2.1	30.7 ± 1.0	0.1	27.3 – 32.7	28.8 – 32.4
	Mean	30.8 ± 2.0	30.9 ± 1.2	0.1	27.3 – 33.7	28.8 – 34.0

Data are presented as mean ± SD, mean difference between teams and range of minimal-maximal value. Abbreviations: VO_{2MAX} =Maximal oxygen uptake; 30m Sprint=30 meter sprint; Knee Flexion=Isokinetic strenght of hamstrings; Knee Extension=Isokinetic strenght of quadriceps; Wide=Wide-players; Central=Central-players; CD=Central-defender; FB=Fullback; DM=Defensive-midfielder; CM=Central-Midfielder; WM=Wide-Midfielder; CF=Central-forward; Wide=Wide-players; Central=Central-players;

Relationship between physical test results and number of sprints in U-16 and U-19 matches

The relationship between physical test results and number of sprints in match is observed in Figure 4. For RSA a strong correlation was observed between number of sprints in match for U-16 ($p<0.05$, S.E.E.=1.4s), whilst no relationship was present in U-19 (S.E.E.=0.6s). In U-16 (S.E.E.=14.7ml/kg$^{0.75}$/min) a moderate correlation was observed between number of sprints in match and VO_{2MAX} whilst a modest relationship was present in U-19 (S.E.E.=13.8ml/kg$^{0.75}$/min). In 30m sprint U-16 ($p<0.05$, S.E.E.=0.2s) correlated strongly, whilst U-19 (S.E.E.=0.1s) had moderate associations with number of sprints in match. The relationship between number of sprints in match and knee extension correlated moderately in the U-16 (S.E.E.=27.9Nm) and modest in the U-19 (S.E.E.=27.9Nm).

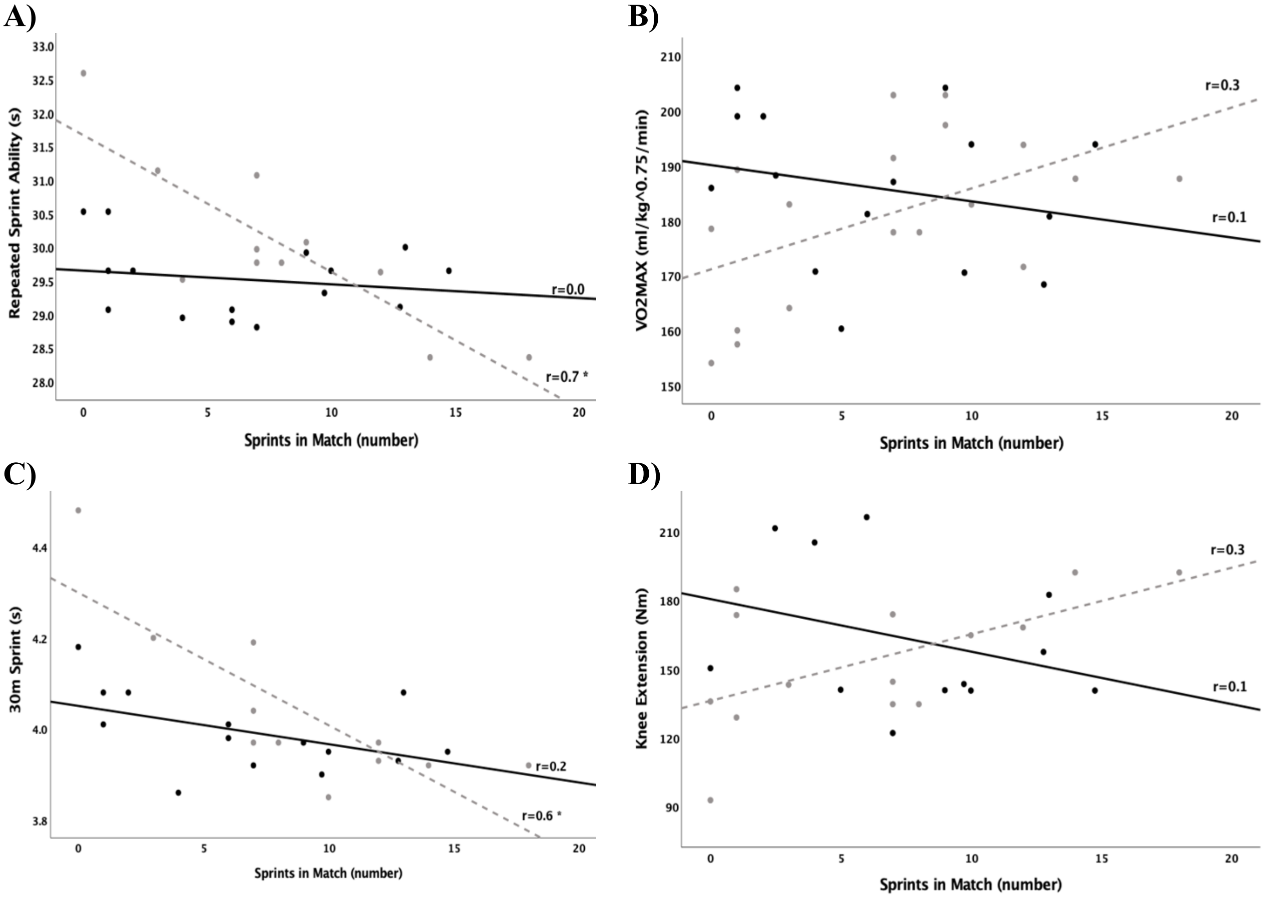
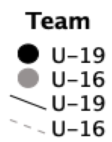


Figure 4: *Linear regression between physical testing: Repeated sprint ability (A); VO_{2MAX} (B); 30m sprint (C); Knee Extention (D); and number of sprints during match in U-16 and U-19 players. Note: r= Pearsons r; statsistical significance p<0.05 is marked by *.*



Discussion

The primary aim of the present study was to compare match load and training load in training-weeks with 1- and 2-match training-weeks to possibly answer the question "do elite academy players train as hard as they play?" The main findings of the present study were in line with our hypothesis that the accumulated training load was affected by the number of matches within the week and that accumulated training load of HIR, sprint distance and distance >90%MV during the training-week were lower than the reference value of a match. Secondary the present study sought to quantify the positional differences in match load and physical capabilities and to compare the latter with the number of sprints in match. In line with hypothesis the external match load differed based on playing-position and team-level, and wide-midfielders possessed the most sprint distance and number of sprints in both teams. Moreover, U-19 players had somewhat higher physical capabilities compared to U-16 players, whilst the wide-players generally had better results on RSA, 30m sprint and velocity, and lower results on VO_{2MAX}, and knee strength compared to central-players. Lastly, strong, and moderate correlations between number of sprints in match and 30m sprint and RSA were observed for the U-16 and U-19, respectively.

Comparisons of external match load in U-16 and U-19 players

We observed that U-19 players had higher external match load compared to the U-16-players in total distance (4%, U-19, 11241m vs. U-16, 10767m), HIR (2%, 384m vs. 376m), sprint distance (19%, 140m vs. 116m), >90%MV (36%, 25m vs. 36m), acceleration (16%, 98 vs. 115), deceleration (12%, 99 vs. 112m), and number of sprints (16%, 7 vs. 6). These findings are for the most similar to what has been reported in elite U-23 Premier League players and elite Norwegian U-17 players (Abbott et al., 2018; Pettersen & Brenn, 2019). However, our HIR observations from U-16 and U-19 were substantially lower compared to elite U-17 players (70%, 380m vs. 788m). Moreover, maximal velocity does not explain the observed differences in HIR since our players were 5% faster (maximal velocity) in contrast to the comparable U-17 players (Pettersen & Brenn, 2019). Therefore, differences in playing style, match observations or GPS systems may be more plausible explanations to the outlined discrepancies. We did not compare acceleration and decelerations across different studies since research has observed variations and between-units variability, although 10Hz GPS systems have been shown to be sensitive in detecting changes in performance (Buchheit et al., 2014; Varley et al., 2011).

Positional differences of external match load in U-16 and U-19 players

The distinct activity profiles observed across positions are similar to those seen in other youth football studies (Abbott et al., 2018; Pettersen & Brenn, 2019). Generally, wide-players have been shown to have more sprint distance, acceleration and deceleration compared to central players, whilst central midfielders generally has the highest total distance (Abbott et al., 2018; Pettersen & Brenn, 2019). Similar to this central-midfielders (U-16) and defensive-midfielders (U-19) had the most (~11600m), whilst central-defenders had the least total distance (~10100m) in both teams in line with other studies (~8974-13867m) (Abbott et al., 2018; Pettersen & Brenn, 2019). The literature has reported lower HIR and sprint distance (HIR; ~250m ; sprinting: ~40m) in central-defenders compared to the other positions (Abbott et al., 2018; Pettersen & Brenn, 2019). Although central-defenders were shown to have the second-lowest HIR(~286m) and sprint distance(~76m), defensive-midfielders had the lowest amount of HIR (~222m) and sprint distance (~24m) in our U-16 and U19 observations. The positional distinction of defensive-midfielder in our study might explain the difference between our findings and the literature, were midfielder position often is comprised of central/defensive and offensive midfielders as one position (Abbott et al., 2018; Pettersen & Brenn, 2019; Vigh-Larsen et al., 2018). Moreover, the present defensive midfielder has a higher responsibility to control the play and balancing the team when attacking, whilst possessing a limited space to accumulate higher velocities. On the other hand, present central-midfielders has a more flexible role producing stretched runs in behind, whilst also balancing offensive and defensive responsibility.

Wide-midfielders and central-forwards had the most distance at HIR and sprinting (HIR~950m; sprint distances~184m) in elite U-17 players, with researchers arguing that their role to run in behind enemy lines accumulates more HIR and sprint distance compared to other positions (Pettersen & Brenn, 2019). (Pettersen & Brenn, 2019). This was somewhat in line with our observations; however, we found a substantial difference in HIR between our U-16 and U-19 central-forwards (21%, 449m vs. 363m). These observations might be explained by the difference in maximal velocity (5%, Δ1.4 km/h) favoring the U-16 central-forward, as well as individual playing styles, tactical differences, and level of opposition between U-16 and U-19 central-forwards. Interestingly, it might suggest an increased responsibility to run in behind opposition lines in the U-16 central-forward compared to the U-19 central forward who possibly might partakes in more build-up play. In line with our hypothesis, wide-midfielders had the most sprint distance (~214m) and number of sprint (~11) in both teams, in accordance with the literature where the rationale is that they operate on the flanks and thereby has more space to produce stretched runs in behind (Abbott et al., 2018). On top of that, wide-players had higher number of sprints (~11 vs. ~5), a slightly higher maximal velocity and performed somewhat better on speed-related tests (RSA ~2%, 30m sprint, ~3%) compared to central-players.

Although we did not quantify percentage of maximal speed in match, elite youth players have been shown to reach 80-92% of maximal sprint-speed in matches. (Buchheit et al., 2020; Al Haddad et al., 2015; Mendez-Villanueva et al., 2011). Moreover, we observed that U-16 and U-19 players covered ~20m >90%MV during match. Interestingly, fullbacks from U-16 and U-19 teams were one of the slowest positions (30.1 km/h, and 30.9 km/h) whilst having the highest distance >90%MV in both cohorts (33m and 63m). This might be due to the fullbacks compensating for their relative lower maximal velocity by using a higher percentage of it when competing against faster players (wide-midfielders), supported by a study reporting slower players running 3-7% closer to their maximal-speed (Al Haddad et al., 2015). Previous research on senior footballers have reported similar positional-differences in total distance, accelerations and decelerations, but generally higher HIR, sprint distance and sprints (Barnes et al., 2014; Bradley et al., 2010; Di Salvo et al., 2010; Ingebrigtsen et al., 2015). Although interesting, comparisons between our findings and senior populations is beyond the scope of this study.

Do elite academy players train as hard as they play?

The elite senior match load serves as indications of future match load expectations for youth players. The higher distance at high-intensity activities (>19.8km/h) observed in senior players during match, highlights the necessity for adequate position-specific training to facilitate development of appropriate aerobic and anaerobic characteristics coping with the physical load imposed in senior football (Abbott et al., 2018; Baptista et al., 2019; Meylan et al., 2014; Pettersen & Brenn, 2019). In line with our hypothesis the 1-match training-week had higher total distance (~54%), HIR (~83%), sprint distance (~115%), distance >90%MV (~43%), accelerations (~36%) and decelerations (~40%) than 2-match training-week for both teams. Moreover, the observed difference between the external load might be explained by the difference in turnover length and training sessions were 2-match training-week had one training-session less compared to the 1-match training-week (U-16, 5 vs. 4 and U-19, 4 vs. 3). Other similar study designs are to the authors knowledge not present, making direct comparisons difficult. However, in senior Champions League players, no significant differences in total distance, HIR and sprint distance between 1 and 2-matches training-weeks was observed (Oliveira et al., 2019). When comparing 1 and 2-match training-weeks to the present youth population (senior vs. mean of U-16 and U-19) senior players seem to have somewhat similar total distance, but higher HIR (60% and 125%) and sprint distance (83% and 155%) with more pronounced differences in a 2-match training-week (Oliveira et al., 2019). Although speculations, these differences may be related to differences in exposure time, a possible higher load-tolerance and closer monitoring of external load in the senior population compared to youth players.

Multiple games per week may restrict the opportunities to achieve a relative high accumulated training load, since it is argued that a turnover length of minimum 5-days is required to produce high training loads for physical stimulations whilst yielding positive adaptations (Buchheit et al., 2021; Dupont et al., 2010; Malone et al., 2019; Stevens et al., 2017). This implies that 1-match training-week would have sufficient turnover days to produce an overall higher accumulated load, whilst 2-match training-week possibly favors lower overall load to limit the fatigue towards the upcoming match. However, our TMr in both training-weeks had higher accumulation of total distance, acceleration, and deceleration (TMr>1), whilst the accumulated load of HIR, sprint distance and 90%MV on the other hand was lower compared to the match reference (TMr<1). Our study is to the authors knowledge the first study to present distance >90%MV in training-weeks with 1 and 2-matches in elite youth players. The U-19 players was faster and bigger compared to the mean U-16 player, but the pitch size remains the same for both. It can therefore be argued that U-16 would have more distance >90%MV, due to a higher relative space, and that slower (younger) players tend to reach higher relative speeds (Al Haddad et al., 2015). However, we observed that U-19 players had somewhat more distance >90%MV, although both our cohorts had low accumulation (~1m and ~7m) in both training-weeks. Thus, the present findings highlight a mismatch between external match load and accumulated training load of HIR, sprint distance and distance >90%MV and suggests that elite youth players may not be ready when their worst-case match arises.

When aiming to keep the entire squad fit, healthy, and competitive throughout the season the use of individualized physical targets to mimic or exceed the external physical load encountered in an intended match is used to plan weekly training load (Akenhead & Nassis, 2016; Buchheit et al., 2021; Stevens et al., 2017). Moreover, due to the importance of repeatedly performing high-intense actions throughout the extensive match duration practitioners should place a special emphasis on replicating the intense accelerations and high-intense activities in match (Akenhead & Nassis, 2016; Buchheit, Mendez-Villanueva, et al., 2010b). The upper range observed of these external load markers (e.g., sprint distance) serves as the position-specific worst-case match reference, which means that the entire squad should theoretically be physically capable of producing individual values. In the attempt to mimic or exceed the observed match-load, short-sided-games (4v4) is frequently being used in training, characterized by a high degree of ball involvements and high intensity movements with multiple changes of directions, producing high cardiovascular stimuli as well as total distance, accelerations and decelerations, but limited distances at higher intensities (Dalen et al., 2019; Hoff, 2002). Importantly, exceeding individual match reference values during the training-week through external load manipulation (e.g., sprint distance TMr>1) may not always be plausible, however ensuring that each available player is competitive in the upcoming match should be prioritized.

Physical testing

The physical fitness results of our U-16 and U-19 are in accordance with results reported on other similar elite youth populations (Buchheit, Mendez-Villanueva, et al., 2010a; Chamari et al., 2005; Gonaus et al., 2019). We observed the older players to have somewhat greater physical capabilities since the U-19 players had higher aerobic capacity (VO_{2MAX} ~3%), was stronger (peak torque in knee extension ~5% and knee flexion ~12%), faster (maximal velocity ~1%, RSA ~2%, 30m sprint ~1%), and possibly also exhibiting greater metabolic-, and neuromuscular capabilities all favoring enhanced match-running performance in U-19 compared to U-16 players (Bishop et al., 2011; Buchheit, Mendez-Villanueva, et al., 2010b; Gonaus et al., 2019; Stolen et al., 2012). These age-related physical differences may be explained by older players (U-19 vs. U-17 vs. U-16), having participated in more organized professional specific training and generally being taller and heavier. Wide players had higher maximal velocity (~2%) and were faster on 30m sprint (~3%) and RSA (~1%) compared to central players in our study, similar to findings from the literature (Buchheit, Mendez-Villanueva, et al., 2010b). Moreover, central-players performed somewhat better on VO_{2MAX} (~4%) and knee strength (~10%). The observed physical test results may contribute to explain some of the positional and age-related differences we observed in the present study, since better results on RSA, VO_{2MAX} and sprint test have been shown to produce more high-intensity running in match (Buchheit, Mendez-Villanueva, et al., 2010b; Chamari et al., 2005; Silva et al., 2011).

Following this note, we hypothesized that there would be a correlation between the RSA, sprint tests and number of sprints in match. Indeed, we observed a strong correlation in the U-16 (30m sprint, r=0.6; RSA, r=0.7) and moderate correlations in the U-19 (30m sprint, r=0.4; RSA, r=0.3). Similar correlation has been observed between RSA and high-intensity activities in match, although these associations was position-specific with strikers having the strongest correlation (r~0.7). Our physical test results highlight a relationship between faster players and their subsequent higher match running performance (number of sprints) compared to players with lower physical capabilities (especially slower players). Moreover, the relationship observed between speed-related tests, might be self-explanatory though, since coaches might select faster players to play in positions that generally partakes in more sprints, thereby gaining a tactical advantage. Moreover, the test-results from the U-16 were compromised from generally faster playing-positions compared to U-19, possibly explaining the observed differences in correlation-strength observed between 30m sprint, RSA, and the number of sprints in match.

Strengths and limitations

The strengths of the present study were firstly that we provided extensive knowledge on the external match and training load in training-weeks with 1 and 2-matches as well as physical capabilities of elite U-16 and U-19 players. Furthermore, we provided insight into the relationship between match- and training load and positional differences in match load and physical capacities. To the authors knowledge, this study is the first to provide insight into distance >90%MV in match as well as training for elite youth population. Additionally, the same GPS-system was used for all players throughout the 2021 season, with the amount of match observations (U-16, 11 and U-19, 25) giving good estimates of the positional-age-specific match reference value, reducing the potential for measurement errors.

Even still, this study contains some limitations. Firstly, a small sample size makes it hard to generalize our findings and comparing them to other teams since individual differences become more detrimental to the results. Additionally, the small sample size increases chances of type II errors and thereby possibly failing to detect true differences. The present study includes a proportion of extrapolated data (match load, >60min + <90min) which might have overestimated full match activities which should be regarded. Moreover, previous research with similar extrapolation observed 2% overestimations of external load variables (Stevens et al., 2017). The unpredictable nature of football with reoccurring sickness and injuries, with sessions and games being rescheduled resulted in few comparable training-weeks fulfilling training-week inclusion criteria. Moreover, the congested season (due to Covid-19) most likely led to the included training-weeks following a high-intense period with multiple games possibly altering the overall focus within the given included training-week. Additionally, the relatively low number of players within the two teams and the design of academies (players moving between team-levels) may have influenced the results. These limitations are although common in similar studies, and consequently to a certain extent not controllable by the researcher. Although expected, a high intra-variability exists within sprint distance, sprint efforts and distance >90%MV indicated by standard deviation being equal or higher than the mean values. Since players have been shown to reach 80-92% of maximal velocity in game, the distance >90%MV might be overestimated, due to the researchers not obtaining a player's true maximal velocity. Importantly, comparing our findings with other studies should be done with caution since possible differences in tracking systems, velocity/acceleration/deceleration thresholds might be present and therefore also should be accounted for. Additionally, direct comparison between youth and senior teams should be considered with caution since younger players generally must run closer to their maximal velocity in arbitrary measurements compared to older players.

Conclusion

In summary the result from the present study gives detailed insight on the important relationship between match and training load in elite youth football players and highlights the need to pursue more position-specific training in relation to their respective worst-case match-reference. Moreover, the results from the present study highlighted a mismatch between the external match load and accumulated training load of HIR, sprint distance and distance >90%MV in training-weeks with 1 and 2-matches in elite U-16 and U-19 players. Additionally, the external match loads and physical capacity varied between playing positions and age-level. We observed strong and moderate correlations between number of sprints in match and RSA and 30m sprint, possibly highlighting the importance of maximal velocity and aerobic power on enhanced match running performance. Despite the highlighted mismatch between training-load and match load it is not feasible to conclude whether academy players train as hard as they play due to the relative low sample size, a congested season and subsequently low number of similar comparable training-weeks. Future research should investigate the combined effect of short-sided-games with additional football-drills and/or high-intensity runs on their capability to replicating respective match running-profiles. Additionally, it would be beneficial to investigate the positions-specific relationship between physical capabilities and match running performance. Although important, investigation of the internal load was not prioritized in this study and therefore advised to evaluate in future research.

Practical implications

This study has provided knowledge about the relationship between match load and training load, which is of great importance for practitioners when prescribing, planning, and monitoring, appropriate training for elite youth U-16 and U-19 players. The positional differences observed in match load highly advise position-specific training. The focus of training-weeks should be to keep the entire squad, fit, healthy, and competitive throughout the season, aiming to eliciting similar or exceeding the physiological stimulus observed during matches in suitable training-weeks, with especially focus on replicating the observed acceleration activity and distance covered at higher intensities. Therefore, short-sided-games with additional high-intensity runs or football-specific drills accumulating high-velocity movements might be needed to compensate for the observed mismatch between accumulated training load (HIR, sprint distance and >90%MV) and match load in elite youth players.

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Appendices

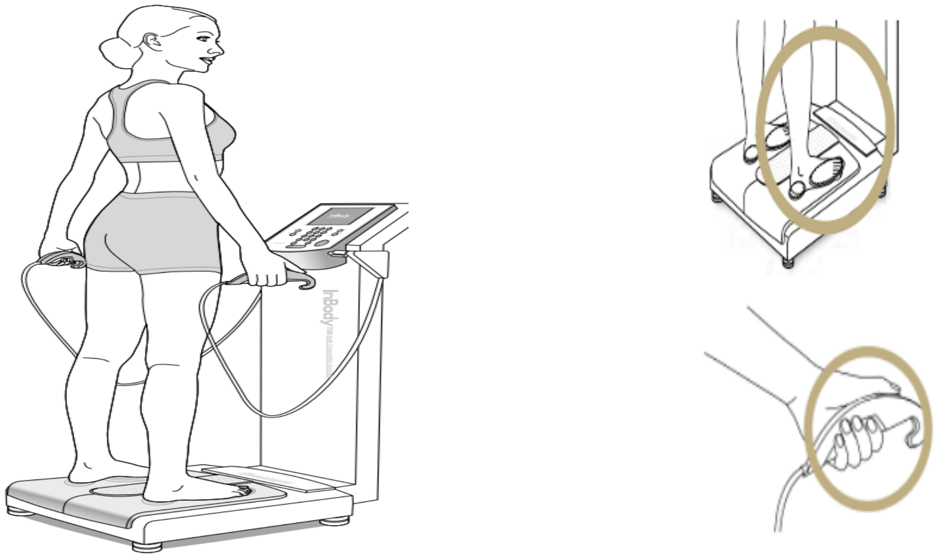
Appendix A - Detailed description of physical testing protocols in U-16 and U-19

Test-day 1 - VO_{2MAX} and InBody body composition

VO_{2MAX} and InBody Bioimpedance was performed on test-day 1. The participants (players) arrived the laboratory and was instructed to use the lavatory prior to a "body scan" to eliminate the volume of urine and excrement. Measurement of their height was obtained with a column scale (SECA 220, Hamburg, Germany), barefoot, and heels placed against the wall. Thereafter, participants ID, age, height, gender, and weight was registered on the InBody Machine (InBody 770, Rådal, Norway). Participants wore light clothing to get precise test-results. Participants stepped barefoot on the InBody 770 machine with the heels on the circular-shaped foot electrode and the whole sole in contact with the other foot electrodes. Also, they were instructed to gently press the handles with four fingers in contact with the bottom electrode and the thumb in contact with the top electrode. During testing the LCD monitor displayed information on body composition which was covered up to protect the sensitive youth group. The arms formed an angle of 15 degrees between the arms and the side of the body. During the test the participants were instructed to stand comfortable, relax muscles and remain posture until the end of the test. When the test was done the players placed the handles back where it was and stepped down from the stand. Body fat percentage, height and weight was used in this study.

Thereafter the participants were instructed to warm-up prior to the $VO2_{MAX}$ testing. The same personnel oversaw a standardized warm-up protocol of 10 minutes of easy jogging with 1% incline, incrementally increased the intensity to 10-12 km/h with 3% incline after 6 minutes and 16-18 km/h and 5% incline after 9 minutes. Individualized starting pace of the VO_{2MAX} test was selected for each participant corresponding to 12 on the Rating of Perceived Exertion Borg Scale. Each player had 4 minutes between the warm-up and the start of the VO_{2MAX} test. Before testing, the ergospirometry system Metalyzer II (Leipzig, Germany) were calibrated against standardized motorized mechanical lung (Motorized Syringe with Metabolic Calibration Kit; VacuMed, Canada). At the end of every test, day volume and gas calibration were performed according to manufacturer´s instructions. Thereafter, volume calibration was before every test, while gas calibration was perfromed before every fourth test. The participants were equipped with a facemask (Hans Rudolph, Germany) connected to the gas analyzer with gas measurements being done every 10s. The VO_{2MAX} test was performed on a treadmill (Woodway PPS MED, USA) and started at 5% incline with the individual starting pace and speed being increased in a stepwise manner each minute to a level that brought the players to exhaustion in 6-8 minutes. Achievement of VO_{2MAX} was accepted when VO_2 leveled off despite further increases in workload and when a respiratory exchange ratio >1.10 was present. Leveling off of VO_2 despite increase in workload has been describe as no increase more than 2ml/kg/min between two 30s epochs (Stensvold et al., 2017). The VO_{2MAX} was registered and used in this study (ml/kg^1/min, and ml/kg$^{0.75}$/min). Since VO_{2MAX} of heavier participants tend to be underestimated and lighter participants overestimated when bodyweight is raised to the power of 1 (kg^1), scaled VO_{2MAX} (ml/kg$^{0.75}$/min) was used for analysis, whilst VO_{2MAX} (ml/kg^1/min) was presented to describe the populations and enabling comparisons with other research (Chamari et al., 2005). Equal verbal encouragement was given to each participant.

A)



B)

Figure 2: *Illustrations of Test-day 1. A=body composition InBody 770. The illustration shows positions of arms, palms, soles, and fingers during test; B=VO_{2MAX}. Illustrations shows two participant performing maximal oxygen uptake test; Consent given by both players.*

Test-day 2 – Bilateral Isokinetic Knee Strength

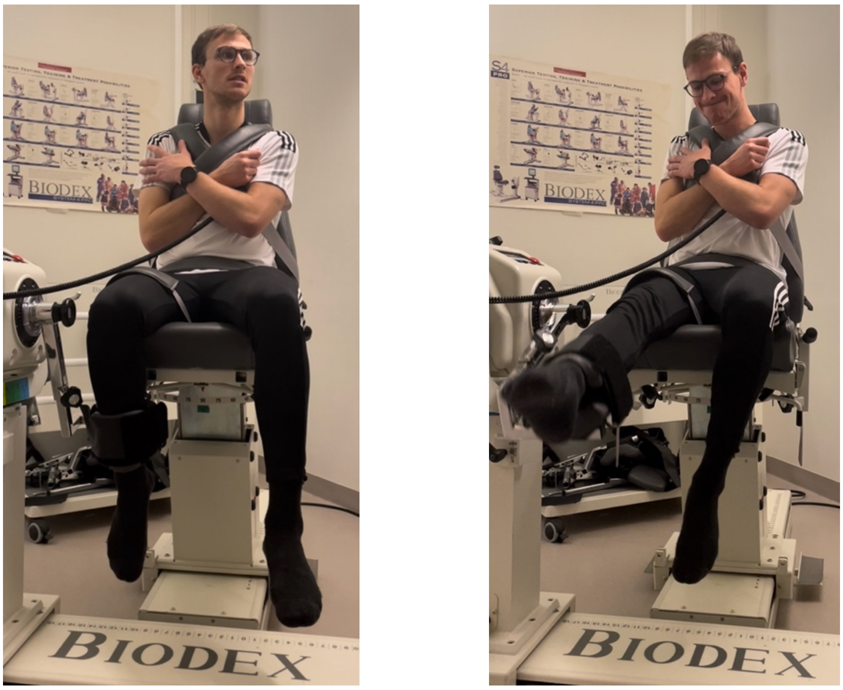
To evaluate participants (players) lower limb muscle function, concentric peak torque during isokinetic knee joint movement were measured of hamstring and quadriceps on test-day 2 (Biodex System 4, New York, USA). Before muscle function measurement participants did a standardized 10-minutes warm-up on an ergometer bike of pedaling at 90 rounds/min (Monark 827E, Vansbro, Sweden) followed by 10 forward lunges on each leg and 10 repetitions of dynamic pedaling of the hamstring and quadriceps muscles. The participants were then seated on the dynamometer chair with stabilization straps at the ankle, thigh, abdomen, and trunk to allow appropriate isolation of the measured muscles. Pain-free individual range of motion was set for each participant, and arms were crossed across the chest. Ten maximal knee extension and knee flexion-repetitions at angular velocity 180°/s (3.14 rad/s) was first carried out on the dominant foot, followed by the non-dominant foot. The peak torque (Nm) obtained during knee extension and knee flexion was used for analysis.

Test-day 3 – 30m Sprint and 30m Repeated Sprint Ability (RSA)

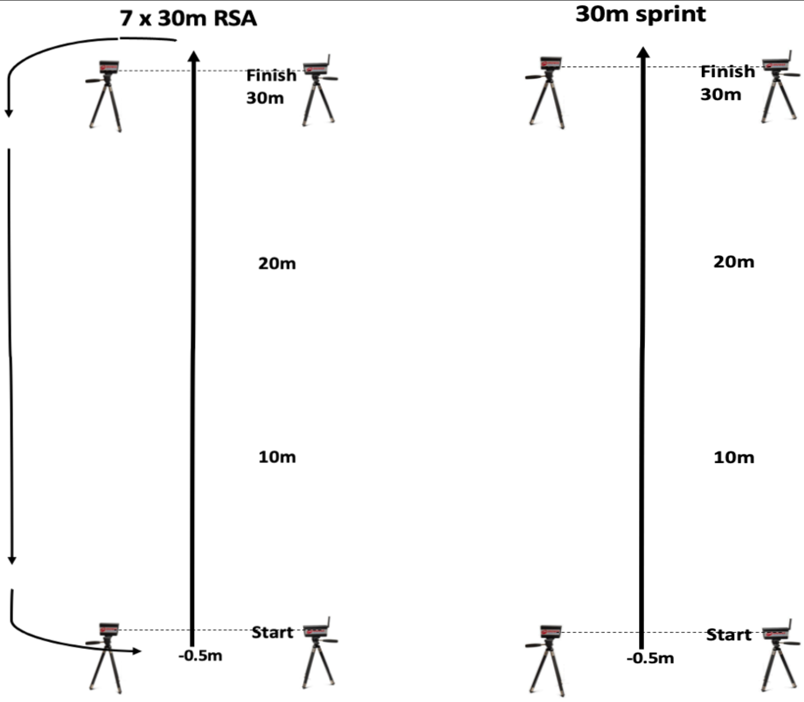
Participants performed one 30m sprint and 7x30m RSA on test-day 3. The field test was located inside a sports dome with artificial gras. The 30m sprint and RSA was performed on a 30m straight line, with the start position (marked by a horizontal tape) 0.5m behind the starting line. Speed gates (TCI System, Browing Timing, USA) were placed on tripods at start and 30m, with the first one being placed 0.5m above ground, and the last at 1 meter above ground. First the participants did a general warm up of 10min which included jogging, dynamic stretching, and specific football warm-up exercises. One participant was extracted from the population each 5 minutes to perform the two tests whilst the rest were active with light sport-specific exercises (square and 5-a-side). The participant tested did then 3 incremental runs across the 16-meters box corresponding to 70, 80 and 90% of max velocity within 4 minutes. Participants was instructed to have one foot on the line (0.5m behind start) and start the sprint and RSA on signal from the test-personnel and timing started when players crossed the first speed gate (0m). After the incremental runs and 1 minute of recovery the participant performed one maximal 30m sprint, followed by 4 minutes recovery prior to the RSA. During RSA a new sprint started every 30s and players was instructed to be ready on start-position 5s prior to the next sprint, meaning that the participants had approximately 20s self-paced recovery back to start in between bouts. According to our protocol, if participants had a time-decrement of >5% in the first sprint in the RSA compared to the 30m sprint the RSA must be restarted. A restart was not required in any of the participants during this study. Strong verbal encouragement was provided in both tests by the same test-personnel and peers throughout all sprints. Time used in the 30m sprint, and total time in RSA was used in this study.

Figure 3: *Illustrations of Test-day 2 (A) and Test-day 3 (B).*

A)



B)



A=Bilateral Isokinetic Knee Strength. Illustration shows positioning of hands, legs, and belts during test and top/bottom position in knee extension/flexion on Right foot; B=7x 30m Repeated Sprint Ability (RSA) and 30m sprint. Illustration shows positioning of timing gates and running pattern of participants.

Appendix B – Catapult GPS Vector/Vicon Validity Preview

VECTOR CONCURRENT VALIDITY

CATAPULT PREVIEW

PURPOSE

- The following slides are a **preview** of the current analysis taking place for the concurrent validity of Vector against a gold standard motion capture system (Vicon – Nexus)

Please note this is a part of Catapult' Vector internal validation works and all data has been processed by catapult staff.

METHODS

- Data collection took place at night under optimal and consistent lighting conditions
- Four Vector devices were chosen at random from a population of 24 and were placed in the middle of the testing area for 15 minutes prior to data collection
- Catapult Clearsky 2.0 was set up around the testing area with 21 anchors.
- A 20 camera Vicon system was set up (outdoors) with a total capture area of 20m x 15m. The Vicon system was calibrated and operated by experienced staff from the Victoria University biomechanics lab.
- Reflective markers were placed on each shoulder and the assigned device of each participant for data capture.
- Participants completed the following trials:
    - 5m Sprint [3]
    - 10m Sprint [3]
    - 20m Sprint [3]
    - 45 deg change of direction [3]
    - 90 deg change of direction [3]
    - Sport simulation [3]

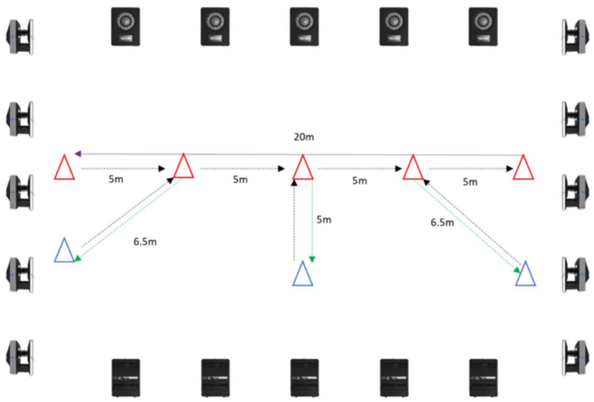


Fig 1 – Vicon camera layout and and trial setup within testing area.

DATA INTEGRITY | VECTOR

VECTOR CONCURRENT VALIDITY

DATA ANALYSIS

- Vicon data down sampled from 250 Hz to 10 Hz (the sampling frequency of Vector technology) in accordance with previous studies [1]
- Vicon data was appropriately filtered to ensure the removal of the effects of centre of mass displacement during locomotion, as this is not present in Catapult data.
- Each trial was isolated within the respective GPS and LPS 10Hz data exports from the OpenField software (ver 2.0)
- Data was processed within R [3.0.6] statistical computing software and initial comparisons made using a cross correlation methodology, from which the following graphs were prepared.

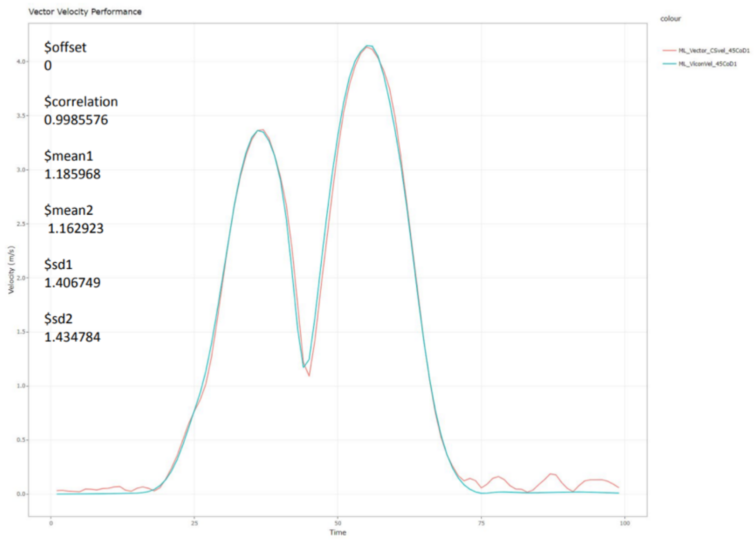


Fig 2. Vector LPS (red) vs Vicon (blue) *Velocity* – 45 degree change of direction task

DATA INTEGRITY | VECTOR

VECTOR CONCURRENT VALIDITY

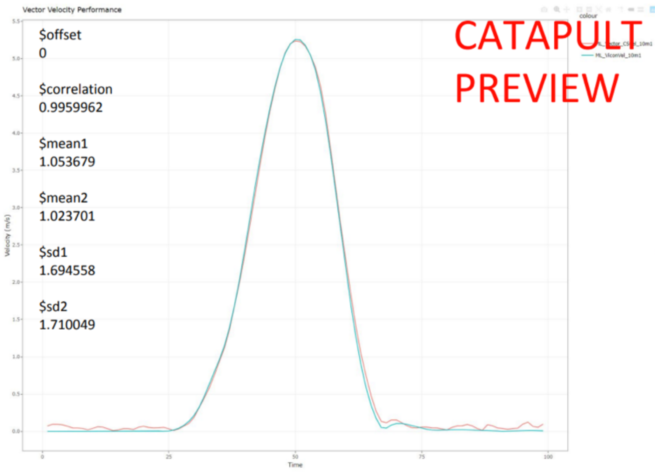


Fig 3 . Vector **LPS** (red) vs Vicon (blue) ***Velocity*** – 10m Linear Sprint task.

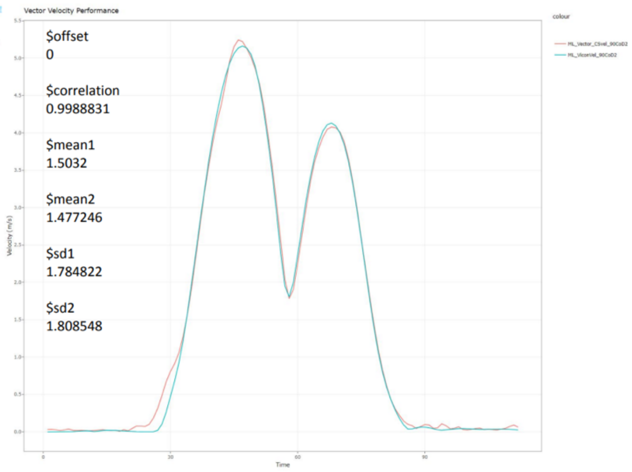


Fig 4 . Vector **LPS** (red) vs Vicon (blue) ***Velocity*** – 90 degree CoD task.

VECTOR CONCURRENT VALIDITY

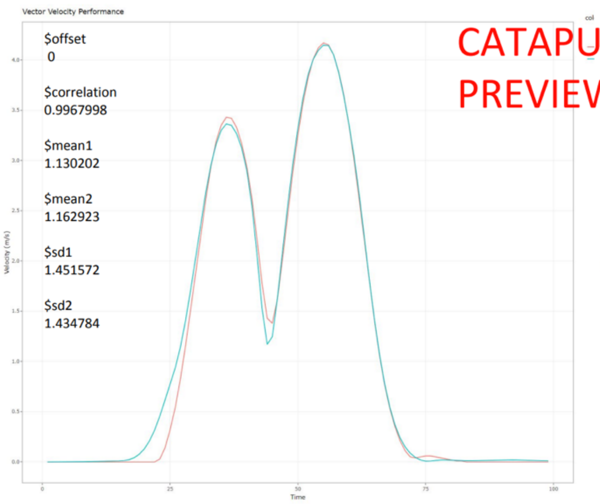


Fig 5. Vector **GPS** (red) vs Vicon (blue) ***Velocity*** – 45 degree change of direction task

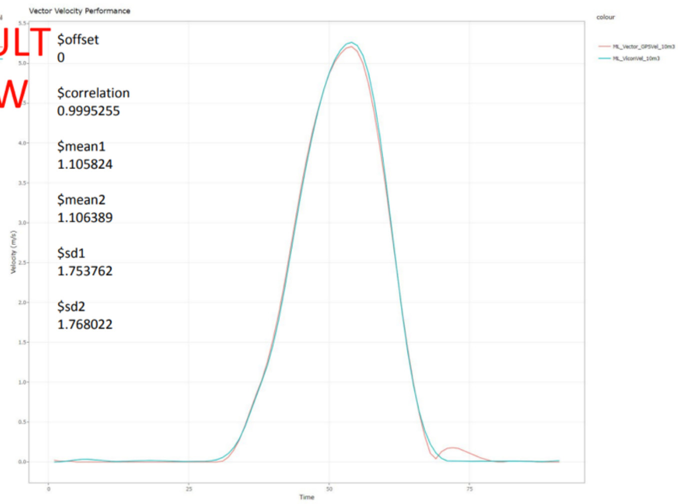


Fig 6 . Vector **GPS** (red) vs Vicon (blue) ***Velocity*** – 10m Linear Sprint task.

VECTOR CONCURRENT VALIDITY

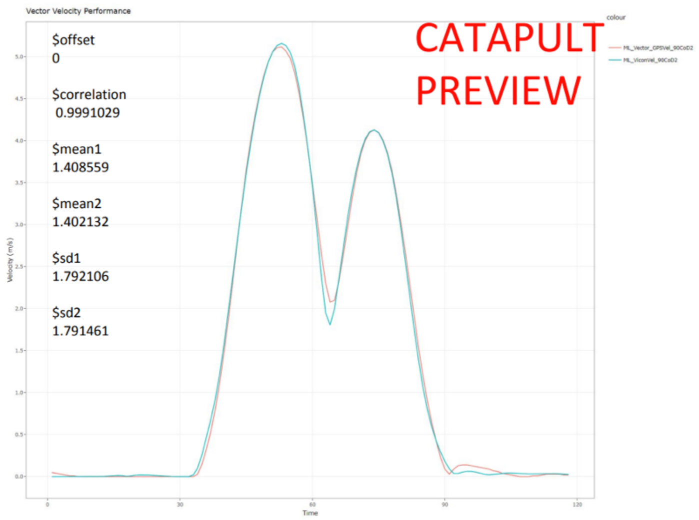


Fig 7 . Vector **GPS** (red) vs Vicon (blue) ***Velocity*** – 90 degree CoD task.

SUMMARY

Early stage analysis indicates a very close relationship between Vector and Vicon, for both linear and multi directional trials.

Larger scale regression analysis is currently in progress for the entire dataset, consisting of 72 total trials over 6 tasks and 4 participants .

[1] Serpiello et al. (2017). Validity of an ultra-wideband local positioning system to measure locomotion in indoor sports. *JSS*

DATA INTEGRITY | VECTOR

Appendix C – Catapult GPS Device Specs

VECTOR

DEVICE SPECS

VECTOR DEVICE

DIMENSIONS	81mm x 43mm x 16mm
VOLUME	48cm³
WEIGHT	53g
BATTERY	6 hours
GLOBAL POSITIONING	10Hz GPS, GLONASS & SBAS (or 18Hz GPS)
LOCAL POSITIONING	10Hz Catapult ClearSky
WIRELESS COMMUNICATION	Ultra-wideband & Bluetooth 5
WIRELESS RANGE	Up to 300m (UWB)
CAPACITY	100 athletes
HEART RATE	ECG Derived (Vector S7, G7) & Polar 5.5kHz Compatible (all models)
ACCELEROMETER	3D +/- 16G. Sampled at 1kHz, Provided at 100Hz
GYROSCOPE	3D 2000 degrees/second @ 100Hz
MAGNETOMETER	3D ±4900 µT @100Hz

VECTOR DOCK

NUMBER OF DEVICES	24
BATTERY LIFE	90 minutes

VECTOR RECEIVER

WIFI	2.4 + 5 GHz
WIRELESS DATA	Ultra-wide Band
BATTERY LIFE	9 hours

VECTOR USER GUIDE 19

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Kunnskap for en bedre verden