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The fit matters: influence of accelerometer fitting and training drill demands on load measures in rugby league players

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Running head: Influence of accelerometer fitting on load measures

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Abstract

PURPOSE: Determine the relationship between drill type and accelerometer-derived loads during various team sport activities, and examine the influence of unit fitting on these loads.

METHODS: Sixteen rugby league players were fitted with microtechnology devices in either manufacturer vests or playing jerseys before completing standardised running, agility and tackling drills. Two-dimensional (2D) and three-dimensional (3D) accelerometer loads (BodyLoad™) per km were compared across drills and fittings (i.e. vest and jersey).

RESULTS: When fitted in a vest, 2D BodyLoad™ was higher during tackling (21.5 ± 14.8 AU/km) compared with running (9.5 ± 2.5 AU/km) and agility (10.3 ± 2.7 AU/km). Jersey fitting resulted in more than two-fold higher BodyLoad™ during running (2D 9.5 ± 2.7 vs 29.3 ± 14.8 AU/km; 3D 48.5 ± 14.8 vs 111.5 ± 45.4) and agility (2D 10.3 ± 2.7 vs 21.0 ± 8.1 AU/km; 3D 40.4 ± 13.6 vs 77.7 ± 26.8 AU/km), compared with a vest fitting. Jersey fitting also produced higher BodyLoad™ during tackling drills (2D = 21.5 ± 14.8 vs 27.8 ± 18.6 AU/km; 3D = 42.0 ± 21.4 vs 63.2 ± 33.1 AU/km). **CONCLUSIONS:** This study provides evidence supporting the construct validity of 2D BodyLoad™ for assessing collision/tackling load in rugby league training drills. Conversely, the large values obtained from 3D BodyLoad™ (which includes the vertical load vector) appear to mask small increases in load during tackling drills, rendering 3D BodyLoad™ insensitive to changes in contact load. Unit fitting has a large influence on accumulated accelerometer loads during all drills, which is likely related to greater incidental unit movement when units are fitted in jerseys. Therefore, it is recommended that athletes wear microtechnology units in manufacturer provided vests to provide valid and reliable information.

Introduction

Global Positioning Systems (GPS), that are embedded into microtechnology devices, have previously been shown to be reliable for measuring the activity profiles of field-based team sport athletes.¹ In addition to GPS data, these microtechnology devices contain accelerometers which provide information on the three-dimensional (3D) forces applied to the device. Accelerometer-derived loads have been shown to display acceptable inter-unit reliability (CV = 1.9%) during team sport matches² and moderate to high test-retest reliability (CV = 5.9%) during treadmill running activities, with stronger reliability displayed at faster running speeds.³ Furthermore, very strong to nearly perfect within-individual correlations have been shown for accelerometer loads and average heart rate (R = 0.98) and VO₂ (R = 0.92) during treadmill running.³ As such, it has been suggested that accelerometers can provide an overall external load measure in team sports by quantifying accelerations, decelerations, changes in direction and impacts.⁴ Currently there is a lack of research examining accelerometer-derived load measures across a range of different collision-based sport activities.

The use of microtechnology devices in the quantification of team-sport activities has increased recently,^{5,6} however, much of the research focus has been directed towards GPS-derived variables (e.g. distance, high-speed running, accelerations, and decelerations). While these measures are useful for quantifying gross locomotor activities, other technical movements such as tackling, changes of direction and getting up and down from the ground occur with limited player displacement and may not be quantified by GPS technology, although these actions may also be energetically demanding. Accelerometers may provide additional information on these smaller movements, which are not detected from GPS velocity. However, any microtechnology (i.e. GPS and/or accelerometer) variable is limited to measuring movement, and is therefore incapable of quantifying work when the body is stationary or not

moving (i.e. static work such as isometric contractions). Despite the seemingly insurmountable limitation of microtechnology not being able to measure static work, some quantification of collision/contact demands is particularly important for practitioners working in rugby league, as these athletes may be involved in up to one collision per minute during match play and an average of 20 collisions per training session.⁷

While the majority of commercially available microtechnology devices contain GPS technology, most also include accelerometers, which usually sample at a frequency of 100 Hz. The accelerometers contained in these commercial devices have been suggested as a valid tool to quantify gravitational forces (g) resulting from accelerations, decelerations, changes of direction and impacts.^{4,8} Indeed, previous research has shown strong correlations between session rating of perceived exertion loads and accelerometer-derived training loads per minute ($r = 0.57$) in professional rugby league players.⁴ Others have described a significant relationship between total distance covered and accumulated accelerometer load ($R^2 = 0.90$) in Australian Football,⁹ suggesting that accumulated accelerometer load may be an alternate measure of overall external work in team sports. However, to date no studies have specifically examined accelerometer loads during different collision sport training modalities (e.g. running/agility vs. match simulation and tackling drills).

Accelerometer-derived loads are often calculated using a summation of load vectors in three dimensions [mediolateral (x), anteroposterior (y), and vertical (z)].² During jogging/running activities, the vertical component of this load calculation accounts for 50-60% of the overall 3D load.³ Therefore, it is likely that 3D loads are strongly influenced by the distance covered during team sport training/matches. Conversely, the mediolateral and anteroposterior vectors account for only 20-25% each of the 3D load calculated during jogging/running.³ Pilot data collected from our laboratory suggests that load accumulated in the mediolateral and anteroposterior vectors increases greatly during training drills that involve

large amounts of contact (e.g. tackles, ground contacts) and change of direction. Further understanding of how accelerometers (particularly in the absence of gyroscope data) may be used to quantify collision load, including the magnitude of impacts and accumulation of total load (opposed to collision counts), may provide an additional tool for the quantification of collision demands in team sport. The differences between accumulated accelerometer loads, including the contribution of x, y and z vectors, during different team sport activities is currently not clearly understood.

Due to the high sample rate of accelerometer-derived data, the fitting of microtechnology units may impact the accuracy of data obtained. Indeed, poorly fitted units may increase incidental unit movement, resulting in increased variability and decreased sensitivity of accelerometer-derived variables. Previous studies that have reported on the reliability of accelerometer load measures during laboratory³ or field² settings have all fitted units within customised vests, which are tightly fitted to the athletes to minimise incidental unit movement and enhance reliability. Similar fitted vests are provided by manufacturers with microtechnology units and are commonly worn by team sport athletes during training activities. However, many teams/athletes now also use custom built pockets in playing and/or training uniforms,¹⁰ which are inserted during the manufacturing process. When using such pockets, the fit of the microtechnology unit is dependent on the fit of the training/playing uniform, which may vary depending on materials, apparel manufacturer, sizing specifications and athlete preferences regarding fitting size.

The aims of this study were to: 1) determine the relationship between drill type (i.e. physical output) and accelerometer loads [two-dimensional (2D) and 3D] during various team sport activities, and 2) examine the influence of unit fitting (custom vest vs. playing jumper) on accelerometer-derived loads during team sport activity.

Methods

Participants

Sixteen rugby league players [19.7 ± 0.8 y (mean \pm standard deviation (SD)), 101 ± 11 kg, 187 ± 7 cm] from one club, competing in the Australian National Youth Competition, were recruited to participate in this study. Participants completed various running and team-sport activities whilst fitted with microtechnology devices (High Performance Unit, Firmware V1.2.27, GPSports, Canberra, Australia) capable of collecting GPS data at 5 Hz (linear interpolation used to output data at 15 Hz).¹¹ These devices are also capable of collecting accelerometer data in three vectors (x, y and z) at 100 Hz, with a peak gravitational acceleration (g) of up to 16 g within each vector. Players were fitted with devices between the scapulae in either custom designed vests (vest), supplied by the microtechnology manufacturer (GPSports, Canberra, Australia), or pockets built into the playing jerseys (jersey) by the club’s apparel manufacturer (ISC Sports, Roseberry, Australia). All participants were informed of the possible risks of involvement in the study, gave voluntary written consent and the study was approved by a university human ethics review panel.

Experimental Procedures

A non-randomised crossover experimental design was used in which participants were first fitted with the microtechnology device in a vest before completing four minutes of three different standardised team sport activities; running and agility (randomised order) followed by tackling (see below for details). During a 15-minute recovery period, players were then re-fitted with the same device in a jersey before again completing three four-minute blocks of the same team-sport specific activities.

Vest and jersey fitting

As unit fitting may influence accelerometer loads, vest and jersey fittings were carefully controlled for each participant. The microtechnology manufacturer does not provide recommendations on vest fitting size, therefore pilot testing was conducted to determine chest circumference that produced a tight fit (i.e. all areas of the vest were in contact with the skin and no visible loose areas) for all participants; this sizing can be found in Table 1. Manufacturer (GPSports, Canberra, Australia) provided vests were made of a neoprene and Lycra® blend, with a neoprene padded device pocket. Since multiple factors may influence jersey fit (e.g. chest circumference, shoulder width, torso length) in rugby league players, each participant was individually fitted into a jersey size by the manufacturer (ISC Sports, Roseberry, Australia). The goal of these individual manufacturer fitting was to provide a jersey fit that was as tightly fitted as possible without restricting movement. This manufacturer and fitting process is used across many professional rugby league clubs in Australia and internationally.¹² Manufacturer fitted jersey sizes were closely matched to vest sizes, with 13 of the 16 participants wearing the same jersey and vest size (e.g. participants wearing a ‘large’ vest also wore a ‘large’ jersey). Of the three participants whose jersey and vest size did not match, two wore a smaller jersey and one participant a larger jersey. The individual pockets that devices were housed in were specifically designed for GPSports units in both conditions (jersey and vest). The jersey ‘pocket’ was an additional piece of neoprene sewn into the jersey, which fitted very tightly around the GPSports unit.

Team sport activities

Team sport activities were designed for participants to cover 240 m during a four-minute period. This speed ($60 \text{ m}\cdot\text{min}^{-1}$) is lower than previously reported in rugby league match-play [$85\text{-}111 \text{ m}\cdot\text{min}^{-1}$].¹³ However, the tackling drill involved a large number of

collisions (six per min) compared with collisions previously reported in rugby league match-play,¹³ thereby increasing the non-running based activity. All drills were completed on a natural grass rugby league field with players wearing playing footwear. Between each team sport activity, players rested for approximately five minutes (always > four minutes), before beginning the next activity.

- **Running:** players completed four 60 m straight line runs, with each repetition starting at one-minute intervals. Each run involved a 20 m acceleration, 10 m deceleration, 20 m acceleration and 10 m deceleration (see Figure 1). Participants were instructed to accelerate maximally during 20 m accelerations, and perform a controlled sub-maximal deceleration during deceleration zones (marked by cones and lines on the field).
- **Agility:** a generic team sport agility protocol was completed involving regular change of direction, acceleration and decelerations, at one-minute intervals. During each agility run (starting each minute), participants covered 60 m in total, with 8 changes of direction (see Figure 1). Participants were instructed to complete the agility circuit as fast as possible on each repetition.
- **Tackling:** players completed 12 tackles and were tackled 12 times during a four-minute period. For each tackle players were required to accelerate forwards 5 m, tackle/be tackled to the ground before standing and retreating 5 m to the start position (see Figure 1). Tackles were completed at 10 s intervals throughout the four-minute period.

Following the testing sessions, data collected by the microtechnology devices were analysed using manufacturer provided software (TeamAMS, Version R1 2015.10C, GPSports, Canberra, Australia), for determination of total distance (m), distance travelled during high speed running ($>20 \text{ km}\cdot\text{h}^{-1}$), peak speed ($\text{km}\cdot\text{h}^{-1}$), number of accelerations ($>1.5 \text{ m}\cdot\text{s}^{-2}$), number of decelerations ($<-2.0 \text{ m}\cdot\text{s}^{-2}$), 3D accelerometer load (i.e. BodyLoadTM) and 2D BodyLoadTM.

BodyLoad™ was calculated by the manufacturers software (TeamAMS, Version R1 2015.10C, GPSports, Canberra, Australia) and represents the sum of overall acceleration vectors in the x + y (2D) and x + y + z (3D) planes. GPSports accelerometers have previously been shown to underestimate absolute static and dynamic accelerations by ~30%,¹⁴ suggesting these accelerometers should not be used to measure the absolute magnitude of accelerations (work completed with GPSports SPI-ProX II, with the capability to measure peak accelerations up to 8 g in each vector¹⁵). However, the same work¹⁴ showed that these devices have excellent intra- and inter-accelerometer reliability, as well as reliable relative increases in peak acceleration across different frequency oscillations in laboratory setting. This suggests that accelerometers in GPSports SPI-ProX II devices can be used as a reliable tool to measure different magnitude accelerations, while the absolute magnitude of these accelerations is likely underestimated by ~30%. It is possible that absolute accelerations measured by the GPSports HPU devices (which are capable of detecting accelerations up to 16 g in each vector) differ, however there is currently no similar validation information available using this device. To adjust for small differences in distance travelled between trials (i.e. participant travelling off set path during testing), all BodyLoad™ data were divided by distance (i.e. BodyLoad™ per km).

Statistical analysis

A magnitude-based statistical approach¹⁶ was used to detect small effects of practical importance. Data were log-transformed to account for non-uniformity error. The magnitude of changes were assessed in relation to the smallest worthwhile change (SWC), set to a small effect size ($d = 0.2 \times$ the between-participant standard deviation). Raw values were reported as the mean \pm standard deviation while differences are expressed a Cohens d effect size \pm 90% confidence limits. A difference was deemed ‘substantial’ if there was >75% likelihood of the

difference exceeding the SWC.¹⁷ Effects where the 90% confidence interval simultaneously overlapped the substantially positive and negative thresholds were deemed ‘unclear’.

Results

GPS data: GPS-derived data are summarised in Table 2. Total distance was substantially higher during tackling drills compared with running and agility drills. During running participants completed 194 ± 13 m above $20 \text{ km}\cdot\text{h}^{-1}$, while no distance was covered in this high-speed running category for either agility or tackling drills. Maximum speeds and average acceleration were substantially different between each drill (see Table 2), and substantially more accelerations and decelerations were completed during agility and tackling when compared with running. Standardised differences (Cohens d) in GPS-derived variables, between vest and jersey conditions, are displayed in Figure 2.

Accelerometer data in vest: The comparison of 2D BodyLoad™ per km to 3D BodyLoad™ per km (i.e. $2\text{D BodyLoad}^{\text{TM}} \text{ per km} / 3\text{D BodyLoad}^{\text{TM}} \text{ per km}$, which represents the contribution of the anteroposterior and mediolateral loads to the overall 3D load) is shown in Table 3. When microtechnology units were fitted in a vest, 2D BodyLoad™ per km was higher during tackling ($21.5 \pm 14.8 \text{ AU/km}$) when compared with both running ($9.5 \pm 2.5 \text{ AU/km}$; $d = 2.26 \pm 0.92$) and agility ($10.3 \pm 2.7 \text{ AU/km}$; $d = 1.97 \pm 1.00$; see Figure 3). Three-dimensional BodyLoad™ per km was substantially higher in running when compared with agility ($d = 0.57 \pm 0.27$) and tackling ($d = 0.55 \pm 0.64$) when the unit was fitted in the vest.

Accelerometer data in jersey: Fitting the unit in a jersey resulted in both 2D BodyLoad™ per km [running (vest = $9.5 \pm 2.7 \text{ AU/km}$, jersey = $29.3 \pm 14.8 \text{ AU/km}$; $d = 3.48 \pm 0.45$), agility (vest = $10.3 \pm 2.7 \text{ AU/km}$, jersey = $21.0 \pm 8.1 \text{ AU/km}$; $d = 2.40 \pm 0.44$), tackling (vest = $21.5 \pm 14.8 \text{ AU/km}$, jersey = $27.8 \pm 18.6 \text{ AU/km}$; $d = 0.44 \pm 0.23$)], and 3D BodyLoad™ per km [running (vest = $48.5 \pm 14.8 \text{ AU/km}$, jersey = $111.5 \pm 45.4 \text{ AU/km}$; $d = 2.38 \pm 0.33$),

agility (vest = 40.4 ± 13.6 AU/km, jersey = 77.7 ± 26.8 AU/km; $d = 1.77 \pm 0.27$), tackling (vest = 42.0 ± 21.4 AU/km, jersey = 63.2 ± 33.1 AU/km; $d = 0.95 \pm 0.27$)] being substantially higher across all drills compared with a vest fitted unit. When fitted in a jersey, 2D BodyLoad™ per km was also substantially higher during running drills (29.3 ± 14.8 AU/km), when compared with agility (21.0 ± 8.1 AU/km; $d = 0.68 \pm 0.27$). In the jersey fitting, running (111.5 ± 45.4 AU/km; $d = 1.28 \pm 0.47$) and agility (77.7 ± 26.8 AU/km; $d = 0.51 \pm 0.41$) drills produced substantially higher 3D BodyLoad's™ per km compared to tackling (63.2 ± 33.1 AU/km). Additionally, 3D BodyLoad™ per km was substantially higher during running when compared with agility ($d = 0.77 \pm 0.30$).

Discussion

The main finding of the current investigation was that, when the microtechnology device is tightly fitted in a vest, 2D BodyLoad™ is substantially higher during collision/tackling drills compared with running only drills. Additionally, when units are fitted into a playing jersey, 2D BodyLoad™ increases more than two-fold during running/agility drills (smaller increase during tackling drills), with a concomitant increase in the variability of this measure. This increased load and variability, paired with a lesser increase in 2D BodyLoad™ during tackling drills, diminishes the ability of 2D BodyLoad™ to differentiate running/agility and tackling drills. In contrast to the increases in accelerometer-derived load, large changes were not observed in GPS-derived variables between vest and jersey fittings. Furthermore, 3D BodyLoad™ is unable to differentiate between running/agility and tackling drills. This is likely due to a large contribution of accelerometer load in the vertical axis (~80% during straight line running), which could mask any small load increases in the anteroposterior and mediolateral axes, that may occur during tackling drills.

It has previously been shown that 3D accelerometer loads are strongly influenced by total distance travelled during locomotor activities (due to the influence of vertical forces applied during foot strike).³ We hypothesised that 2D BodyLoad's™ may provide information independent of total distance in overall load accumulation, and therefore, be more sensitive in detecting accelerations/decelerations and impacts/collisions in rugby league drills. However, the present data shows that 2D load is similar during straight line running and agility drills (see Figure 3A), when fitted in a vest, and this measure therefore appears insensitive to accelerations, decelerations and changes of direction, in this specific context. In contrast, there was an approximate two-fold increase in 2D BodyLoad™ per km (vest fitted) during tackling drills, suggesting that this may be a more appropriate measure of impacts/collision load. It should be noted that running speeds were quite high during straight line running in this study (~80% of total distance >20 km·h⁻¹) and previous work has shown that greater accelerometer loads are accumulated in all three dimensions at higher running speeds.³ Conversely, during the agility condition, no high speed running (>20 km·h⁻¹) was completed. Therefore, further investigation is required to determine if 2D BodyLoad™ may be sensitive to changes in direction, accelerations and decelerations, but also increases during high speed running. Future work to elucidate the relationship between BodyLoad™ in speed matched straight line running and agility activities will further enhance understanding of the factors contributing to the accumulation of BodyLoad™ during team sport activities.

Incidental unit movement, which is likely influenced by the positioning and fitting of the unit, may also have an impact on accelerometer-derived training loads. The most common position for unit fitting in team sport athletes is in the centre of the upper back, slightly superior to the scapula.³ This positioning allows the unit to move with the athletes torso, without being inhibitive of rugby league match-play, and accelerometer-derived loads have shown very strong reliability when tightly fitted in custom designed vests in this position.² Since the use of

microtechnology devices have become more common practice across sporting teams, apparel manufacturers have begun to build customised pockets into playing uniforms, presumably in an attempt to reduce the amount of equipment needed and increase player comfort while wearing these devices. However, due to the high sampling rate and sensitivity of the accelerometers in these devices, incidental movement (which is likely influenced by unit fitting) may have a large impact on accelerometer-derived loads. The present results show that 2D and 3D BodyLoad™ increases across all drill types when fitted in a jersey compared with a vest. While 2D BodyLoad™ clearly discriminated between running/agility and tackling drills while fitted in a vest, when units were fitted in a jersey the differences in 2D BodyLoad's™ between drills was less apparent. These differences are likely due to a greater increase in incidental unit movement during running and agility drills, compared with tackling drills in the jersey fitting. This work shows that alternate unit fitting (i.e. vest vs jersey) can lead to a two-fold increase in accelerometer loads. Therefore, considering the influence of unit fitting in these type of analyses is likely critical to accurate interpretation of the data. Whilst unit fitting had a large influence on accelerometer loads, only very small or no differences were seen in GPS-derived variables (see Figure 2). Furthermore, any small differences observed in GPS-derived variables were lower in the jersey condition compared with the vest (opposed to large increases in accelerometer load with jersey fittings), which may be due to a small fatigue related order effect of completing the jersey trial after the vest trial (discussed further below). These results would suggest that unit fitting (vest vs jersey) has minimal impact on the quality of GPS-derived data.

Several limitations should be considered when interpreting the current results. Firstly, for the BodyLoad™ analysis there was no variation between straight-line running speeds across trials. During the running drill in the current study, participants were instructed to maximally accelerate for 20 m, decelerate for 10 m before repeating this to complete a 60 m

run. This protocol produced high running speeds, which are somewhat infrequent during rugby league match-play. Conversely, no high-speed running (above $20 \text{ km}\cdot\text{h}^{-1}$) was completed during the agility condition in the present study. Since greater accelerometer loads are accumulated at higher running speeds,³ different results may have been obtained if running speeds were matched between straight line running and agility drills. The design of the tackling drill should also be considered when interpreting the current findings. The density of collisions (i.e. six per minute) in our protocol was quite a high comparison data reported in rugby league match-play.¹³ It is possible that the frequency of collisions in this experimental design created more chance for a difference in 2D BodyLoad™ between tackling and running/agility drills.

There is also the possibility of an order effect occurring within this study; due to logistical challenges during data collection, the order of wearing a vest or jersey was not randomised (i.e. all participants first completed the protocol wearing a vest). This means there may have been residual fatigue during the second (jersey) trial. However, due to the small volume of work and long rest periods between activities (approximately 5 minutes) and conditions (approximately 15 minutes), accumulated fatigue would likely be minimal. Whilst some residual fatigue may be present in this study, as evidenced by very small reductions in some GPS-derived variables (see Figure 2), any reductions in intensity should reduce accelerometer load. As accelerometer loads are highest during the second condition, we are confident that residual fatigue did not confound the finding that higher accelerometer loads are accumulated when wearing the microtechnology device in a jersey.

Practical Applications

The present results show that 2D BodyLoad™ increases with the addition of tackling/collisions in rugby league specific drills (in the case that devices are worn in a tightly fitted, manufacturer provided vest, but not in a playing jersey). Therefore, practitioners can use

this variable to quantify contact loads in team sport athletes. This measure of external load may be particularly important for specific rugby league players who complete less overall distance and high-speed running, but may be involved in more collisions/tackles (e.g. front row forwards). This study also shows large increases in accelerometer-derived loads when microtechnology units are fitted into playing jerseys, whilst GPS-derived variables do not appear sensitive to unit fitting. As this increase in load is not related to changes in the physical demands of the sport, rather an increase in incidental unit movement due to a looser fit, practitioners should interpret accelerometer data collected within jersey fittings with caution. Indeed, if this data is going to be used to inform decision-making, it is suggested that athletes wear microtechnology units in manufacturer provided vests, or other tightly fitted garments, throughout both training and matches.

Conclusions

The present results show that 2D BodyLoad™ is able to detect accumulated collision/tackling load in rugby league training drills. In contrast, large contributions of the vertical load vector in 3D BodyLoad™ appears to mask any small increases in load in the mediolateral and anteroposterior vectors during tackling drills, rendering 3D BodyLoad™ insensitive to changes in the contact load of training drills. Additionally, unit fitting is shown to have a large influence on accumulated accelerometer loads during running, agility and tackling drills, which appears to be related to greater incidental unit movement when units are fitted in playing jerseys.

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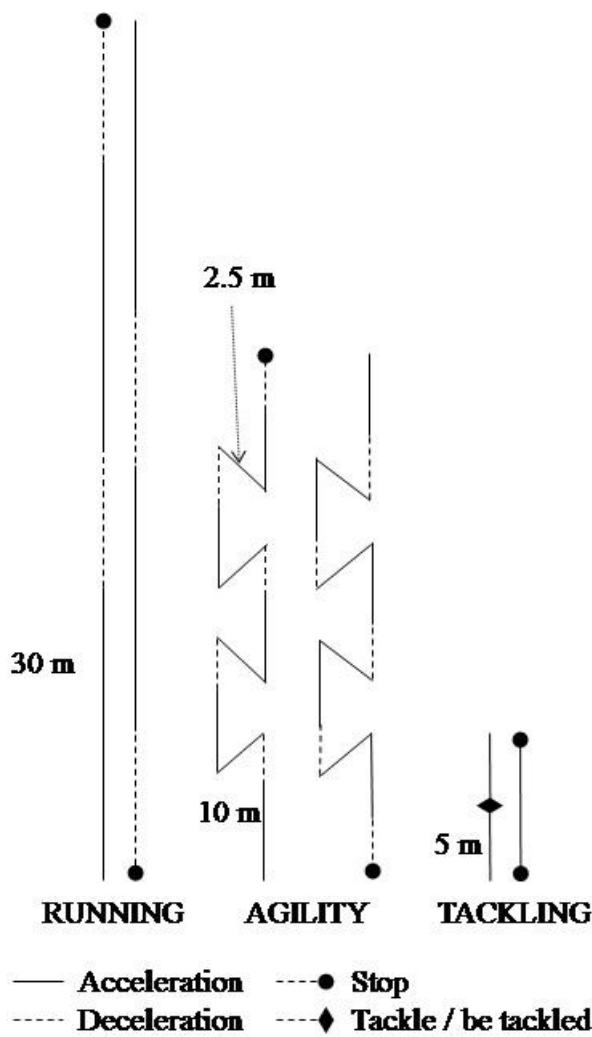


Figure 1. Schematic of the team sport activities. Running and agility drills were completed four times, while the tackling drill was completed 24 times (12 tackles, 12 times being tackled) within a four-minute period

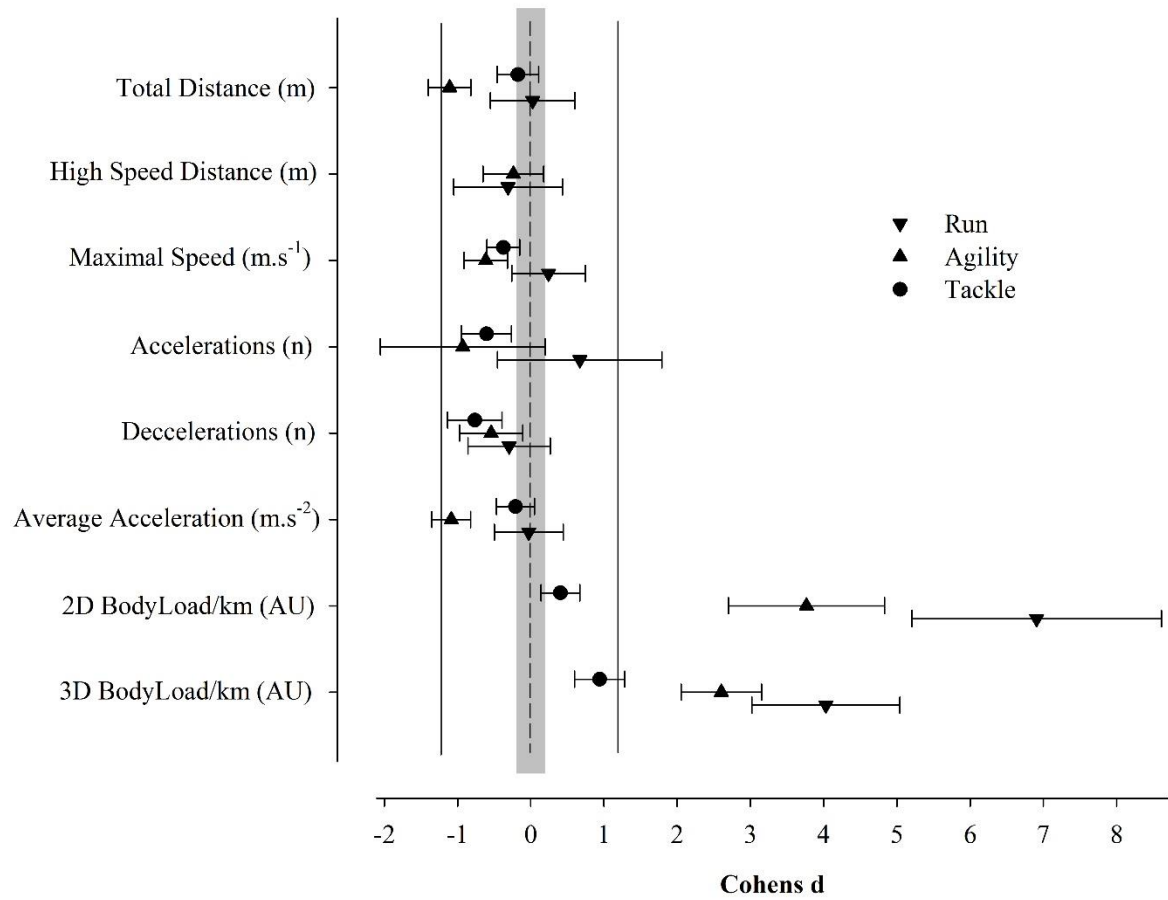


Figure 2. Standardised differences (Cohens d) in GPS and accelerometer variables between vest and jersey conditions (positive Cohens d reflects higher numbers in jersey condition). Note: High speed distance not shown for tackling as there was zero high speed distance in this drill.

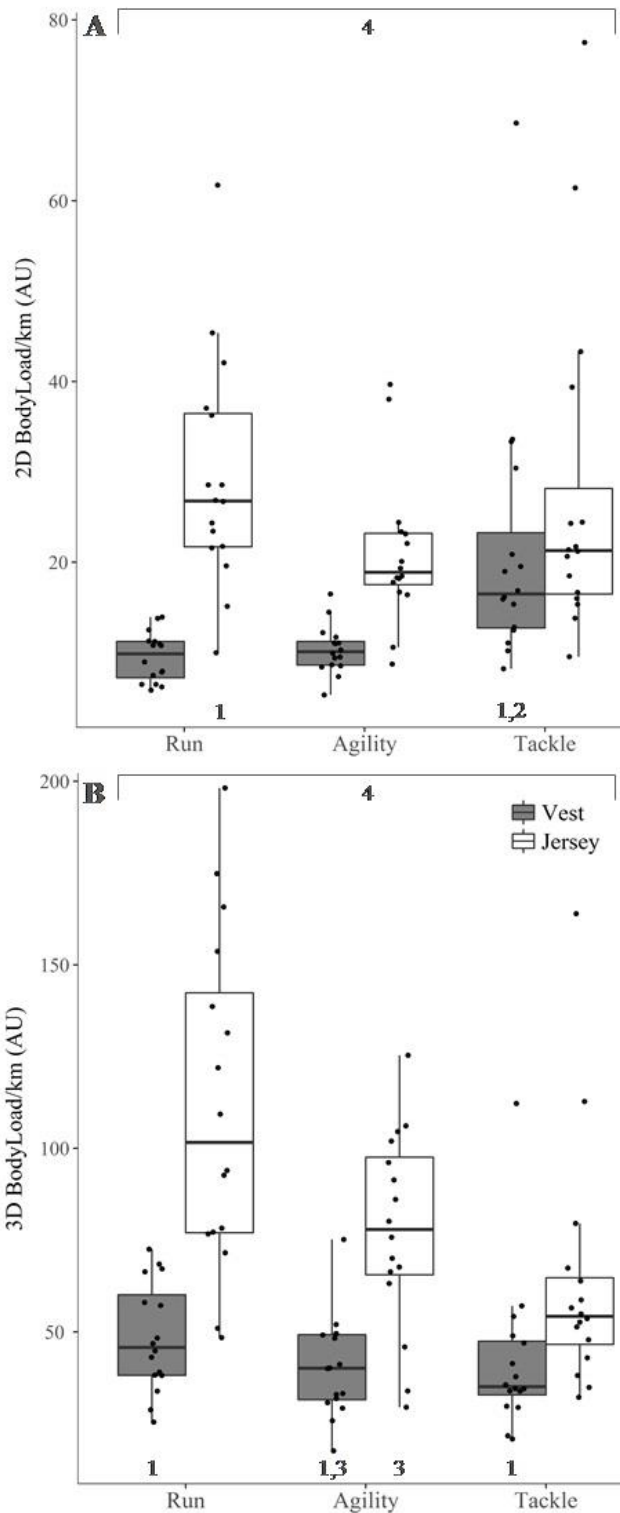


Figure 3. 2D (A) and 3D (B) BodyLoad™, expressed per km, during different drill types (running, agility and tackling) wearing a vest or jersey. ¹Denotes substantially higher than agility; ²denotes substantially higher than running; ³denotes substantially higher than tackling; ⁴denotes jersey values substantially higher than vest values in all drill types.

Table 1. Chest circumference and vest sizing’s.

Chest circumference (cm)	VEST Size [Vest circumference (cm)]
≤ 104	M [77]
105-110	L [83]
111-116	XL [89]
≥ 117	XXL [94]

Table 2. GPS variables during different drills and unit fittings. Data presented are mean \pm SD.

	Unit fitting	Running	Agility	Tackling
Total distance (m)	Vest	242 \pm 15	235 \pm 7	323 \pm 26 ^{1,2}
	Jersey	242 \pm 14	227 \pm 9	318 \pm 22 ²
High speed running distance (>20 km·h ⁻¹)	Vest	196 \pm 11 ^{2,3}	0 \pm 0 ¹	0 \pm 0 ¹
	Jersey	192 \pm 14 ^{2,3}	0 \pm 0 ¹	0 \pm 0 ¹
Max speed (km·h ⁻¹)	Vest	29.2 \pm 1.0 ^{2,3}	18.8 \pm 0.9 ¹	12.7 \pm 1.5 ^{1,2}
	Jersey	29.5 \pm 1.4 ^{2,3}	18.2 \pm 0.9 ¹	12.2 \pm 1.6 ^{1,2}
Average acceleration (m·s ⁻²)	Vest	0.26 \pm 0.02 ^{2,3}	0.50 \pm 0.04 ^{1,3}	0.85 \pm 0.07 ^{1,2}
	Jersey	0.26 \pm 0.02 ^{2,3}	0.45 \pm 0.04 ^{1,3}	0.83 \pm 0.08 ^{1,2}
Accelerations (n)	Vest	4.1 \pm 0.4 ^{2,3}	19.8 \pm 0.4 ¹	19.3 \pm 5.8 ¹
	Jersey	4.4 \pm 1.1 ^{2,3}	19.3 \pm 11.0 ¹	23.0 \pm 5.9 ¹
Decelerations (n)	Vest	4.6 \pm 1.2 ^{2,3}	19.6 \pm 1.2 ¹	19.1 \pm 3.6 ¹
	Jersey	4.3 \pm 0.7 ^{2,3}	18.9 \pm 1.5 ¹	16.3 \pm 6.0 ¹

¹substantially different from running; ² substantially different from agility; ³ substantially different from tackling.

Note – all statistical comparisons made in same unit fitting.

Table 3. Percent 2D BodyLoadTM per km in comparison to 3D BodyLoadTM per km. Data presented are mean \pm SD.

	Running	Agility	Tackling
Vest	20.8 \pm 6.0 %	27.5 \pm 9.3 %	48.8 \pm 10.2 %
Jersey	27.3 \pm 7.9 %	28.0 \pm 7.8 %	42.3 \pm 10.4 %