

DISSERTATION FROM THE
NORWEGIAN SCHOOL OF
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Live Steinnes Luteberget // Physical demands in elite female team handball

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Analyses of high intensity events in match and training
data via inertial measurement units

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Summary

Developments in tracking technology have made it possible to get more accurate insights into the physical demands of team sports, including indoor sports where global navigation satellite systems cannot be used. The main aim of this thesis was to investigate the physical demands of female team handball players using inertial measurement units (IMUs), and to validate a commercially available local positioning system (LPS) for indoor use.

In total, 75 handball players took part in the four studies (Studies I-IV), including participants at international, national and lower levels. To examine the reliability of IMUs for measuring physical activity in team handball, a between-devices setup was used (Study I). In study II, an observational design was used to investigate the physical demands in female team handball players in international matches. Study III aimed to investigate the physical demands of game-based training (3vs3 and 6vs6), and compare them to official matches. This was done by observation of prescribed training drills, and official matches. In study IV, the validity of an LPS was investigated. The LPS was compared to an infrared light-based camera system, in indoor conditions. Studies I-III all included the use of IMU (OptimEye S5, Catapult Sports, Melbourne, Australia), containing an accelerometer, gyroscope and magnetometer, all collecting data at 100 Hz. In all studies, the participants wore the IMU in a manufacturer-supplied vest. In studies II and III players were categorized into four different playing positions: backs, wings, pivots, and goalkeepers (GKs). The raw data from the IMUs were converted into the variables PlayerLoad™ and high intensity events (HIEs) using the manufacturer's software. All HIEs $>2.5 \text{ m}\cdot\text{s}^{-1}$ were included in the studies. In study I, the magnitude of HIE was investigated, in addition to variations of the metric PlayerLoad™. In study IV, the LPS (Catapult ClearSky T6, Catapult Sports, Melbourne, Australia) was investigated. Two-dimensional position data were used to calculate distance and instantaneous speed.

HIE magnitude showed good reliability (Coefficient of variation; CV: 3.1%) in well-controlled tasks. However, the CV increased (4.4-6.7%) in more complex tasks. Both PlayerLoad™ (and its variations; CV $<2\%$) and HIE count (CV $<3\%$) showed good reliability. Match data from international female team handball matches showed a mean

Summary

value of 8.82 ± 2.06 PlayerLoadTM·min⁻¹ when all playing positions were combined. Small to very large differences were found between playing positions, with backs and pivots showing the highest PlayerLoadTM·min⁻¹ values. Differences in HIE among playing positions were also apparent, with back players showing highest values of HIE·min⁻¹ (5.02 ± 1.05 HIE·min⁻¹). In addition, national-level outfield players showed lower values of HIE·min⁻¹ than international players (Effect Size; ES: 0.61-1.13). In international matches, a substantially higher PlayerLoadTM·min⁻¹ in the first 10 minutes of the first half, compared to the following 10-min periods for outfield players was observed. Substantial declines in PlayerLoadTM·min⁻¹ were observed throughout matches for players with several consecutive 5-min periods on the field. When comparing game-based training drills, backs (ES: 1.63), wings (ES: 1.91), and pivots (ES: 1.58) had greater PlayerLoadTM·min⁻¹ in 3vs3 than 6vs6. Substantially greater HIE·min⁻¹ in 3vs3 was also observed for all positions. There was substantially greater PlayerLoadTM·min⁻¹ in 3vs3 and 6vs6 than in match for backs, wings, and pivots. Wings (ES: 1.95), pivots (ES: 0.70), and goalkeepers (ES: 1.13) had substantially greater HIE·min⁻¹ in 3vs3 than in match. In the validation of LPS, measures of position, distance travelled, and average speed from the LPS showed low errors (<35 cm, <2%, and <3%, respectively). However, instantaneous speed calculated from the raw data showed large errors ($\geq 33\%$).

In conclusion, the studies show that PlayerLoadTM and HIE count was reliable, as long as it was not divided into intensity bands. The studies demonstrated a high occurrence of HIEs in female team handball. Differences existed between playing positions and between playing standards in the number of HIEs in match play. The results also suggest that PlayerLoadTM·min⁻¹ is not sustained throughout matches in international female team handball matches. The number of players involved in game-based training drills appeared to affect the intensity of the drill, whereby a lower number of players resulted in an increase of both PlayerLoadTM·min⁻¹ and HIE·min⁻¹. Positional differences were apparent when comparing the intensity of game-based training drills to official matches. Wings showed higher HIE·min⁻¹ in training than matches, while backs and pivots did not. Lastly, measures of position, distance, and mean speed from the investigated LPS can be used confidently in time-motion analyses for indoor team sports, provided that positioning between field of play and walls/corners and anchor nodes are appropriate.

Sammenndrag (summary in Norwegian)

Teknologisk utvikling har gjort det mulig å få en mer presis innsikt i fysiske arbeidskrav i lagidretter, inkludert innendørsidretter som ikke kan benytte seg av globale navigasjonssatellittsystemer. Hovedformålet med denne oppgaven var å undersøke fysiske arbeidskrav hos kvinnelig håndballspillere på høyt nivå, ved å bruke bevegelsessensorer (inertial measurement units; IMU). I tillegg var et formål å validere et kommersielt tilgjengelig lokal posisjoneringssystem (LPS) for innendørsbruk.

Totalt deltok 75 håndballspillere i de fire studiene som ble gjennomført (studie I-IV), inkludert utøvere fra internasjonalt, nasjonalt og lavere nivå. For å undersøke reliabiliteten til IMU for måling fysisk aktivitet i håndball ble det brukt et mellom-enhet oppsett (studie I). I studie II ble det brukt ett observasjon-design, for å undersøke fysiske arbeidskrav i internasjonal kamper. I studie III var formålet å undersøke fysiske arbeidskrav i ulike spill-baserte treningsøvelser, og sammenligne de med offisielle kamper. Dette ble gjort ved observasjon av foreskrevet treningsøvelser og offisielle kamper. Validiteten av ett LPS (Catapult ClearSky T6, Catapult Sports, Melbourne, Australia) ble undersøkt i studie IV, i en innendørshall. LPS ble sammenlignet med ett kamerasystem basert på infrarød teknologi. I studiene I-IV ble det brukt IMU (OptimEye S5, Catapult Sports, Melbourne, Australia), som inneholder et akselerometer, gyroskop og magnetometer, som alle samler inn data med en frekvens på 100 Hz. I studiene hadde deltakerne på seg en vest (Catapult Sports, Melbourne, Australia) som IMUene var festet i. I studie II-IV ble deltakerne kategorisert i fire spillerposisjoner; bakspillere, kantspillere, strekspillere og målvakter. Rådataene fra IMUene ble konvertert til variablene PlayerLoad™ og høy-intensitetsaksjoner (HIA) ved hjelp av Catapult Sports sin programvare. Alle HIA $>2,5 \text{ m}\cdot\text{s}^{-1}$ ble inkludert i studien. I studie I ble flere variasjoner av variablene undersøkt, inkludert inndeling av HIA i intensitetskategorier og PlayerLoad_{2D}. I studie V ble todimensjonal posisjonsdata brukt til å kalkulere distanse og momentan fart.

HIA-størrelse viste god reliabilitet (variasjonskoeffisient; VK: 3,1%) i vel-kontrollerte øvelser, men VK økte (4,4 – 6,7 %) i mer komplekse øvelser. Både PlayerLoad™ (VK <2 %) og antall HIA (VK <3 %) viste god reliabilitet. Kampdata fra internasjonale

kvinnelige håndballkamper viste gjennomsnittsverdier på $8,82 \pm 2,06$, når alle spillerposisjonene ble slått sammen. Forskjeller ble funnet mellom de ulike spillerposisjonene, der bakspillere og strekspillere fremstilte høyest verdier av $\text{PlayerLoad}^{\text{TM}} \cdot \text{min}^{-1}$, mens målvakter hadde lavest verdier. Forskjeller mellom spillerposisjonene ble også funnet for HIA, der bakspillere hadde høyest verdier ($5,02 \pm 1,05 \text{ HIA} \cdot \text{min}^{-1}$). Det ble også funnet forskjeller mellom internasjonalt og nasjonalt nivå, der spillere på nasjonalt nivå hadde lavere verdier av $\text{HIE} \cdot \text{min}^{-1}$ (Effekt størrelse; ES: 0,61-1,13). I internasjonale kamper ble det observert en høy $\text{PlayerLoad}^{\text{TM}} \cdot \text{min}^{-1}$ i de ti første minuttene av kampen, sammenlignet med de ti påfølgende minuttene for utespillerne. Det ble også observert nedgang i $\text{PlayerLoad}^{\text{TM}} \cdot \text{min}^{-1}$ gjennom kampen for spillere som hadde flere påfølgende 5-minutters perioder på banen. I sammenligningen av de spill-baserte treningsøvelsene hadde bakspillere (ES: 1,63), kanstspillere (ES: 1,91) og strekspillere (ES: 1,58) høyere $\text{PlayerLoad}^{\text{TM}} \cdot \text{min}^{-1}$ i 3vs3 enn i 6vs6. I tillegg ble det observert høyere $\text{HIA} \cdot \text{min}^{-1}$ i 3vs3 for alle posisjoner. Høyere $\text{PlayerLoad}^{\text{TM}} \cdot \text{min}^{-1}$ ble observert i både 3vs3 og 6vs6 sammenlignet med offisielle kamper for bakspillere, kantspillere og strekspillere. Kantspillere (ES: 1.95), strekspillere (ES: 0.70) og målvakter (ES: 1.13) hadde høyere $\text{HIA} \cdot \text{min}^{-1}$ i 3vs3 sammenlignet med offisielle kamper. I valideringen av det LPS så viser posisjon, distanse og gjennomsnittlig fart lave feilmarginer (henholdsvis $<35 \text{ cm}$, $<2 \%$, and $<3 \%$). Momentan fart viser derimot høyere feilmargin ($\geq 33 \%$).

Studiene viser at $\text{PlayerLoad}^{\text{TM}}$ og HIA er reliabelt, så lenge det ikke blir delt inn i smale intensitetskategorier. Studien demonstrerer også en høy forekomst av HIA i kvinnelige håndballkamper, samtidig som det vises at det er forskjeller mellom spillerposisjonene, og mellom spillnivå. Resultatene tyder også på at PL ikke blir opprettholdt gjennom kamper, spesielt for spillere med flere påfølgende perioder på banen. Antall spillere på banen i spill-baserte treningsøvelser kan påvirke intensiteten av øvelsen, og ett lavere antall spillere resulterte i høyere $\text{PlayerLoad}^{\text{TM}} \cdot \text{min}^{-1}$ og $\text{HIA} \cdot \text{min}^{-1}$. Forskjeller mellom spillerposisjonene ble observert når de spill-baserte treningsøvelsene ble sammenlignet med offisielle kamper. Avslutningsvis, variablene posisjon, distanse og gjennomsnittsfart kan med sikkerhet brukes for analyse av innendørsidretter, så lenge posisjoneringen mellom spillarealet og vegger/hjørner og systemet er tilfredsstillende.

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```
% Matthias, Amelie and Marie - thank you for your patience when I was
trying to learn MatLab
help = [Matthias;Amelie;Marie];
newb = Live;
trial = properties(help);
for i = 1:length(trial)
    MatLabSkillsImprovement = newb .* help.(trial{i});
    gratitude = ∞.* help.(trial {i});
end
```

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Oslo, May 2018 Live S. Luteberget

List of papers

This dissertation is based on the following original research papers, which are referred to in the text by their Roman numerals. The articles are reprinted with the permission of the publisher.

- I. **Luteberget, L. S.**, Holme, B. R., & Spencer, M. (2017). Reliability of Wearable Inertial Measurement Units to Measure Physical Activity in Team Handball. *International Journal of Sports Physiology and Performance*, 32, 1–24. doi: 10.1123/ijsp.2017-0036 – *in press*
- II. **Luteberget, L. S.**, & Spencer, M. (2017). High Intensity Events in International Female Team Handball Matches. *International Journal of Sports Physiology and Performance*, 12, 56–61. doi: 10.1123/ijsp.2015-0641
- III. Wik, E. H., **Luteberget, L. S.**, & Spencer, M. (2017). Activity Profiles in International Female Team Handball Using PlayerLoad TM. *International Journal of Sports Physiology and Performance*, 12(7), 934–942. doi: 10.1123/ijsp.2015-0732
- IV. **Luteberget, L. S.**, Trollerud, H. P., & Spencer, M. (2017). Physical demands of game-based training drills in women’s team handball. *Journal of Sports Sciences*, 1–7. doi: 1080/02640414.2017.1325964
- V. **Luteberget, L. S.**, Spencer, M., & Gilgien, M. (2018). Validity of the Catapult ClearSky T6 Local Positioning System for Team Sports Specific Drills, in Indoor Conditions. *Frontiers in Physiology*, 9, 115. doi: 10.3389/fphys.2018.00115

Abbreviations

Abs	Absolute
AU	Arbitrary Units
CI	Confidence interval
CL	Confidence limits
cm	Centimeters
CoD	Changes of direction
CV	Coefficient of variation
ES	Effect size
GK	Goalkeeper
GNSS	Global navigation satellite system
GPS	Global positioning system
HIE	High intensity event
Hz	Hertz
ID	Identifier
IMU	Inertial measurement unit
LPS	Local positioning system
m·s ⁻¹	Meter per second
min ⁻¹	Per minute
mm	millimeters
MSP	Most strenuous period
n	Number
PL _{2D}	PlayerLoad™ two-dimensional
PL _{AP}	PlayerLoad™ anterior-posterior
PL _{ML}	PlayerLoad™ medio-lateral
PL _V	PlayerLoad™ vertical
SD	Standard deviation
SWD	Smallest worthwhile difference
TE	Typical error
vs	Versus

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Introduction

Team handball is an indoor team sport, played between two teams of seven players each. A match is 60 min (effective playing time), and the winner is the team with the most goals scored when the game is finished. Team handball has existed in its current form since the 1920s, when the first rules for indoor handball were drafted (Skjerk, 1999). The sport is now played worldwide, but is especially popular in Europe, with many professional leagues. Since 1972 team handball has also been an Olympic sport. Team handball performance is comprised of several different factors, including the technical, tactical, social and physical characteristics of players (Karcher & Buchheit, 2014; Wagner, Finkenzeller, Würth, & von Duvillard, 2014).

Analysis of movement profiles of team-sport athletes has been of interest to many researchers and sports scientists since the 1970s (Brooke & Knowles, 1974), and assessment of the physical demands in training and matches is now common practice in many professional team sports (Aughey, 2011; Dellaserra, Gao, & Ransdell, 2014). Analyses of matches can provide important insights and a better understanding of the workload, physical performance and match demands, which may help to improve the practice of training and the physical development of players (Cunniffe, Proctor, Baker, & Davies, 2009; Di Salvo et al., 2007; Michalsik, Madsen, & Aagaard, 2014a), and assist in load management (Pyne, Spencer, & Mujika, 2014; Scott, Lockie, Knight, Clark, & Janse de Jonge, 2013). Research on physical demands in team sports have typically focused on field-based male athletes (Aughey, 2011). Thus, scientific knowledge of the physical demands in court-based sports, including team handball, is limited (Karcher & Buchheit, 2014). In addition, female athlete are underrepresented in sports research (Costello, Bieuzen, & Bleakley, 2014), including research in team handball.

The technology used for analysis of physical demands in team sport has developed during the last decade. These developments have made it possible to use more sophisticated methods of analysis than have previously been applied to indoors sports. Therefore, this thesis aims to investigate the physical demands of female team handball players in both matches and training.

Background

Match analysis in team handball

In team handball, as in other team sports, a high level of physical conditioning is required for elite players to be able to exploit their technical and tactical qualities in play (Gabbett, King, & Jenkins, 2008; Manchado, Tortosa, et al., 2013). Knowledge of the physical demands of a sport can improve the planning and execution of optimal training, and the understanding of physical performance and injury risk in sports. Such analyses are therefore conducted in many individual and team sports (Bangsbo, Mohr, & Krstrup, 2006; Gabbett, 2013; Gilgien, Spörri, Chardonens, Kröll, & Müller, 2013; Michalsik et al., 2014a; Montgomery, Pyne, & Minahan, 2010; Póvoas et al., 2014b). The movement of athletes can be captured via different tracking technologies, such as global positioning systems (GPSs) or video-based analysis. Such systems estimate an athlete's position, and displacement, speed, and acceleration over time can then be calculated. Such analyses are often called position-based or time-motion analyses, and is a common method to quantify the physical demands of players during match and training. Such analyses can provide a scope for a better understanding of the specific and positional physical demands of team sports (Cummins, Orr, O'Connor, & West, 2013). Research on team sports has typically focused on distance covered and time or distance spent at varying speeds. Threshold values of speed are used to group time or distance into different categories. Such categories are often given a qualitative descriptor, such as walking, running or sprinting. In indoor sports, such as team handball, video-based analysis has been the main method used to analyze time-motion variables (Chelly et al., 2011; Karpan, Bon, & Sibila, 2015; Manchado, Pers, et al., 2013; Manchado, Navarro-Valdivielso, Pers, & Platen, 2008; Michalsik et al., 2014a; Michalsik, Aagaard, & Madsen, 2013; Póvoas et al., 2012, 2014b; Sibila, Vuleta, & Pori, 2004).

Total distance covered during a match is reported to be between ≈ 3 and ≈ 5 km for male players (Cardinale, Whiteley, Hosny, & Popovic, 2017; Michalsik et al., 2013; Póvoas et al., 2012, 2014b; Sibila et al., 2004) and between ≈ 2 and ≈ 5 km for female players (Manchado, Pers, et al., 2013; Michalsik et al., 2014a). Specific playing position is shown to account for some of the variation in the total distance covered. Specifically, backcourt players were found to cover 15% and 21% more, respectively, than wings and pivots for

male players (Póvoas et al., 2014b). For female players, wing players have been shown to cover the largest total distance in matches (Michalsik et al., 2014a). Most of the total distance covered is executed with low-intensity activity. For male players, 56-77% of the total distance covered was classified as walking or jogging (Cardinale et al., 2017; Michalsik et al., 2013; Póvoas et al., 2012, 2014b). For female players the amount of walking or jogging is reported to be 60-80% (Manchado, Pers, et al., 2013; Michalsik et al., 2014a). Fast running accounted for approximately 6-16% and 2-30%, for male and female players respectively. Distance covered at speeds defined as sprinting is reported to be low, ranging from 1.5-3.9% for male players, and 0.2% for female players (Cardinale et al., 2017; Michalsik et al., 2014a, 2013, Póvoas et al., 2012, 2014b). Position-related demands may be a main contributor to the large variation displayed in distance covered, but individual variation in conditioning capacities and movement patterns not related to playing position should also be acknowledged (Póvoas et al., 2014). In addition, varying on-field time and varying classification of speed categories in different studies may also contribute to some of the range reported (Sweeting, Cormack, Morgan, & Aughey, 2017).

While distance covered and speed can be good indicators of the workload in many instances, there are also movements such as rapid changes of direction, tackles/collisions, accelerations, and jumps present in many team sports (Gastin, McLean, Spittle, & Breed, 2013; Michalsik, Aagaard, & Madsen, 2015; Póvoas et al., 2014b; Varley & Aughey, 2012). Such actions are not easy to quantify using position-based systems, due to the short duration of the tasks and the fact that they do not necessarily result in displacement of the athlete. However, such actions are an important aspect of the physical workload that the athletes are subjected to during a match or training (Gastin, Mclean, Breed, & Spittle, 2014; Osgnach, Poser, Bernardini, Rinaldo, & di Prampero, 2010; Varley & Aughey, 2012). Even though the accelerative nature of handball is poorly described in the available literature, there appears to be no doubt that acceleration and other high intensity actions are an important part of the game, and that handball players' performance depends on these variables. The ability to accelerate, quickly change direction, jump, and throw are factors that often are mentioned in published studies as important for top-level playing performance in team handball (Manchado, Tortosa, et al., 2013; Michalsik, Madsen, & Aagaard, 2014b; Michalsik et al., 2013; Póvoas et al., 2012, 2014b).

Background

Some studies have included counts of various physical high-intensity actions, such as jumps, changes of direction, shots, tackles and one-on-one situations (Michalsik et al., 2014b, 2015; Póvoas et al., 2014b). The number of jumps was reported to be 10.4 per player on average; however, there was a large difference between playing positions, with backcourt players and pivots completing a high number of jumps (19.1 and 14.0 jumps, respectively) compared to wings (3.8 jumps). The number of tackles is also shown to differ between playing positions. Male players have been shown to be involved in ≈ 65 tackles during a match, while female players are involved in ≈ 35 tackles, with pivots showing higher numbers than backs and wing players (Michalsik et al., 2014b, 2015). When combining all actions investigated, it is evident that male players on average perform ≈ 100 high-intensity actions during a single match (Michalsik et al., 2014b; Póvoas et al., 2014b), while female players perform ≈ 75 high-intensity actions (Michalsik et al., 2015). The data were attained by video analysis in these studies and there are some methodical limitations to quantifying the intensity of these actions using this technique. However, these studies provide an indication that handball players perform a large number of high-intensity actions during match play.

Changes in physical output during match play

In addition to investigate the overall physical demands of match play in team sports, some studies have also investigated changes in physical output during match play. A consistent finding in time–motion studies of team handball is overall decreases in high-intensity activity in the second half both for male and female players (Michalsik et al., 2014a, 2013, Póvoas et al., 2012, 2014a). In addition, studies have reported declines in physical performance after team handball match play (Póvoas et al., 2014a; Ronglan, Raastad, & Børghesen, 2006; Thorlund, Michalsik, Madsen, & Aagaard, 2008). These findings are in accordance with findings in other team sports (Bangsbo et al., 2006; Cormack et al., 2014; Jones, West, Crewther, Cook, & Kilduff, 2015; Mohr, Krusturup, & Bangsbo, 2003). Furthermore, activity levels have been reported to be below the match average five minutes after the most intense period of soccer games, with values restored to baseline values ten minutes after this period (Akenhead, Hayes, Thompson, & French, 2013; Bradley & Noakes, 2013). Decreased activity in the five minutes after a peak period is also reported by a similar study of rugby league (Kempton, Sirotic, & Coutts, 2015). These results support the occurrence of transient fatigue or pacing in

team sports. However, the occurrence of transient fatigue or pacing have, to my knowledge, not been investigated in team handball.

Game-based training in team handball

The complexity of team handball requires economical training regimes to include all the important performance factors. Game-based training, which also often is referred to as small-sided games or skill-based conditioning games, are modified games – often involving modified rules, numbers of players, or field/court size. Game-based training is a commonly used training modality, which is used as a means of improving the technical and physical skills, while maintaining a competitive environment (Gabbett, Jenkins, & Abernethy, 2009). Thus, game-based training drills promotes training effectiveness via a combination of the different components of the game (Gabbett, 2010; Hill-Haas, Dawson, Impellizzeri, & Coutts, 2011). Indeed, game-based training drills are commonly used to improve technical and tactical skills in many team sports, and it has been shown that such drills provide an aerobic stimulus comparable with traditional interval-training methods in team handball (Buchheit et al., 2009; Iacono, Eliakim, & Meckel, 2015).

Due to the incorporation of game-based training drills in many team sports, several studies have been conducted to look at the physical demands of such drills. A variety of prescriptive factors that can be controlled by the coach have been shown to affect the intensity of game-based training in team sports, including the number of players involved, field/court size, work:rest ratio, and different rule modifications (Bělka et al., 2016; Corvino, Tessitore, Minganti, & Sibila, 2014; Alexandre Dellal, Logo-Penas, Wong, & Chamari, 2011; Rampinini, Impellizzeri, et al., 2007). For example, there is usually an increase in heart rate, lactate concentration, Rating of Perceived Exertion (RPE) and greater total distance covered with fewer players participating in game-based training drills (Bělka et al., 2016, 2017; Foster, Twist, Lamb, & Nicholas, 2009; Rampinini, Impellizzeri, et al., 2007).

Although there is a substantial growth in research related to game-based training in team sports, there is a lack of research specific to team handball. To my knowledge, a limited number of studies have investigated the effect of different factors on the intensity of game-based training in team handball (Bělka et al., 2016, 2017; Corvino et al., 2014; Dello Iacono et al., 2016). It is shown that the court size (Corvino et al., 2014), rules

modifications (Dello Iacono et al., 2016), and number of players involved (Bělka et al., 2016, 2017) in game-based training affect the intensity, as in other team sports. However, to my knowledge, no studies in team handball have investigated the intensity of game-based training in the context of playing positions. As the physical demands are different between playing positions in matches (Michalsik et al., 2014a), it would be interesting to investigate if these differences are present in training drills as well.

As game-based training mimics specific game demands, it is assumed that the training provides an effective transfer to match play (Aguiar, Botelho, Lago, Maças, & Sampaio, 2012). Some studies have investigated how the intensity in game-based training drills compares to the intensity in friendly or official matches in soccer (A Dellal et al., 2012; Gabbett & Mulvey, 2008). It was found for female soccer players that game-based training simulates the overall movement patterns of official matches (Gabbett & Mulvey, 2008). However, the study also showed that game-based training did not elicit the same high values of repeated sprints as in international matches (Gabbett & Mulvey, 2008). There are, to my knowledge, no studies comparing the intensity of game-based training to the intensity of official matches in team handball.

Advances in tracking technology

To measure the parameters that describe these physical demands, Global Navigation Satellite Systems (GNSS; e.g. GPS) are among the most frequently used methods for kinematic metrics in team sports (Malone, Lovell, Varley, & Coutts, 2016). GNSS technology is now capable of efficiently collecting positional data for players throughout the duration of a match or training session (Carling, Bloomfield, Nelsen, & Reilly, 2008). The main drawback of GNSS is its restriction to outdoor facilities; thus indoor sports, such as team handball, are in general not able to use GNSS for tracking of players in competitions or training. Consequently, video-based analysis has been the main method used to analyze position-related variables in indoor sports.

Technological advances in the last decade, have made it possible to produce local positioning systems (LPSs). In addition, the development of micro-technology in sports has led to the integration of inertial measurement units (IMUs) in match and training analyses. These systems do not require satellite coverage and can thus be used in indoor sports.

Inertial measurement units

Inertial sensors, such as accelerometers (acceleration sensors) and gyroscopes (angular rate sensors), are often collectively called inertial measurement units (IMUs). IMUs were initially used for gait analyses (e.g. Aminian & Najafi, 2004; Kavanagh & Menz, 2008); however, the use of IMUs is growing, especially in team sports (Chambers, Gabbett, Cole, & Beard, 2015). High sampling frequencies, small size (and low weight), and the lack of interference with athletes' technique have favored the use of IMUs in the field of sport science.

There are several different manufacturers of IMUs (integrated with GNSSs or LPSs) designed for monitoring team-sport athletes, including Catapult Sports in Australia (ClearSky, MinimaxX, and OptimEye), ChyronHego in USA (ZXY Arena) and STATSports in Ireland (Viper pod). In addition to their respective hardware technology, these manufacturers have developed specific algorithms within the software to automatically convert the raw IMU data into readily usable metrics for physical demand analysis in team sports. In general, these variables can be categorized into so-called workload variables or event detection variables (Chambers et al., 2015). Workload variables have been used as a general measure of physical activity, and aim to measure both running-based activity and non-running-based activity (Boyd, Ball, & Aughey, 2011; Chambers et al., 2015). PlayerLoad™ from Catapult Sports is an example of a workload variable (Boyd et al., 2011). Event detection variables register the frequency and magnitude, and distinguish between different non-running-based activities, such as changes of direction and tackles/collisions (Gabbett, Jenkins, & Abernethy, 2010; Meylan, Trewin, & McKean, 2017). Workload variables are based on accelerometer data only, while event detection variables include gyroscope data. Multiple studies have previously investigated the validity and reliability of the use of IMUs in team sports, both for workload variables (Barreira et al., 2016; Barrett, Midgley, & Lovell, 2014; Boyd et al., 2011; Hollville, Couturier, Guilhem, & Rabita, 2016; Walker, McAinch, Sweeting, & Aughey, 2016), and event detection variables (Hulin, Gabbett, Johnston, & Jenkins, 2017; McNamara, Gabbett, Chapman, Naughton, & Farhart, 2015; Meylan et al., 2017; Wundersitz, Josman, et al., 2015).

Background

PlayerLoad™ has been found to have a high correlation with total distance covered (Gallo, Cormack, Gabbett, Williams, & Lorenzen, 2015; Polglaze, Dawson, Hiscock, & Peeling, 2015), and has also been shown to correlate with measures of heart rate and energy expenditure (Barrett et al., 2014; Walker et al., 2016). Boyd et al. (2011) investigated both the within-device and between-device reliability for PlayerLoad™ in MinimaxX devices. They found a within-device CV of 0.9-1.1%, and a between-device CV of 1.0-1.1% for PlayerLoad™, using a mechanical shaker. They also demonstrated a between-device reliability of 1.9% in Australian football matches. Meylan et al. (2016) used video synchronization to investigate the validity of the manufacturers' classification of different event detection variables (acceleration/deceleration/changes of direction) in soccer. They found MinimaxX S4 and its software correctly identified all cases of high acceleration, deceleration and change of direction, indicating a high validity for the event variables (Meylan et al., 2017). Collision sports, such as rugby and Australian rules football, have used this to automatically detect collisions and tackles (Gabbett et al., 2010; Gastin et al., 2014, 2013; Hulin et al., 2017; Kelly, Coughlan, Green, & Caulfield, 2012).

Despite the growing interest and literature available for IMU technology, there have been, to my knowledge, no studies investigating the use of IMU in team handball. As a high number of high-intensity actions are reported in team handball (Michalsik et al., 2014b; Póvoas et al., 2014b), the integration of IMUs for use in match and training analyses can provide effective detection of high intensity movements.

Local positioning systems

LPSs are based on the same technology as GNSS, but instead of using global satellites, they are dependent on local base stations (anchor nodes). There are several commercially available LPSs for use in sports, including ClearSky T6 (Catapult Sports, Australia), InMotio LPM (Inmotio Object Tracking BV, Netherlands), and Swiss Timing LPS (Swiss Timing, Switzerland). Most LPSs used in team sports are radio-frequency based (Frencken, Lemmink, & Delleman, 2010; Leser, Schleindhuber, Lyons, & Baca, 2014; Muthukrishnan, 2009; Ogris et al., 2012; Rhodes, Mason, Perrat, Smith, & Goosey-Tolfrey, 2014; Sathyan, Shuttleworth, Hedley, & Davids, 2012; Stevens et al., 2014), in which radio-frequency signals are used to measure the distance between several anchor nodes, at known locations, distributed around the field of play, and mobile nodes worn

by the athletes (Hedley et al., 2010; Muthukrishnan, 2009). The accuracy of LPS is mainly dependent on signal type; environmental conditions, such as obstructions and materials in the surroundings of the field of play; the geometry between signal anchor nodes and the units on the athletes; and the signal analysis and parameter calculation process (Malone et al., 2016; Muthukrishnan, 2009).

The use of LPSs for analyses in team sports is relatively new, and the first study investigating the validity of LPSs in a sport setting was published in 2010 (Frencken et al., 2010). From 2010 to 2016, to my knowledge, only six studies were published in this area (Frencken et al., 2010; Leser et al., 2014; Ogris et al., 2012; Rhodes et al., 2014; Sathyan et al., 2012; Stevens et al., 2014). The mean error in distance is reported to be 1.3% - 3.5% (Frencken et al., 2010; Leser et al., 2014; Rhodes et al., 2014; Sathyan et al., 2012; Stevens et al., 2014). Some studies show an underestimation of distance with LPSs (Frencken et al., 2010; Leser et al., 2014; Stevens et al., 2014), while others find overestimations (Rhodes et al., 2014; Sathyan et al., 2012). These differences could be due to differences in the filtering techniques applied in generating the trajectories (Sathyan et al., 2012). It is shown that LPSs elicit a higher variability in distance when the complexity of the task increases, and when speed increases (Frencken et al., 2010; Ogris et al., 2012; Rhodes et al., 2014; Sathyan et al., 2012; Stevens et al., 2014).

Mean speed has been investigated in several studies (Frencken et al., 2010; Ogris et al., 2012; Rhodes et al., 2014; Stevens et al., 2014), and is often used as an overall indicator of the intensity of an activity. Frencken et al. (2010) found a mean speed difference of $0.1 \text{ km}\cdot\text{h}^{-1}$ for walking, while the difference increased to $0.4 \text{ km}\cdot\text{h}^{-1}$ in sprinting. Similarly, Ogris et al. (2012) found mean absolute speed differences ranging from 0.01 to $0.71 \text{ km}\cdot\text{h}^{-1}$ in the different tasks, with the highest errors occurring when players executed a 90° turn. In small-sided games the mean absolute speed difference was $0.32 - 0.46 \text{ km}\cdot\text{h}^{-1}$ (Ogris et al., 2012). Thus, a higher variability in mean speed seems to be present in tasks involving fast changes of direction (Frencken et al., 2010; Ogris et al., 2012; Stevens et al., 2014). Peak speed shows a higher variability than mean speed (Ogris et al., 2012; Rhodes et al., 2014; Stevens et al., 2014). For peak speed, Ogris et al. (2012) reported a difference in a LPS compared to a reference system of 10%. However, two later studies displayed considerably lower errors (2 - 4%) in peak speed (Rhodes et al.,

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2014; Stevens et al., 2014). In addition to mean and peak speed, instantaneous speed is often used in match and training analyses. Distance data are often categorized into speed zones in order to provide a more comprehensive metric for “intensity distribution” of the athletes` physical demands (Malone et al., 2016). Such categorization relies on instantaneous speed measurements. To my knowledge, no studies have investigated the validity of instantaneous speed measurements for LPSs.

In commercial positioning systems, data processing, such as derivation of kinematic metrics from position data, may vary between different LPS (and GNSS) systems, and even between different software in the same commercial product (Malone et al., 2016). However, the derivation of metrics is often not elucidated in the manufacturer`s documentation, which complicates comparisons between different systems and software (Malone et al., 2016; Specht & Szot, 2016). Currently, multiple LPSs are commercially available, which differ in data acquisition technology, sampling rates and data processing steps. Thus, the validity of one system does not apply to other systems, and individual validation of each system is required. Although the current available data seems promising, there is a need for more studies to confidently state that LPS is valid in a range of sports in different conditional settings.

Purpose

In light of the current literature available, the purpose of this study was to examine the physical demands of high-level female team handball players. Given the constraints of the current available data mentioned in the introduction, the thesis aimed to investigate the physical demands with the use of IMUs. The specific aims of the thesis were:

- to assess the between-device reliability of commercially available IMUs to measure physical demands in team handball
- to investigate the position-specific high-intensity events (HIEs) in international women`s team handball matches with the use of IMUs, and to investigate activity profiles of international women`s team handball matches
- to compare training intensity in game-based training with official matches
- to investigate the validity of position, distance travelled, and instantaneous speed measurements of a commercially available LPS

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Participants

In total, 75 participants volunteered to participate in one or more of the studies in this thesis (Table 1). Study I and study III included national-level team handball players, study II included international-level team handball players, while study IV included active team handball players of varying levels. Studies II and III included female participants only, while studies I and IV included both male and female participants. All studies were completed in accordance with the Helsinki declaration and according to the Norwegian law, and was approved by the Norwegian Centre for Research Data (Appendix I).

Table 1: Subject characteristics in studies I-IV.

Study	Paper		n	Level	Age (years)	Height (cm)
I	I	Laboratory assessment	10	National	21.2 ± 1.3	175.1 ± 7.4
		Field assessment	12	National	23.8 ± 4.6	192.3 ± 9.1
II	II		20	International	25.0 ± 3.8	175.3 ± 4.5
II	III		18	International	25.4 ± 3.8	175.3 ± 4.5
III	IV		31	National	22.2 ± 3.3	171.1 ± 6.4
IV	V		4	Varying	23.0 ± 2.2	172.3 ± 10.1

Note: Data are mean ± standard deviation

When conducting research involving human participants, one should always aim to minimize the harms and risk involved. Participation in the studies involved wearing IMUs in training or matches, and could in theory increase the risk of injuries. However, I could not find any published or anecdotal information of injuries involving these kinds of analyses. While participants in study II did not receive any additional trainings or matches, or changes to their training scheme, participants in study I, III and IV did. To minimize the injury risk for these participants, thorough warm-up routines were implement. We considered the injury risk not to be different from their normal everyday training scheme.

Experimental approach

To examine the reliability of IMUs for measuring physical activity in team handball players, a between-devices setup was used (Study I). In study II, an observational design was used to investigate the physical demands of female team handball players in international matches. Study III aimed to investigate the physical demands of different game-based training drills, and compare them to each other and to official matches. This was done by monitoring of prescribed training sessions and official matches. In study IV, an LPS was validated against an infra-red-based camera system. Data collection for studies I, III and IV was conducted in the first half of the in-season period. Data collection for study II was conducted throughout a full competitive season (2014/15). Study IV, and the laboratory assessment of study I, were conducted in the sports hall at The Norwegian School of Sport Sciences, while the other studies were conducted in different sports halls in Norway, Denmark and France.

Equipment and variables

IMU

Studies I-III all included the use of IMUs (OptimEye S5, Catapult Sports, Melbourne, Australia), containing an accelerometer, gyroscope and magnetometer, all collecting data at 100 Hz. The IMU measured length: 52 mm x height: 96 mm x depth: 13 mm, and weighed \approx 70 grams. In all studies, the participants wore the IMU on the posterior side of the upper trunk, in a manufacturer-supplied vest (Catapult Sports, Melbourne, Australia). In study I, participants were instrumented with two IMUs. The two devices were taped together to minimize misalignments of the devices. In studies II and III each participant wore only one device. All data collection was monitored in real time using the manufacturers' software (Sprint, version 5.1.4, Catapult Sports, Melbourne, Australia).

After data acquisition, the raw data from the IMU was downloaded from the devices and imported into the software. The software converts the raw data into the main variables used, PlayerLoad™ and inertial movement analysis (IMA) variables. PlayerLoad™ (Equation 1) is an arbitrary unit defined as the square root of the sum of the instantaneous rate of change in acceleration from three vectors, divided by a scaling factor of 100 (Boyd et al., 2011). PlayerLoad™ was expressed in its original formula in studies I-III, in addition to variations of this metric, including PlayerLoad's individual axes: anterior-

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posterior (PL_{AP}), medio-lateral (PL_{ML}) and vertical (PL_V) and PlayerLoad 2D (anterior-posterior and medio-lateral axes; PL_{2D}) in study I.

$$PlayerLoad^{TM} = \sqrt{\frac{(a_{y1}-a_{y-1})^2 + (a_{x1}-a_{x-1})^2 + (a_{z1}-a_{z-1})^2}{100}} \quad (1)$$

IMA uses raw accelerometer and gyroscope data to create a non-gravitational acceleration vector based on Kalman filtering algorithms. These algorithms detect specific acceleration events, which can be regarded as instant one-step movement events (e.g., sudden changes of direction). From here on, IMA events are termed high-intensity events (HIE). The magnitude of an event is calculated by integrating the event, based on the sum of anterior-posterior and medio-lateral accelerations. HIE magnitude is expressed as change in velocity ($m \cdot s^{-1}$). The direction of an event is calculated relative to the device's orientation at the time of the event, and is based on the angle of the applied acceleration and is measured in degrees ($\pm 180^\circ$). In contrast to PlayerLoadTM (and its variations) that include all data, HIE has a magnitude inclusion criteria (default from manufacturer: $>1.5 m \cdot s^{-1}$). The number of HIEs (HIE counts) was categorized into the manufacturers' default intensity bands: low (1.5 to $2.5 m \cdot s^{-1}$); medium (2.5 to $3.5 m \cdot s^{-1}$); and high ($>3.5 m \cdot s^{-1}$) in study I, while only one band was used in studies II-IV ($>2.5 m \cdot s^{-1}$). HIE count was also categorized within specific directional bands, based on direction. These included forward (-45 to 45°), backward (-135 to 135°), left lateral (-135 to -45°) and right lateral (45 to 135°) counts.

LPS

In study IV, the validity of an LPS (Catapult ClearSky T6, Catapult Sports, Melbourne, Australia) was investigated. The LPS consists of anchor nodes, which are nodes with a known location, and mobile nodes worn by the participants. The LPS was set up with sixteen anchor nodes in fixed positions around the handball court (Figure 5), to capture participants' movements at a reported capturing frequency of 20 Hz. The LPS was set up to cover a field size of 20 x 40 m. The mobile node measured length: 40 mm x height: 52 mm x depth: 14 mm, and weighed ≈ 28 grams. The mobile nodes used the firmware version 1.40. Similar to the IMU device, the mobile node was located on the posterior side of the upper trunk, in a manufacturer-supplied vest (Catapult Sports, Melbourne, Australia). Data acquisition was conducted using the manufacturer's software

(OpenField, Version 1.13.4, Catapult Sports, Melbourne, Australia). A tachymeter (Leica Builder 509 Total Station, Leica Geosystems AG, Heerbrugg, Switzerland) was used to spatially calibrate the LPS before commencement of the data acquisition.

Infrared light-based camera system

In study IV, an infrared light-based camera system (Qualisys Oqus, Qualisys AB, Gothenburg, Sweden) was used as the reference system. An 8-camera setup, mounted on tripods, was used to track an area of 10 x 14 m, using a capturing frequency of 100 Hz. A reflective marker of 12 mm in diameter was mounted on the LPS mobile node's center, to obtain the three-dimensional position. The system was spatially calibrated according to the manufacturer's recommendations preceding data acquisition. Infra-red camera systems, such as the reference system in this study, can provide accuracy within an error range of millimeters (Chiari, Della Croce, Leardini, & Cappozzo, 2005; Jensenius, Nymoen, Skogstad, & Voldsund, 2012; Windolf, Götzen, & Morlock, 2008). The accuracy is dependent on the number of cameras used, capturing volume, technical specifications and settings of system parameters (Jensenius et al., 2012; Windolf et al., 2008). In the current study, the calibration was carried out using a calibration wand, with an exact length of 749.2 mm. The calibration resulted in standard deviations (SDs) of 6.14 mm and 6.85 mm of the wand length, for optimal and sub-optimal conditions, respectively.

Data acquisition

Study I

In study I, a between-device setup was used to investigate the reliability of wearable IMUs to measure physical activity in team handball players. All participants were instrumented with two IMUs (OptimEye S5). The two devices were taped together to minimize misalignments between the two devices. Both the laboratory assessment and the field assessment were conducted in indoor sports halls. The laboratory assessment consisted of seven different movement tasks (Figure 1). Four tasks consisted of a single one-step movement action (one-step action), performed in different directions. These efforts are described as a start action (T1), stop action (T2), left changes of direction (T3) and right changes of direction (T4). Three tasks involved repeated changes of direction (T5), start and stop actions (T6), and multidirectional changes of direction (T7). In T1-T6 the

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subjects were instructed to face forward throughout the duration of the task (Figure 1). T3-5 included cutting movements, while T7 included turning movements. Subjects were instructed to give maximal effort in all tasks. All tasks were repeated four times, and subjects were given a two-minute recovery between trials.

The field assessment consisted of 12 handball-training sessions. All sessions were performed as planned by the coach, with no interference from the researcher. The training sessions consisted of a warm-up, technical and tactical drills, transition games, and game simulations. A separate period was created for each drill in the software. Rest periods and interchanges were excluded. The analysis thus consisted of only active periods, which accounted for 63.8 ± 7.2 min.

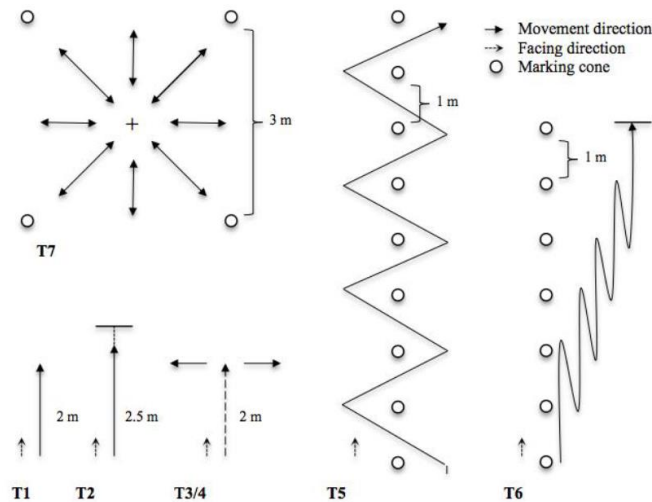


Figure 1: Illustration of the tasks executed in the laboratory assessment. Well-controlled one-step actions: start action (T1), stop action (T2), CoD (T3 and T4). Chaotic movement patterns: lateral CoD (T5), start-stop action (T6), and multidirectional CoD (T7). CoD = Change of direction.

Study II

In study II, match data from female national team players, competing in nine international matches was collected. The nine matches included in the studies were a part of the Golden League tournament, which is a series of three 4-nation tournaments over a single season (Figure 2). During the tournament, the team participating in the studies experienced four

losses and five wins. Participants were equipped with one IMU during matches. Other than participants wearing the IMU, the study did not intervene in any of the participants' pre-match routines or in the matches. All participants were familiarized with wearing the IMU in training sessions before the commencement of the study.



Figure 2: Timeline displaying the matches played in the 2014/15 Golden League tournament series, including rest days, and time between tournaments.

Data collection was monitored in real time using the manufacturers' software. Interchanges were manually tracked, ensuring that only time spent on the field was included in the analyses. During timeouts, all players' IMUs were deactivated. As interchanges were frequent and could involve several players; the interchange area was video recorded and notes were made. Thus, uncertainties and eventual errors in interchanges could be corrected post-match.

Participants were divided into four different playing positions; back (left back, center back, and right back pooled together), wing (left wing and right wing pooled together), pivot, and goalkeeper (GK). Study II resulted in two papers (paper II and paper III). In paper II, an inclusion criterion of a minimum 5 min of on-field time was used. This resulted in 97 match-data samples. Of these, there were 44 backs, 25 wings, 14 pivots, and 14 GKs. Eight of the 44 backs were offensive players, meaning participants who were specialized to the offence part of the game throughout the whole duration of the match. In paper III all outfield players with a minimum of 1 min in at least one 5- or 10-min period were included. This resulted in 85 match-data samples; 46 backs, 24 wings, and 15 pivots.

Study III

Study III included measurements of both training sessions and official matches. Two teams were included in the study, and were each monitored in five training sessions, and five matches. Participants were each equipped with one IMU during both game-based training sessions and official matches. Monitoring of game-based training sessions was

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conducted at each team's respective home-court arena. Each session began with a general warm-up and a handball-specific warm-up. All participants for each session completed game-based training with 3vs3 and 6vs6, with a duration of 5 min of each. Each participant completed one or two repetitions of the 3vs3 and 6vs6 game-based training conditions in each session, depending on the total number of players available for the session. In addition, because of the varying number of players available, it was not possible to standardize the length of the rest period for each participant. Participants could either have a five or ten min rest period. The 3vs3 condition consisted of three field-players on each team, in addition to a goalkeeper on each team. The 6vs6 condition consisted of six field-players on each team, in addition to a goalkeeper on each team (Figure 3). The playing area was equivalent to the area of a standard handball court (20 × 40 m). The aim of the game-based training drills was to create a match-like setting; thus, the rules of the drills were kept the same as for official matches, with the exception that the goalkeeper was allowed to keep a spare ball next to the goal for a rapid replacement of the ball after a missed shot. Verbal encouragement from the coaches was allowed, and the coaches were instructed to give encouragement similar to what they would do in official matches. The order in which participants performed the two drills was alternated between sessions. For participants to be included in the analysis, they had to complete a minimum of three monitored training sessions where they were active in both 3vs3 and 6vs6. Participants were divided into four different playing positions (as in study II), based on their playing positions in official matches. Match monitoring was performed in the same way as in study II, on five matches for each team.

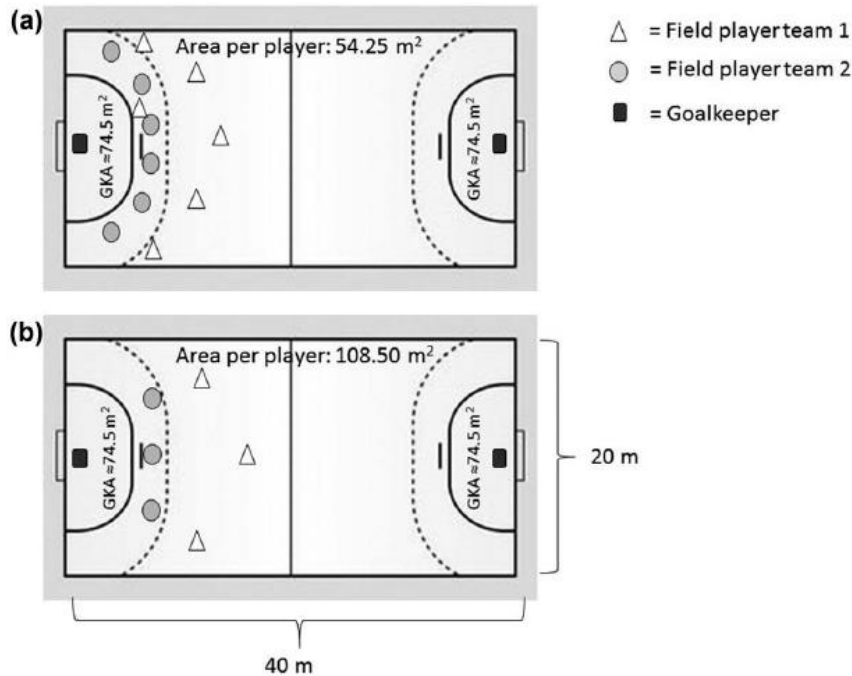


Figure 3: Setup for the two different game-based training conditions. 6vs6 (a) includes a total of 14 players; six field players and one goalkeeper on each team. 3vs3 (b) includes a total of eight players; three field players and one goalkeeper on each team. The playing area was the same as the area of a standard handball court (20×40 m) in both conditions. Note that the area per player refers to outfield players only; the goalkeeper area (GKA) is kept constant in both conditions.

Study IV

In study IV, the LPS (Catapult ClearSky T6) was compared to the reference system (Qualisys Oqus). Both the LPS and the reference system were installed around the field of play to capture the athletes' motion with both systems. The participants wore the mobile node positioned between the shoulder blades, in the manufacturer-supplied vest, and completed a total of five tasks, all designed to imitate team-sports movements (Figure 4). Task 1 was a straight-line sprint and deceleration to a stop. Task 2 comprised two diagonal movements, forward and back to the left and the right, with the paths separated by an angle of $\approx 75^\circ$. Task 3 involved a straight-line sprint, a 90° turn, and then deceleration to a stop. Task 4 consisted of a sig-sag (angle of turns $\approx 60^\circ$) course executed with sideways movements, and a 360° turn. Task 5 was five continuous laps of the same course as in task 4, without the 360° turn. All tasks were commenced from a stationary

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position. Each task was executed five times, with the exception of task 1, which was executed nine times. Participants completed an individually selected warm-up before commencement of the tasks. All tasks were practiced during the warm-up. Participants were instructed to give maximal effort in all tasks. Subjects were tested on two separate days. The same protocol was completed in both sessions, on one day with an assumed optimal setup of the LPS (Optimal; Figure 5, field B), and on another day with a sub-optimal setup of the LPS (Sub-optimal; Figure 5, field A). In the optimal setup, the LPS was arranged symmetrically, with a larger distance between the nodes and the testing area. In the sub-optimal setup, the LPS was asymmetrical, and the distance between the nodes and the testing area was small (Figure 5). This was undertaken to imitate a space-reduced environment. At all times during the data acquisition, 14 mobile nodes were turned on to simulate the usual data load on the system.

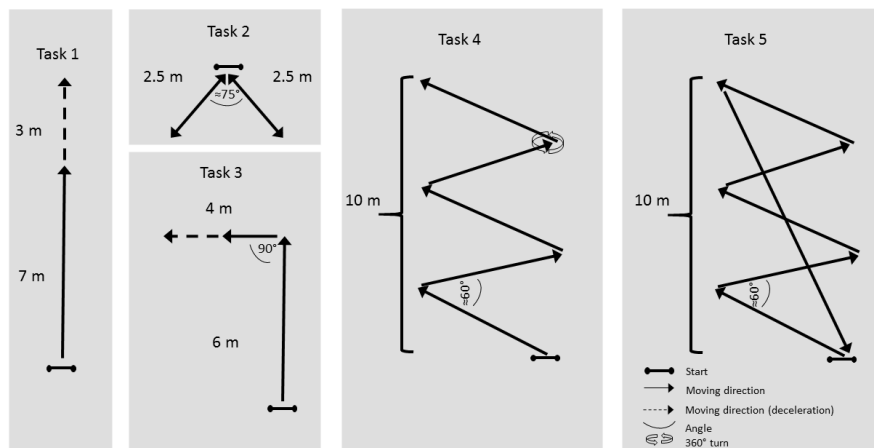


Figure 4: Diagram of the tasks completed by the participants

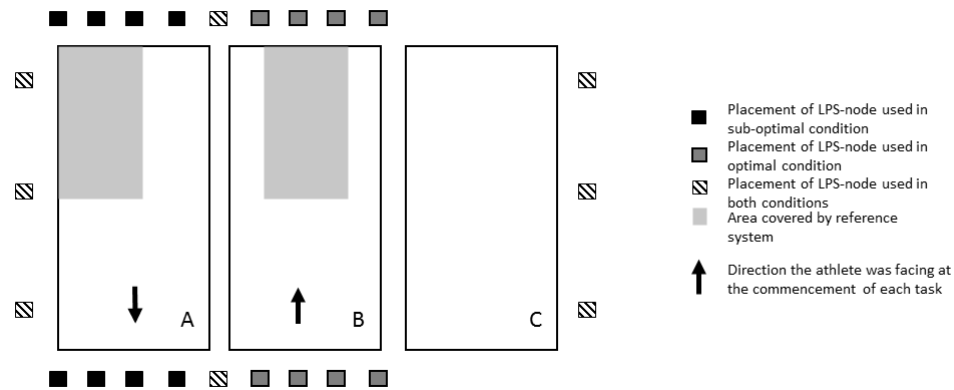


Figure 5: Setup of nodes around the handball court. The anchor nodes were placed approximately 3 meters above the court.

Data processing

Study I - III

Match data were downloaded from the OptimEyeS5 to the manufacturers' software using a USB interface. PlayerLoad™ and HIE variables were extracted from the manufacturers' software, and then exported to Microsoft Excel (Microsoft Corp, Redmond, WA, USA). In studies II-III, variables were normalized per minute of on-field time to minimize the variability in reporting absolute values with varying match length and individual on-field time.

Both in the laboratory and in the field assessment in study I, a separate period was created in the software for each drill. In the laboratory assessment, each HIE was identified in the manufacturers' software and the magnitude and direction for the event was manually transferred to Excel. In the field assessment, only the time spent on-field, active in a drill, was included.

In studies II and III, five-minute periods were calculated from the start of each half of the match, and only full five-minute periods were included in the analyses. The five-min period with the highest value, for each individual player, was extracted and represented the most strenuous period (MSP) in match play. This served as a "worst-case scenario". Players had to be on-field for the entire five-min period (100%), and they had to have at

Method

least two five-min periods in the match to be included in the analyses of MSP. The MSP was extracted individually for each variable, meaning that $\text{PlayerLoad}^{\text{TM}} \cdot \text{min}^{-1}$ and $\text{HIE} \cdot \text{min}^{-1}$ were not necessarily extracted from the same period.

In addition to five-minute periods, study II included ten-minute periods, which covered the absolute first and final ten minutes of each half of the match, in addition to the middle ten minutes. Only players completing a minimum of 60% of a given period were included in the individual analyses of fatigue, while all players with a minimum of one minute on the field in a given period were included in the analyses of team activity. In the team analyses, in each period players were compared against their match mean. Values in each period was presented as a percentage of the match mean. In the individual analyses, baseline five-minute mean values were calculated from the five-minute periods in the game satisfying the 60% inclusion criterion. In the analysis of individual temporal fatigue, consecutive five-minute periods fulfilling the inclusion criterion for on-field time were analyzed for each half of the match. A player's first five-minute period with 60% on-field time was considered her first period of play in the respective half, independent of game time. Subsequent periods fulfilling the criteria were then counted as the second, third, fourth, and subsequent consecutive periods of play. Consecutive periods could not cross the halftime break, and only bouts of a minimum of two consecutive periods were included. In this manner, each player could be represented twice in a game, with one bout in the first and one in the second half. In the analysis of transient fatigue, each player's peak five-minute period was identified for each match. The peak period was then compared with the preceding five-minute period (Pre-5) and subsequent five-minute (Post-5) and ten-minute (Post-10) period, provided that these periods also fulfilled the criterion of 60% of playing time.

Study IV

Raw position data (X and Y coordinates) were extracted, both from the LPS and from the reference system, using their respective software (LPS: OpenField, Catapult Sports, Melbourne, Australia. Reference system: Qualisys Track Manager, Qualisys AB, Gothenburg Sweden). All data analyses were conducted in MatLab (The MathWorks Inc., Natick, MA, USA). To compare the LPS-based data with the reference system, the coordinate system of the reference system was transformed into the LPS's coordinate system using a Helmert transformation (Sheynin, 1995). The transformation between the

coordinate systems was based on four reference points (12 mm reflective markers, positioned one meter above court level, in the four corners of the testing area). The positions of the reference points were measured with the reference system in all trials, and with a tachymeter (Leica Builder 509 Total Station, Leica Geosystems AG, Heerbrugg, Switzerland) in the LPS coordinate system. The Helmert transformation resulted in a mean position residual per calibration point of 2.3 cm for the optimal condition and 0.4 cm for the sub-optimal condition.

Due to incomplete LPS raw data (resulting from prolonged loss of signal during parts of the trials), 22 (sub-optimal condition) and 1 (optimal condition) trials were excluded from further data analyses. The capture frequency of the LPS system was not constant. The mean capture frequency was calculated to be 17.5 Hz. To overcome the issue of a variable capture frequency, the position data, from both the LPS and the reference system, were resampled at the mean capture frequency of the LPS using a second order spline function. Trials including data gaps >1 second were excluded from the analyses. This resulted in the exclusion of 30 (sub-optimal condition) and 12 (optimal condition) trials from analysis. Thus, 64 (55%) trials (sup-optimal condition) and 103 (89%) trials (optimal condition) were available for analysis in this study. LPS and reference system data were time synchronized using cross-correlation of speed data. For that purpose the following steps were undertaken: 1) Position data in the horizontal plane (X and Y coordinates) were differentiated to obtain horizontal plane speed, for both the LPS and the reference system, using a four-point finite central difference formula (Gilat & Subramaniam, 2011). 2) LPS and reference system data were time synchronized using cross-correlation (Buck, Daniel, & Singer, 2002) of horizontal plane speed data. After time synchronization, data were trimmed to reflect only the time athletes were performing the trials, by using a speed threshold of $0.5 \text{ m}\cdot\text{s}^{-1}$ (determined from the reference system). Two-dimensional position data at 17.5 Hz were used to calculate distance and speed. Distance traveled per trial was calculated as sum of the Euclidean distance between consecutive points. Speed in the horizontal plane (hereafter called speed) was calculated from position data, as previously stated.

Statistical analyses

All data are presented as mean \pm SD, or as mean \pm 90% confidence limits (CL). The percentage likelihood of difference was calculated (Studies II-III) and considered almost certainly not (<0.5%), very unlikely (0.5-5%), unlikely (5-25%), possibly (25-75%), likely (75-95%), very likely (95-99.5%) or most likely (>99.5%). A percentage likelihood of difference \geq 75% was considered a substantial magnitude. Threshold chances of 5% for substantial magnitudes were used, meaning a likelihood of >5% in both positive and negative directions was considered an unclear difference (Hopkins, Marshall, Batterham, & Hanin, 2009). The magnitudes of differences were expressed as standardized mean differences (Cohen's d effect size; ES). ESs of <0.20, 0.20 to 0.59, 0.60 to 1.19, 1.2 to 1.99 and \geq 2.00 were considered trivial, small, moderate, large, and very large, respectively (Hopkins et al., 2009). Correlation were assessed by Pearson's product-moment correlation coefficient. Magnitude of the correlations was based on the following scale: trivial (<0.10), small (0.10-0.29), moderate (0.30-0.49), large (0.50-0.69), very large (0.70-0.89), and nearly perfect (>0.89; Hopkins et al., 2009). Statistical calculations were performed using Microsoft Excel (Redmond, USA; Study II), SPSS[®] Statistics (IBM Corp., Armonk, NY, USA; Study III), and SAS[®] Studio (SAS Institute Inc., Cary, NC, USA; Study I).

In studies I and III, a linear mixed model was used to analyze the results. The strength of such analyses is that they allow for repeated measurements and individual responses, while not being very sensitive to missing data. In study I, separate analyses were conducted for each variable. The fixed effects in the laboratory assessment model were device placement (two levels: proximal, distal) and the direction of the event (four levels: forward, backward, right lateral, left lateral). The random effects were subject identity, device identity, and set identity*session identity*action identity. Set identity identifies each set the subjects completed, and action identity is a count of all different actions detected by the device. In the field assessment, the fixed effect was device placement. The random effects were subject identity, device identity, session identity and subject identity*session identity. Data presented as coefficients of variation (CV) were log-transformed to reduce bias from potential non-uniformity error. In Study III, fixed effects in the model were playing position (four levels: back, wing, pivot and

GK), condition (4 levels: 3vs3, 6vs6, match, and MSP), position*condition and team ID. The random effects were athlete ID and Game ID. Separate analyses were performed for the dependent variables $\text{PlayerLoad}^{\text{TM}} \cdot \text{min}^{-1}$ and $\text{HIE} \cdot \text{min}^{-1}$.

In study I, the reliability between devices was established using the typical error of measurement (TE), expressed in absolute terms and as a percentage CV. The uncertainty was expressed as 90% confidence interval (CI). The CV was rated as good (CV <5%), moderate (CV 5 to 10%) or poor (CV >10%). The smallest worthwhile difference (SWD) was calculated as the 0.1 x between-subject SD (Hopkins et al., 2009) and was used as a measure to identify *real* differences.

In study IV, position, distance and speed were compared for each task, using the norm of the differences between the LPS and the reference system. Mean difference, SD, and maximal difference in position were calculated. To express the results for position, the difference for each task from the reference system was assigned to bin limits in a histogram, and expressed as a percentage of the total number of raw data points. This was done to exclude the effect of duration of the task on the results. For distance, instantaneous and mean speed, the differences were characterized by mean, SD and maximal difference.

Results

Reliability of PlayerLoad™ and HIE (Study I)

The CV of the magnitude of an HIE event in the laboratory assessment was good (CV <5%; Table 2) in controlled movement tasks (T1-5). However, an increase in CV was apparent in more complex movement tasks (T6-7). A higher TE was also apparent for directional HIE measurements in the more complex movement tasks (Table 2). The mixed model output from the laboratory assessment showed that the device identity accounted for 0.1-0.4% of the variation in magnitude, and 0.4-1.0° of the variation in direction.

In the field assessment, total HIE count showed a CV lower than the SWD (Table 3). When categorized into intensity bands, the CV increased, and only the bands of high and medium/high (combined) showed CV less than SWD. When categorized into direction bands, HIE counts showed good to moderate CV (CV of 3.9-6.6%; Table 4).

Table 2: Between-device reliability for magnitude and direction in the laboratory assessment

Movement tasks	Variable	Device 1 Mean \pm SD	Device 2 Mean \pm SD	TE (Abs)	90% CI (Abs)	CV (%)	90% CI (%)	Events (n)
One-step (n = 320)	Magnitude (m·s ⁻¹)	3.2 \pm 1.0	3.3 \pm 1.0	-	-	3.1	2.9 - 3.3	320
	Direction (°)	100.8 \pm 50.1	100.6 \pm 50.4	2.4	2.3-2.6	-	-	
Lateral CoD (n = 80)	Magnitude (m·s ⁻¹)	3.1 \pm 0.7	3.0 \pm 0.7	-	-	4.4	4.3 - 4.6	1138
	Direction (°)	94.5 \pm 19.0	94.4 \pm 18.9	2.4	2.3 - 2.5	-	-	
Start / stop (n = 80)	Magnitude (m·s ⁻¹)	2.9 \pm 0.9	2.9 \pm 0.9	-	-	6.7	6.4 - 7.0	863
	Direction (°)	86.6 \pm 69.5	86.9 \pm 69.3	3.4	3.3 - 3.5	-	-	
Multi CoD (n = 80)	Magnitude (m·s ⁻¹)	3.4 \pm 1.4	3.4 \pm 1.4	-	-	5.9	5.8 - 6.1	1301
	Direction (°)	97.7 \pm 33.6	97.7 \pm 33.5	3.6	3.5 - 3.8	-	-	

Note: Abs= absolute, TE= typical error, CV= coefficient of variation, CI= confidence interval, CoD = changes of direction.

n= the number of trials, Events (n) = the number of events included in the analyses.

Results

Table 3: Between-device reliability for high intensity event (HIE) variables in the field assessment. HIE counts were categorized into intensity bands. n=83.

Intensity bands	Device 1 Mean \pm SD	Device 2 Mean \pm SD	CV (%)	90% CI (%)	SWD (%)
Low	416.5 \pm 97.7	417.2 \pm 97.2	2.7	2.4 - 3.1	2.3
Med	120.3 \pm 31.6	120.4 \pm 31.7	4.6	4.0 - 5.3	3.0
High	68.9 \pm 26.9	69.4 \pm 28.2	5.3	4.7 - 6.2	5.6
Med/High	189.2 \pm 55.8	189.7 \pm 56.4	3.1	2.7 - 3.6	3.7
Total	605.8 \pm 144.7	606.9 \pm 144.8	1.8	1.8 - 2.1	2.5

Note: CV= coefficient of variation, CI= confidence interval, SWD= smallest worthwhile difference. Low= 1.5-2.5 m·s⁻¹, Medium= 2.5-3.5 m·s⁻¹, High= >3.5 m·s⁻¹, Med/high= >2.5 m·s⁻¹, Total= >1.5 m·s⁻¹.

Table 4: Between-device reliability for high intensity event (HIE) variables in the field assessment. HIE counts were categorized within direction bands, and divided further into intensity bands. $n=83$.

Direction bands	Device 1 Mean \pm SD	Device 2 Mean \pm SD	CV (%)	90% CI (%)	SWD (%)
Forward					
Low	48.7 \pm 15.2	49.0 \pm 15.2	10.1	8.9 - 11.8	3.2
Medium	18.2 \pm 7.8	17.9 \pm 7.9	20.6	17.9 - 24.1	4.9
High	17.4 \pm 10.7	17.5 \pm 12.1	21.5	18.8 - 25.3	7.9
Med/High	35.6 \pm 17.2	35.3 \pm 18.4	10.8	9.5 - 12.6	5.3
Total	84.2 \pm 28.1	84.4 \pm 29.6	6.6	5.8 - 7.6	3.5
Backward					
Low	59.0 \pm 21.1	59.6 \pm 21.7	7.7	6.8 - 9.0	4.0
Medium	22.6 \pm 7.5	22.8 \pm 7.3	11.7	10.3 - 13.7	3.6
High	14.0 \pm 5.9	13.9 \pm 5.8	13.7	12.0 - 16.0	5.5
Med/High	36.6 \pm 11.4	36.6 \pm 11.1	7.1	6.3 - 8.3	3.6
Total	95.6 \pm 29.2	96.2 \pm 29.5	5.5	4.8 - 6.3	3.5
Lateral - left					
Low	152.5 \pm 51.3	152.7 \pm 49.8	4.6	4.1 - 5.4	3.2
Medium	41.0 \pm 16.0	40.3 \pm 15.2	8.4	7.4 - 9.8	3.8
High	19.0 \pm 9.5	19.1 \pm 10.2	12.6	11.0 - 14.7	6.5
Med/High	60.0 \pm 24.1	59.4 \pm 23.9	6.4	5.6 - 7.4	4.1
Total	212.5 \pm 71.0	212.1 \pm 68.8	3.9	3.4 - 4.5	3.2
Lateral - right					
Low	156.4 \pm 48.0	155.9 \pm 47.2	4.8	4.2 - 5.6	3.0
Medium	38.5 \pm 13.5	39.5 \pm 14.0	9.8	8.6 - 11.4	4.7
High	18.6 \pm 10.4	18.8 \pm 10.7	16.6	14.6 - 19.5	6.3
Med/High	57.1 \pm 22.2	58.3 \pm 22.9	6.6	5.8 - 7.7	4.9
Total	213.5 \pm 64.7	214.2 \pm 65.2	4.1	3.7 - 4.8	3.1

Note: CV= coefficient of variation. CI= confidence interval, SWD= smallest worthwhile difference. Low= 1.5-2.5 $\text{m}\cdot\text{s}^{-1}$, Medium= 2.5-3.5 $\text{m}\cdot\text{s}^{-1}$, High= $>3.5 \text{ m}\cdot\text{s}^{-1}$, Med/high= $>2.5 \text{ m}\cdot\text{s}^{-1}$, Total= $>1.5 \text{ m}\cdot\text{s}^{-1}$.

Results

The CV of PlayerLoad™ and its associated variables was good (CV<2%, table 5), and lower than the SWD. The mixed model output from the field assessment showed that device placement (distal or proximal) accounted for 1.3-5.9% of the variation in the data. Higher values in the distal device were apparent in all cases, with the exception of PL_{AP}. Device identity did not account for any of the variation in the PlayerLoad™ variables.

Table 5: Between-device reliability for PlayerLoad™, and its associated variables, in the field assessment. n=83.

Variables (AU)	Device 1 Mean ± SD	Device 2 Mean ± SD	CV (%)	90% CI (%)	SWD (%)
PlayerLoad™	418.3 ± 78.9	418.9 ± 82.0	0.9	0.8 - 1.1	2.1
PlayerLoad™·min ⁻¹	6.6 ± 1.0	6.6 ± 1.0	0.9	0.8 - 1.1	1.5
PL _{2D}	260.3 ± 47.8	260.5 ± 48.6	1.0	0.9 - 1.1	2.0
PL _{AP}	154.2 ± 27.8	154.3 ± 27.8	0.4	0.3 - 0.5	2.0
PL _{ML}	175.9 ± 35.1	176.2 ± 35.9	1.7	1.5 - 1.9	2.1
PL _V	280.9 ± 56.9	281.5 ± 60.0	1.1	1.0 - 1.3	2.3

Note: AU= Arbitrary Unit, CV= coefficient of variation, CI= confidence interval, SWD= smallest worthwhile difference, 2D=anterior-posterior and medio-lateral axes, AP= anterior-posterior axis, ML= medio-lateral axis, V= vertical axis.

Match data from international female team handball matches (Study II)

The mean match length of the nine matches investigated was 71.9 ± 2.4 minutes. The mean on-field time for individual players was 33.2 minutes, ranging from 7 to 70 minutes. Differences in on-field time for the different playing positions were found, where GKs had the highest on-field time (Table 6). Mean goal differences in the matches was 2.3 ± 6.2. Scoring details, including mean goals scored and conceded in each half of the match, are presented in Table 7.

Table 6: On-field time for the different playing positions.

	Minutes of on-field time		Differences	
	(mean \pm SD)	Range		Effect size
Back	30.9 \pm 16.0	7.4 – 62.8	vs wing vs pivot vs GK	0.1 0.4* 0.8**
Wing	31.4 \pm 14.7	7.0 – 62.7	vs pivot vs GK	0.3 0.7**
Pivot	34.4 \pm 12.5	17.7 – 61.1	vs GK	0.5**
GK	42.2 \pm 16.6	18.1 – 69.9		

Note: Substantial likelihood of differences between playing positions are denoted in the table as: * likely, ** very likely, and *** most likely.

Table 7: Match scoring details

	Goals scored (n)			Goals conceded (n)		
	Mean \pm SD	Min	Max	Mean \pm SD	Min	Max
1st-half	12.6 \pm 2.4	8	16	12.4 \pm 2.2	9	16
2nd-half	12.9 \pm 3.4	9	18	10.7 \pm 3.4	6	15
Full-time	25.4 \pm 4.4	21	32	23.1 \pm 4.5	15	28

Mean total PlayerLoad™ for all players combined was 283.73 ± 140.12 . PlayerLoad™ was positively correlated with on-field time with r-values of 0.97 for all out-field positions combined, and 0.94 for GK ($r = 0.82$ for all players combined, Figure 6).

Mean PlayerLoad™·min⁻¹ for all players combined was 8.82 ± 2.06 , with small to large differences between playing positions (Figure 7A). Offensive backs showed higher values compared to 2-way playing backs in PlayerLoad™·min⁻¹ (100%; ES: 2.2) and in HIE·min⁻¹ (98%, ES: 1.2). Mean HIE·min⁻¹ for all players combined was 3.90 ± 1.58 . Differences between playing positions in HIE·min⁻¹ were apparent for all playing positions (Figure 7B).

Results

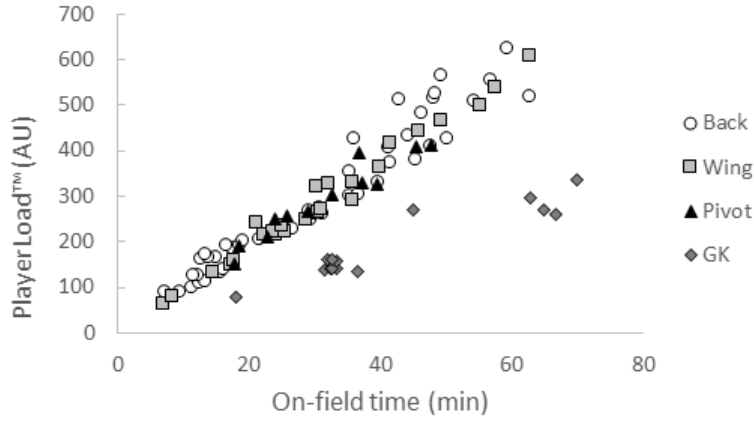


Figure 6: Plot of on-field time and $PlayerLoad^{TM}$ for all positions. GK = goalkeeper.

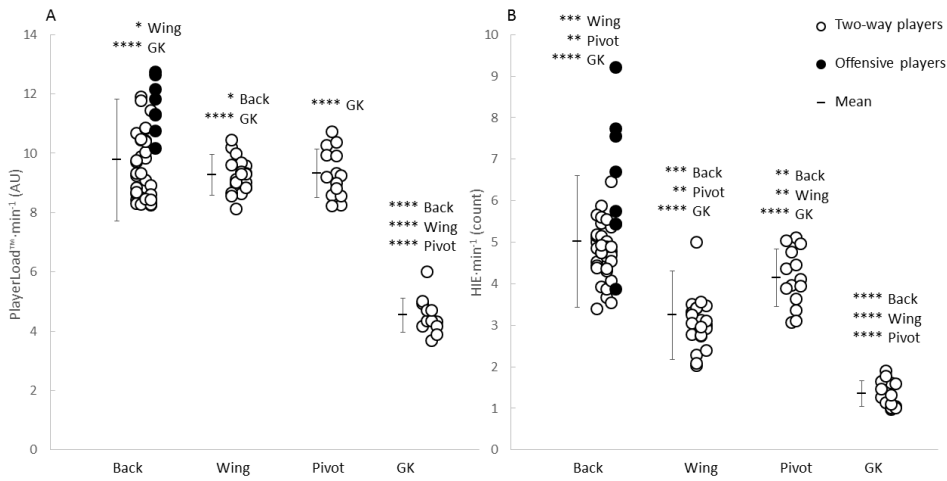


Figure 7: Mean \pm SD and individual data for all playing positions are shown for (A) $PlayerLoad^{TM}$ per minute and (B) high-intensity events (HIE) per minute. Effect sizes between different playing positions are indicated by the stated symbols and are marked with position name. Only effect sizes with a substantial likelihood of difference (>75%) are shown. *Small, **moderate, ***large ****very large. GK = goalkeeper

PlayerLoad $\cdot\text{min}^{\text{TM}-1}$ was substantially higher in the first 10 minutes of the first half, compared to the following 10-min periods for outfield players (Figure 8). Higher intensity in the first periods of the match is also apparent in the analysis of 5-min periods. In the first half, the 15-, 20-, and 30-minute periods were substantially lower than all previous periods combined, while the 35-min period was substantially higher. In the second half, the 10-, and 30-minute periods were substantially lower than all previous periods of the second half combined. The 10-, 25-, and 35-minute periods in the second half were substantially lower than the corresponding periods in the first half.

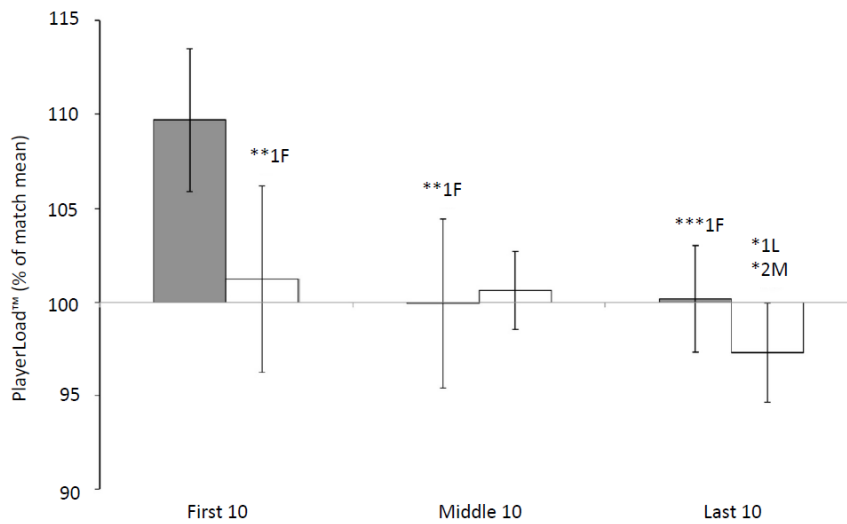


Figure 8: PlayerLoad $\cdot\text{min}^{-1}$ for outfield players on field in 10-minute periods, presented as percentages of match mean $\pm 90\%$ CL for all outfield positions combined. 1F = first period of first half, 1M = middle period of first half, 1L = last period of first half, 2F = first period of second half, 2M = middle period of second half, 2L = last period of second half. Substantial likelihoods of differences between periods are denoted in the figure as: * likely, ** very likely, and *** most likely.

Results

Of the 81 Peak periods for PlayerLoad™·min⁻¹ in the initial analysis, 19 samples satisfied the inclusion criterion of a Pre, Post-5, and Post-10 period (Figure 9). All periods were substantially lower than the Peak period, and the Post-5 period was also substantially lower than the Pre period.

The effect of consecutive periods of play on PlayerLoad™ is presented in Figure 10. For all outfield players combined, the second, third, fourth, sixth, and seventh consecutive periods of play were substantially lower than all previous periods combined (Figure 10A). When assessing each playing position individually, backs showed lowered values in the second, third, and fourth periods compared to all previous periods combined (Figure 10B). Wings were lower in the second, fourth, and seventh periods, while pivots were lower in the third and seventh periods compared to all previous periods combined.

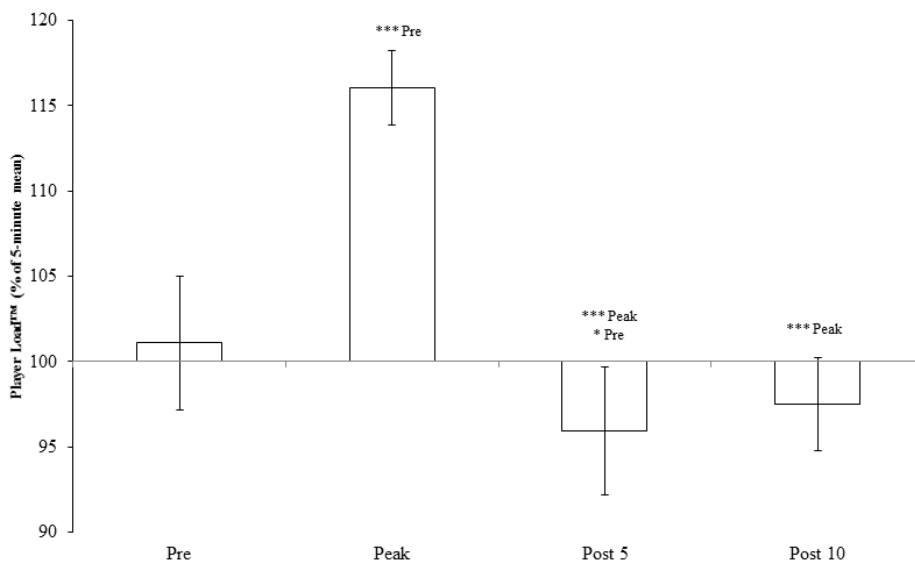


Figure 9: Percentage of 5-min mean $\pm 90\%$ CL for PlayerLoad™·min⁻¹ for individual players (n=19 samples). Periods are the most intense 5-minute period (Peak), the 5-minute period preceding the peak (Pre), and the two 5-minute periods after peak (Post-5 and Post 10). Substantial likelihood of differences are denoted in the figure as: * likely, ** very likely, and *** most likely.

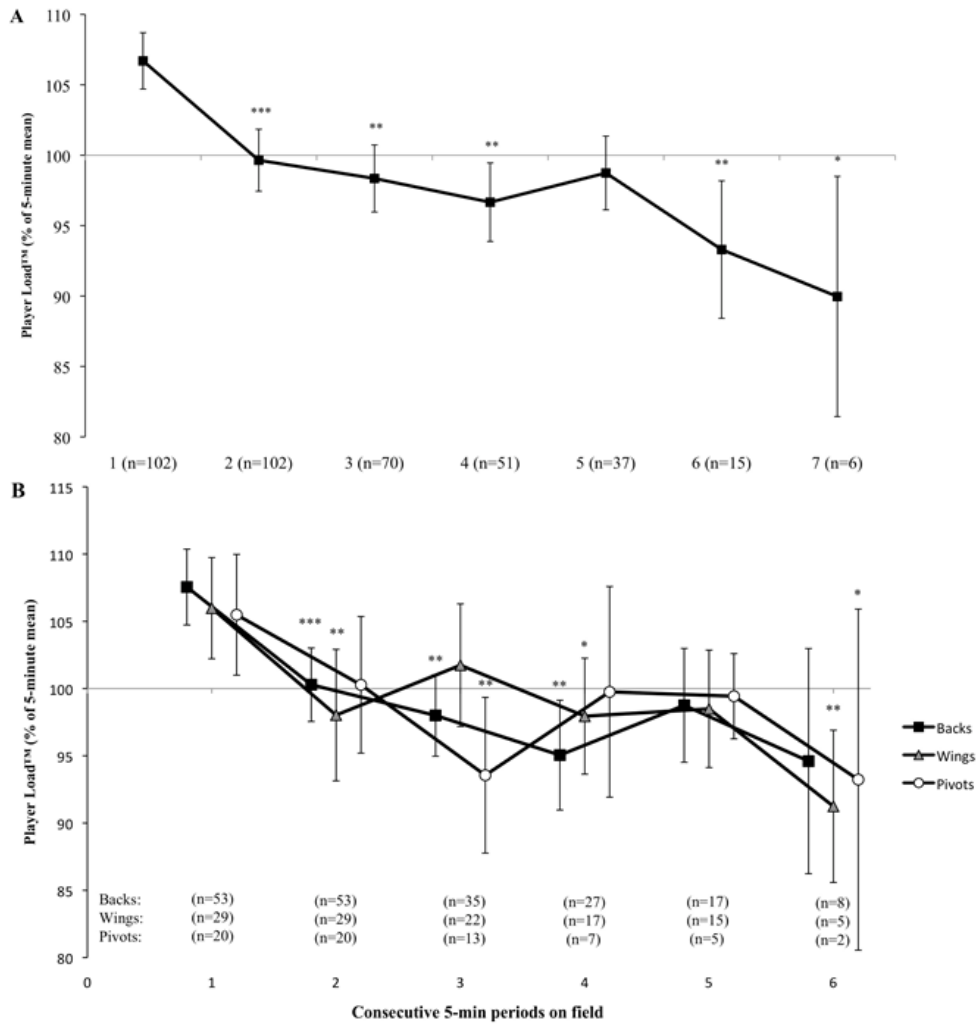
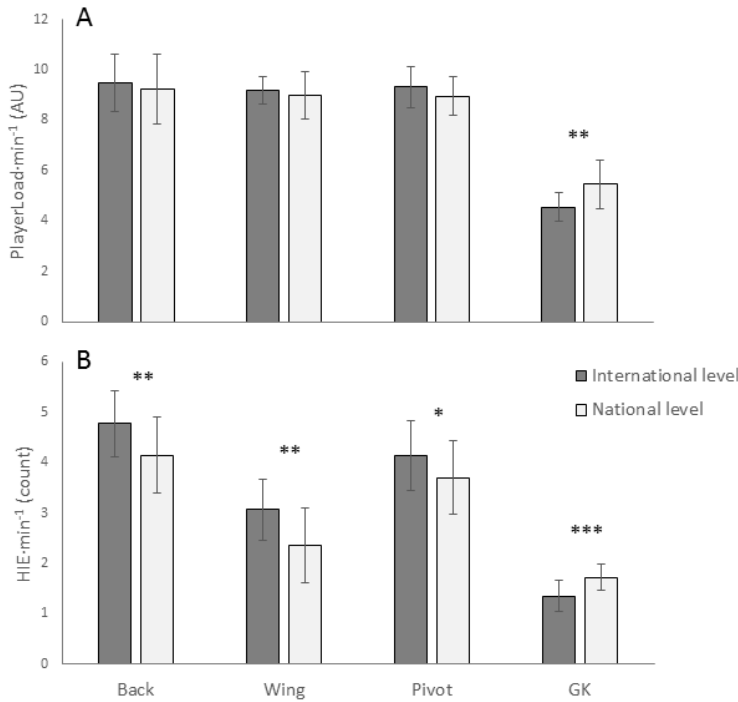


Figure 10: Percentage of 5-min mean $\pm 90\%$ CL for PlayerLoad™·min⁻¹ for individual players with minimum two consecutive 5-minute periods of play, for all outfield players combined (A) and for each position (B). Substantial likelihood of differences from all previous periods are denoted in the figure as: * likely, ** very likely, and *** most likely

Results

Comparison of match data from international and national female team handball matches (Study II and III)

Match data from both international-level players (Study II) and national-level players (Study III) were collected. No clear differences were observed in on-field time between the two levels, for any of the playing positions. No substantial differences in $\text{PlayerLoad}^{\text{TM}}\cdot\text{min}^{-1}$ were observed for any of the outfield playing positions. However, national-level GKs showed higher $\text{PlayerLoad}^{\text{TM}}\cdot\text{min}^{-1}$ than international-level GKs (Figure 11A). International-level backs, wings and pivots display higher $\text{HIE}\cdot\text{min}^{-1}$ compared to national-level players (Figure 11B). International-level GKs display lower $\text{HIE}\cdot\text{min}^{-1}$, compared to national-level GKs.



*Figure 11: Mean \pm SD for $\text{PlayerLoad}^{\text{TM}}\cdot\text{min}^{-1}$ (A) and $\text{HIE}\cdot\text{min}^{-1}$ (B) for international and national level, for all playing positions (only two-way players included). Effect sizes between different playing standards are indicated by the stated symbols. Only effect sizes with a substantial likelihood of difference (>75%) are shown. *Small, **moderate, ***large ****very large. GK = goalkeeper*

Game-based training (Study III)

The mean values of $\text{PlayerLoad}^{\text{TM}} \cdot \text{min}^{-1}$ for all players combined were 11.37 ± 0.49 , 9.71 ± 0.3 , 8.73 ± 0.25 and 9.85 ± 0.36 $\text{PlayerLoad}^{\text{TM}} \cdot \text{min}^{-1}$ for the 3vs3, 6vs6, mean match and MSP conditions, respectively. The 3vs3 condition resulted in higher values of $\text{PlayerLoad}^{\text{TM}} \cdot \text{min}^{-1}$ compared to the 6vs6 condition, for all outfield playing positions (Table 8). The mean HIE values for all players combined were 4.27 ± 0.20 , 3.03 ± 0.17 , 3.29 ± 0.22 and 4.13 ± 0.27 $\text{HIE} \cdot \text{min}^{-1}$ for the 3vs3, 6vs6, mean match and MSP conditions, respectively. All playing positions displayed differences in $\text{HIE} \cdot \text{min}^{-1}$ when comparing 3vs3 and 6vs6, where higher values were observed for back, wing and pivot, while lower values were apparent for GK.

*Table 8: Mean and upper and lower confidence limits (CL) for each playing position in 3vs3 and 6vs6. ES for differences between conditions are given. Substantial likelihoods of differences between conditions are denoted in the table as: * likely, ** very likely, and *** most likely. ES = Effect size, GK = goalkeeper*

		n	Mean (90% CL)		Differences ES
			3vs3	n 6vs6	
PlayerLoadTM·min⁻¹ (AU)					
Back	63	13.24 (12.45 - 14.07)	78	10.54 (9.92 - 11.19)	1.63***
Wing	56	13.87 (13.02 - 14.79)	72	10.62 (9.97 - 11.30)	1.91***
Pivot	17	13.14 (11.64 - 14.82)	22	10.52 (9.36 - 11.84)	1.58**
GK	47	4.90 (4.47 - 5.37)	32	4.57 (4.17 - 5.01)	0.49
HIE·min⁻¹ (counts)					
Back	63	4.50 (4.03 - 5.01)	78	3.69 (3.17 - 4.29)	0.58*
Wing	56	4.36 (3.89 - 4.90)	72	1.98 (1.69 - 2.31)	2.32***
Pivot	13	5.34 (4.23 - 6.73)	17	3.64 (2.57 - 5.14)	1.12*
GK	47	2.83 (2.42 - 3.31)	32	2.06 (1.63 - 2.60)	0.93**

Results

When compared to mean match values, both 3vs3 and 6vs6 showed higher values in $\text{PlayerLoad}^{\text{TM}} \cdot \text{min}^{-1}$ for all outfield playing positions (Figure 12A). However, when compared to MSP, only 6vs6 displayed higher values in $\text{PlayerLoad}^{\text{TM}} \cdot \text{min}^{-1}$ for outfield players. For GK, a lower $\text{PlayerLoad}^{\text{TM}} \cdot \text{min}^{-1}$ was apparent when comparing 6vs6 with mean match values, and when comparing both 3vs3 and 6vs6 compared to MSP (Figure 12B).

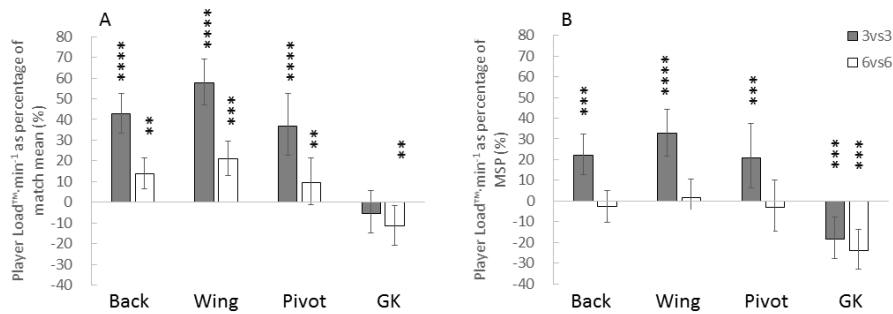


Figure 12: $\text{PlayerLoad}^{\text{TM}} \cdot \text{min}^{-1}$ mean $\pm 90\%$ confidence limits for percentage differences from match mean (a) and MSP (b) for the 3vs3 condition and 6vs6 condition. Effect size (ES) between the different game-based training conditions and match mean or MSP is indicated by the stated symbols. Only ESs with a substantial likelihood of difference ($>75\%$) are shown. * = small, ** = moderate, *** = large, **** = very large. GK: goalkeeper; MSP: most strenuous period.

No differences were found between mean match play and 6vs6 in $\text{HIE} \cdot \text{min}^{-1}$ (Figure 13A) for any playing positions. When compared to MSP, all playing positions showed lower values of $\text{HIE} \cdot \text{min}^{-1}$ in 6vs6 (Figure 13B). Wings showed higher values in 3vs3, when compared to both mean match and MSP, while pivots and GK only showed higher values in 3vs3 when compared to mean match values.

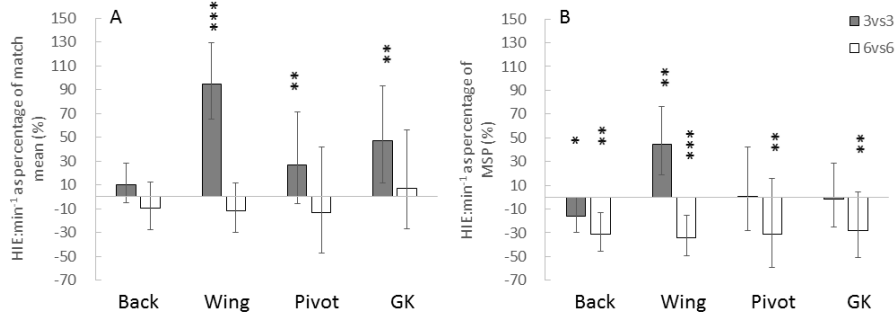


Figure 13: HIE: min⁻¹ mean \pm 90% confidence limits for percentage differences from match mean (a) and MSP (b) for the 3vs3 condition and 6vs6 conditions. Effect size (ES) between the different game-based training condition and match mean or MSP is indicated by the stated symbols. Only ESs with a substantial likelihood of difference (>75%) are shown. * = small, ** = moderate, *** = large, **** = very large. GK: goalkeeper; MSP: most strenuous period

Validity of LPS (Study IV)

The mean difference between the LPS and the reference system for all position estimations was 0.21 ± 0.13 m (n=30,166) in the optimal setup, and 1.79 ± 7.61 m (n=22,799) in the sub-optimal setup. Task 2 and task 5 showed the lowest mean (<0.20 m) and maximal differences (<1 m) in the optimal setup (Table 9). In the sub-optimal condition, task 3 showed the lowest mean and maximal differences, but all differences in the sub-optimal condition were greater than in the optimal condition. Figure 14 presents the different distribution in position in the five tasks, for both the optimal and sub-optimal conditions.

Table 9: Difference between the LPS and the reference system for absolute position, for optimal and sub-optimal conditions respectively.

	Optimal			Sub-Optimal		
	n	Average (m)	Maximum (m)	n	Average (m)	Maximum (m)
Task 1	2468	0.27 ± 0.22	1.40	1449	1.46 ± 1.95	13.07
Task 2	4675	0.17 ± 0.11	0.81	2822	1.72 ± 1.42	8.24
Task 3	1190	0.34 ± 0.24	1.41	565	1.37 ± 1.72	9.60
Task 4	2379	0.26 ± 0.17	1.91	2118	1.41 ± 1.52	9.85
Task 5	19454	0.19 ± 0.10	0.96	15845	1.89 ± 9.10	194.64

Results

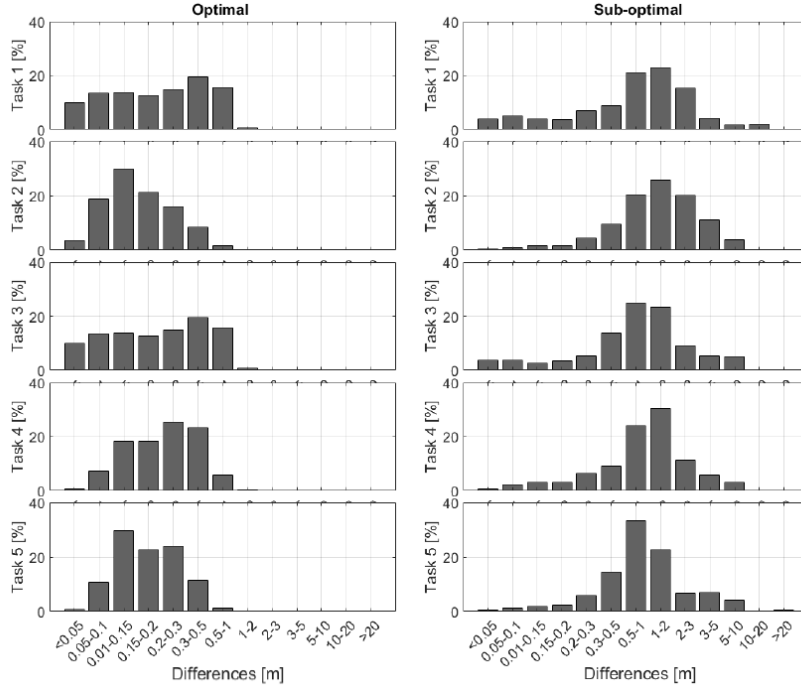


Figure 14: Distance differences for each task compared to the reference system. The differences were assigned to accuracy categories, and expressed as percentages of the total number of raw data points.

For distance, the mean differences between systems were 0.31 ± 0.40 m and 11.42 ± 26.21 m in the optimal and sub-optimal conditions, respectively, for all tasks combined. The mean difference was well below 2% in the optimal condition, for all tasks (Table 10). Task 5 showed the lowest difference in the optimal condition. In the sub-optimal condition, all tasks showed higher differences, of $\geq 15\%$, in all tasks. The LPS overestimated the distance compared to the reference system for both the optimal and sub-optimal conditions.

Instantaneous speed showed mean differences of $\geq 33\%$ for both the optimal and sub-optimal conditions (Table 11). Figure 15 displays all instantaneous speed measurements and reveals a direct association between speed and mean error. For mean speed, the mean difference was below 3% for all tasks (Table 12) in the optimal condition. The sub-optimal condition showed higher values across all tasks ($\approx 15\text{--}30\%$).

Table 10: Differences in distance as estimated by LPS and reference, for both optimal and sub-optimal conditions respectively.

n	<u>Optimal</u>				<u>Sub-optimal</u>			
	Reference (m)	Average (m)	Diff (m)	Max Diff (%)	Reference (m)	Average (m)	Diff (m)	Max Diff (%)
Task 1	9.52 ± 1.40	0.14 ± 0.26	1.00	10.5	9.90 ± 0.16	2.46 ± 2.10	7.68	77.6
Task 2	33.31 ± 1.25	0.60 ± 0.57	2.18	6.5	23.88 ± 1.53	6.92 ± 5.07	17.37	72.7
Task 3	9.41 ± 2.36	0.15 ± 0.21	0.86	9.1	11.71 ± 0.29	2.45 ± 2.75	8.73	74.5
Task 4	15.97 ± 6.19	0.24 ± 0.18	0.64	4.0	21.38 ± 2.47	3.21 ± 3.35	9.43	44.1
Task 5	132.81 ± 3.92	0.64 ± 0.46	1.65	0.5	140.17 ± 4.95	41.38 ± 48.23	192.54	137.4

Table 11: Differences in instantaneous speed between the LPS and the reference system, for optimal and sub-optimal conditions respectively.

n	<u>Optimal</u>				<u>Sub-optimal</u>			
	Average (m/s)	Diff (m/s)	Max Diff (%)	n	Average (m/s)	Diff (m/s)	Max Diff (%)	n
Task 1	0.77 ± 0.86	10.40	34.8	375	1.43 ± 1.86	16.79	83.7	6101
Task 2	0.78 ± 0.70	7.56	33.5	237	1.60 ± 1.97	18.62	74.4	353
Task 3	0.92 ± 0.88	7.40	39.2	355	2.30 ± 2.94	31.25	87.7	982
Task 4	0.79 ± 0.71	8.10	35.3	477	1.64 ± 1.79	18.44	90.8	1175
Task 5	0.68 ± 0.58	8.67	37.0	197	1.73 ± 3.41	53.73	75.4	769

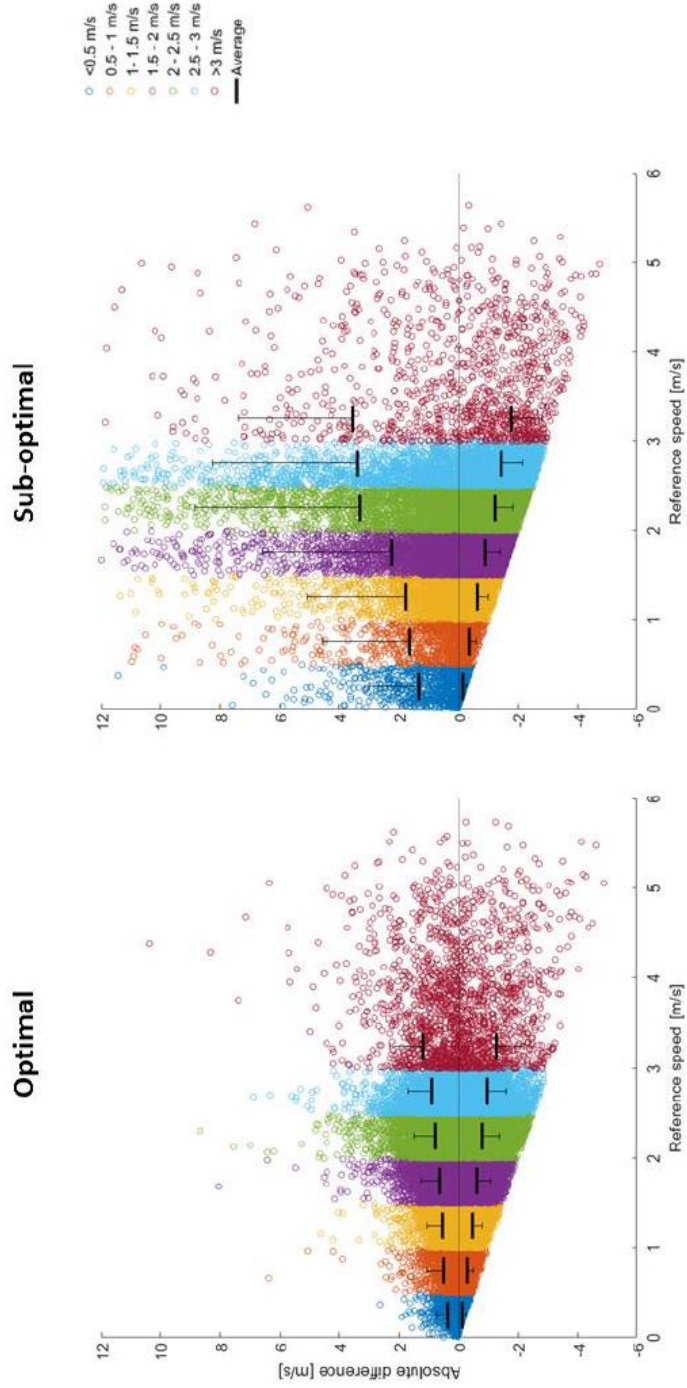


Figure 15: Differences in instantaneous speed from the reference system, divided into speed thresholds.

Table 12: Difference in average speed between the LPS and the reference system, for optimal and sub-optimal conditions respectively.

n	<u>Optimal</u>				<u>Sub-optimal</u>					
	Reference (m/s)	Average (m/s)	Diff (m/s)	Max Diff (%)	Reference (m/s)	Average (m/s)	Diff (m/s)	Max Diff (%)		
Task 1 34	2.30 ± 1.38	0.05 ± 0.14	0.77	2.2	17	1.93 ± 1.46	0.50 ± 0.47	2.02	26.0	105.1
Task 2 16	2.00 ± 0.71	0.03 ± 0.03	0.08	1.4	13	1.82 ± 0.76	0.50 ± 0.34	1.12	27.6	61.4
Task 3 19	2.64 ± 1.25	0.07 ± 0.17	0.71	2.8	8	2.75 ± 1.47	0.55 ± 0.62	2.00	20.2	72.8
Task 4 18	2.12 ± 0.79	0.05 ± 0.07	0.30	2.3	13	2.18 ± 0.90	0.32 ± 0.33	0.94	14.7	43.4
Task 5 16	1.91 ± 0.56	0.01 ± 0.01	0.02	0.5	13	1.90 ± 0.54	0.55 ± 0.67	2.65	29.1	139.0

Discussion

Match and training analysis is a common feature in team sports. This thesis provides new information about physical demands of female team handball players, with special reference to high intensity actions. The novelty of the work in this thesis was the use of IMUs to evaluate the match and training demands of female team handball players. To my knowledge, this is the first study to perform match analyses in team handball using IMUs.

Reliability of inertial measurement units

In the last decade the use of IMUs in sport science has increased substantially (Chambers et al., 2015), and multiple studies have investigated the validity and reliability of IMUs in team sports (Meylan et al., 2017; Nicoletta, Torres-Ronda, Saylor, & Schelling, 2018; Wundersitz, Josman, et al., 2015; Wundersitz, Gastin, Robertson, & Netto, 2015). However, there are, to my knowledge, no studies investigating the reliability of IMUs for use in team handball. In addition, to my knowledge, no studies have looked at the between-device reliability of HIE (as defined by the manufacturer Catapult Sports). The reliability of tracking technology is important for the interpretation of data, and our data show that both HIE and PlayerLoad™ have a CV below the SWD. Thus, suggesting that these variables are reliable for use in team handball.

In the field assessment, total HIE count showed a CV of 1.8%, which was well below the SWD (2.5%). However, the reliability decreased when HIE count was categorized into intensity bands; low, medium and high. Based on the current data it is recommended that the HIE count should be categorized into wider intensity bands (such as combined medium/high), to reduce variation. In the following studies (Study II and III) HIE is thus presented in a combined medium/high band ($>2.5 \cdot \text{min}^{-1}$). The CV appeared to increase in more complex tasks in the laboratory assessment for HIE magnitude and direction values (Table 2). It is previously shown that the intensity and type of activity (or movement) have the potential to affect the reliability of raw inertial signals (Welk, 2005), and could be an explanatory factor for the results in in the current study. Other factors, such as filtering inconsistency could also be a possible contributor. However, due to restricted insight into the detailed data-filtering and algorithms methods used in the calculation of

HIEs (Malone et al., 2016), we were not able to further investigate this. Moreover, further investigations of the validity of manufacturer-developed variables (e.g. HIE) should be undertaken for confident use in different sports.

In addition to overall HIE count, a categorization of the HIE count within direction bands could provide a more detailed insight into players' movement patterns. A moderate reliability was found for forward, backward, and left and right lateral counts for the Optimeye S5 devices in this study. Further, when the direction bands were divided into intensity bands, the reliability decreased. Caution should be taken when interpreting HIE counts with respect to directional bands, especially when categorizing into intensity bands.

In agreement with previous research on Australian football (Boyd et al., 2011), the CV of PlayerLoad™ was well below the SWD. This was also evident for PL_{2D} and the individual axes. PlayerLoad™ and associated variables may therefore be considered sensitive enough to measure physical activity demands in team sports. Compared to previous studies in treadmill running, team sport movements and simulated football matches (CV ≈4-6%; Barrett et al., 2016, 2014; Johnston et al., 2012), our study show greater reliability. Large variations in the specific research designs used in the different studies (test-retest vs between device) may account for some of the differences to other studies.

It has been recommended that that same device be used for the same athlete over the course of time, due to a poor inter-device reliability of PlayerLoad™ data from OptimEye S5 (Nicoletta et al., 2018). However, in the current study, the inter-device variability did not account for any of the variation in the data. Thus, implying that the device ID does not influence the data. These conflicting results imply the need for further investigations to be fully confident to either disregard or recommend that the same device should be used for the same athlete over the course of time. In addition, how the IMU is attached to the body (e.g. vest) should consistent to confident in the results, and the IMU should be worn in a tight fitted garment, to limit noise in measurements.

Different locations (placement of the unit) and orientations of the sensors will affect the IMU output, as the IMU measure the acceleration and angular rate of the segment it is attached to. The position of the IMU in the current studies was established according to the manufacturers' recommendation. It has been previously shown that different placement can elicit different results, and that placement at the center of mass may be more reliable for detecting alterations in lower-limb movement strategies (Barrett et al., 2016). However, the feasibility of this is unclear, due to considerations of GPS/LPS signal, fixation method, and safety for the athletes. The results from the current study is thus only applicable for placement similar to this.

Match data

To my knowledge, this is the first study to investigate HIEs in team handball with the use of IMUs. The data show that female team handball players execute multiple HIEs per min of on-field time. The current study show higher values of HIE than previously reported from video analyses (Michalsik et al., 2015). The high number of HIEs for female team handball players found in this study underlines the accelerative nature of female team handball, and suggests high demands on the anaerobic glycolytic system during match play (Gastin, 2001; Glaister, 2005; Spencer, Bishop, Dawson, & Goodman, 2005). This underlines the need for well-developed physical factors, such as strength and acceleration for performance in team handball (Karcher & Buchheit, 2014; Michalsik et al., 2015). The data also display differences between playing positions, where backs display the highest values of $\text{HIE} \cdot \text{min}^{-1}$, followed by pivots, then wings, and lastly GKs.

Differences between playing positions

Previous studies have shown differences between playing positions in terms of physical demands for female team handball players (Manchado, Pers, et al., 2013; Michalsik et al., 2014a, 2015), which is in line with the current study. In the current study of international female matches, wings are largely lower than backs in $\text{HIE} \cdot \text{min}^{-1}$, but only display a small difference in $\text{Player Load}^{\text{TM}} \cdot \text{min}^{-1}$. This suggests that wing players complete a relatively greater amount of lower-intensity accelerative actions e.g., running at a steady velocity. This is in accordance with data on female team handball players showing a higher total distance covered by wings in match play, compared to backs (Michalsik et al., 2014a). This may be attributed to the fact that the playing area is greater in the outer lanes of the

court where wing players are located, in comparison to the central domain of the court where backs are located. The addition of distance and speed variables could give a more comprehensive understanding of the physical demands in team handball and better elucidate the differences between playing positions. Thus, future studies should try to include both IMU and distance and speed variables.

Wing players displayed the lowest values of $\text{HIE} \cdot \text{min}^{-1}$ of the outfield players in the current study. It has been previously shown that backs and pivots execute higher numbers of different physical high intensity actions (e.g., changes of direction, one-on-one situations, and sudden stops; Póvoas et al., 2014), which supports the findings in our study. Compared to wings, back players are more involved in tactical play in both offence and defense, with a more central position in the middle area of the court. This could lead to a higher number of play involvements and player movements, and could thus potentially explain the higher number of $\text{HIE} \cdot \text{min}^{-1}$ found in the current study. Pivots also show a higher number of $\text{HIE} \cdot \text{min}^{-1}$ compared to wings. Similar to back players, pivots have a more central position on the field, and involvement (especially in defensive play) could be a contributing factor to the higher values. The tactical role of backs in offence constitute a higher number of ball contacts and player movements compared to pivots (Póvoas et al., 2014b), and could be an explanatory factor for the lower $\text{HIE} \cdot \text{min}^{-1}$ of pivots compared to back players. This suggests that the different playing positions need different physical training to mimic (or potentially exceed) the demands of match play.

As expected, GK is the position that stands out the most when comparing $\text{PlayerLoad}^{\text{TM}} \cdot \text{min}^{-1}$ and $\text{HIE} \cdot \text{min}^{-1}$ between the different playing positions. This is in line with previous data, showing that male GKs display the lowest distance per min of all positions (Sibila et al., 2004), in addition to the highest percentage of stationary time (86% of match). GKs play in a dedicated (spatially restricted) zone on the court, and are only involved in the defensive play of their team. This is likely to be the main reason for the lower values for all variables. However, GKs had the highest mean on-field time, and thus the accumulated load over a match should not be underestimated. As Figure 6 shows, a GK's total $\text{PlayerLoad}^{\text{TM}}$ may be higher than certain outfield players. Further research on GK physical demands is needed to fully elucidate the load and HIE demands. For example, different inertial movement analysis variables may be more appropriate for GK than for the other playing positions. In addition, the rule change in 2016 that allowed

teams to substitute their goalkeeper to have seven outfield players on court, may have impacted on GK' match loads. As this rule makes it easier to replace the GK with an outfield player in the offensive part of the team's play, it may be speculated that GKs' total distance and HIE may increase as a consequence of the rapid substitutions needed between the bench and the GK area.

Differences within playing positions

To my knowledge, this is the first study to include analyses of offensive players. It is proposed that international team handball may involve a larger portion of specialized players than national team handball, due to a less homogeneous playing standard in the national leagues (Michalsik et al., 2014b). This may explain why data for specialized players has not been reported in previous studies, as few studies have investigated international team handball. Study II demonstrates that offensive players are located in the higher range in both Player LoadTM·min⁻¹ and HIE·min⁻¹, and show large to very large differences from the two-way playing backs (Figure 7). The recovery time (time off field during the teams defensive play) for offensive backs may contribute to the difference in these variables. However, different playing strategies cannot be excluded as a possibility. In fact, the playing strategies for players who are specialized for offence may be an explanatory factor for why they have this specialized role in their team. In addition, the need for rapid substitutions (both from and to the bench) could contribute to their higher values.

Previous studies in team handball have aimed to elucidate the demands of full-time players, thus setting a high ($\geq 70\%$) on-field time as a inclusion criteria (Michalsik et al., 2014a, 2014b, 2013, Póvoas et al., 2012, 2014b; Sibila et al., 2004). In the current study, players with considerably reduced on-field time were included, thus considering all on-court players and a possibly wider range of intensities. The individual data plots from female international matches (Figure 7) show the differences in Player LoadTM·min⁻¹ and HIE·min⁻¹ between playing positions, in addition to a considerable range between players within the same playing position. Differences in physical conditions or body anthropometry could contribute to these within-playing position differences. Furthermore, the player's technical and tactical capacities could be an important factor, in addition to their positional role in the defense, which may vary from their offensive

position. This change in positional role from offense to defense was not taken into consideration in this study. By allowing for players with a wide range of on-field time, the time to recover will also vary between players. This could be a contributing factor for the range between players, which is especially relevant for offensive players. However, this study was not designed to investigate the possible reasons for the range in these data, and further studies are required to examine the potential reasons for the individual variances.

Differences between playing standards

Previous studies investigating the physical characteristics of top-level handball players have shown that top-level handball players score better than their non-elite peers in sprint tests, endurance tests, and strength tests (Granados, Izquierdo, Ibañez, Bonnabau, & Gorostiaga, 2007; Massuça, Fragoso, & Teles, 2013). To my knowledge, no studies have previously investigated whether there are any differences between playing standards in match data for team handball. Data from studies II and III show that there were no differences in $\text{PlayerLoad}^{\text{TM}} \cdot \text{min}^{-1}$ for the outfield positions, while both backs and wings at international level showed higher $\text{HIE} \cdot \text{min}^{-1}$ than their national level peers (Figure 11). Similarly to when comparing wings and back players, these studies suggest that national-level players complete a relatively greater amount of lower-intensity accelerative actions, such as running at a steady velocity, than their international-level peers. In soccer, investigations of the physical demands of different playing standards have shown that players at a higher playing standard perform more high-intensity running than their peers at lower standards (Andersson, Randers, Heiner-Møller, Krstrup, & Mohr, 2010; Ingebrigtsen et al., 2012; Mohr et al., 2003). For instance, Ingebrigtsen et al. (2012) found that players at a higher playing standard sprinted 25-33% longer than lower level players, although the total distance covered was not significantly different. Similarly, Mohr, Krstrup, and Bangsbo (2003) found that Italian League players did 28% more high intensity-running than elite Danish peers. Although not directly comparable, the notion that high-intensity running or HIE is the discriminating factor between playing standards may be useful for planning training, and especially important for players who change playing standard. However, additional research is necessary to provide an even more valid expression of the distinguishing characteristics of physical demands between competitive standards in team handball. For example, monitoring of physical performance in the same

players who have moved up and down between levels would enable a greater understanding of the influence of standard on match-play physical performance. In addition, the inclusion of technical indicators could be beneficial in explaining additional differences between playing standards.

Changes in physical output during match play

An elevated PlayerLoadTM·min⁻¹ at the beginning of matches is consistent with previous findings of high initial work rates from video-based analyses in team handball (Michalsik et al., 2013; Póvoas et al., 2012). This has been suggested to indicate that fatigue begins in the first half, at least temporarily for full-time players (Michalsik et al., 2013). This is further supported by studies reporting that declines in activity levels are related to high work rates in previous stages of matches in football and Australian football (Bradley & Noakes, 2013; Coutts, Quinn, Hocking, Castagna, & Rampinini, 2010; Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007). High intensities in the start phase of team sports may be related to greater exercise economy at the start of matches, as reported in rugby league (Kempton et al., 2015). However, it is also likely that situational factors play a large role in the activity levels of team-sport athletes. Tactical enforcements by coaches, increased motivation and arousal, longer time of effective play, and the rest period after the pre-game warm-up have all been proposed as reasons for the elevated opening intensities apparent in team sports (Akenhead et al., 2013; Kempton et al., 2015; Lovell, Barrett, Portas, & Weston, 2013). An elevated start intensity may also be beneficial from a tactical standpoint, as an early lead puts pressure on opponents throughout the game.

The same elevated start intensity was not apparent in the second half of the game in this study, which is in line with previous studies in handball (Michalsik et al., 2014a, 2013, Póvoas et al., 2012, 2014b). A less intense start to the second half in team sports could be an indication of fatigue caused by the first half. This is possibly attributed to physical impairment of players and a consequent inability to work at the desired rate. This is supported by findings of decreased physical performance after team handball games (Póvoas et al., 2014b; Ronglan et al., 2006; Thorlund et al., 2008). However, other possible factors, such as pacing strategies or a lack of re-warm-up after the halftime break may also contribute to the findings of less intense starts in the second half (Bradley &

Noakes, 2013; Michalsik et al., 2013; Póvoas et al., 2012). In addition, since unlimited numbers of substitutions are allowed in team handball, this may also influence the changes in intensity of a team during the match.

The findings of the current study suggest that handball players experience substantial declines in $\text{PlayerLoad}^{\text{TM}} \cdot \text{min}^{-1}$, with the Post-5 period showing below average values, with substantially differences to the Pre period. These results could indicate the occurrence of transient fatigue in team handball, which is in line with findings in other team sports (Akenhead et al., 2013; Bradley & Noakes, 2013). Short rest periods between intense actions in team handball (Póvoas et al., 2012, 2014a) could hinder the recovery of energy stores (Póvoas et al., 2012; Spencer et al., 2005), and thus may cause the observed declines after the most intense period.. Alternatively, transient declines in team sports have been suggested to be caused by micro pacing strategies (Waldron & Highton, 2014). In this case, the periods with lower intensity may be a protective strategy, aiming to maintain an overall pacing strategy for the match or the half (Edwards & Noakes, 2009). Situational factors may also be an explanatory factor, thus the declines could simply be a result of variations in the game dynamics and the intermittent nature of team sports. In support of this, time of “ball in play” has been reported to be longer in the peak periods of soccer matches (Carling & Dupont, 2011), possibly increasing the players involvement in the game. This has, to my knowledge, not been investigated in team handball.

When investigating players with consecutive periods of on-field time, it was found that the highest value of $\text{PlayerLoad}^{\text{TM}} \cdot \text{min}^{-1}$ was in their first period. This is similar to what was observed in the team profile, and, as discussed, it may be attributed to situational variables. However, in the analyses of consecutive periods, the first period of on-field time could be at any point during the match. Consequently, a possible explanation is that players are more motivated and active, wanting to make an impact on the match, as soon as they enter the field, irrespective of match time. The observed decrease in $\text{PlayerLoad}^{\text{TM}} \cdot \text{min}^{-1}$ with two or more consecutive periods of on-field time are in line with the previously discussed declines in team activity levels, which can be linked to either fatigue or pacing strategies. The profiles for individual players have similar characteristics to a “slow-positive” pacing profile of whole-game players in team sports,

with progressive declines in intensity across a match (Waldron & Highton, 2014). These findings also further strengthen the possibility that declines in activity levels on a team level are partly explained by declines in individual player activity. This can be indicative of match-induced fatigue in players who play large parts of halves without rest periods. It is possible that the unlimited-interchange rule can lead players to positively alter their pacing strategies, as they know that they can be replaced if they are fatigued (Waldron & Highton, 2014).

Game-based training

The differences between the 3vs3 and 6vs6 conditions in the present study are in line with previous research in team handball, and in other team sports, with an increase in intensity when number the of players is reduced (Bělka et al., 2016, 2017; Foster et al., 2009; Rampinini, Impellizzeri, et al., 2007). In addition, studies altering the pitch size show similar results to the current study. Specifically, a greater intensity occurs with an increase in area per player. For example, a study investigating game-based training in team handball found differences in intensity between approximately 36 m², 56 m², and 64 m² per player, when altering the pitch size and holding the player number constant (Corvino et al., 2014). The largest area per player elicited greater values in total distance covered, RPE and heart rate (Corvino et al., 2014). In the current study, the 3vs3 condition resulted in an area of 108.5 m² while the 6vs6 resulted in an area of 54.3 m² per player, and again the larger area per player elucidated the highest intensity. Thus, it is important to note that the changes in the current study may not be solely attributable to player number per se, as the changes in area per player may be of equal importance.

In soccer, it has been reported that game-based training can simulate the overall movement patterns in friendly matches at a domestic, national, and international standard of competition (Casamichana, Castellano, & Castagna, 2012; Gabbett & Mulvey, 2008). However, there are, to my knowledge, no previous studies comparing the intensity of game-based training to the intensity of official matches in team handball. The current study shows a greater PlayerLoadTM·min⁻¹ for backs, wings and pivots in both game-based training conditions, when compared to the mean of the match; this is in line with research in other team sports. The PlayerLoadTM values are also comparable to the values in MSP, and thus can be recommended as an effective training regime to mimic or

overload official matches. The reduced duration of the game-based training compared to official matches is most likely a contributing factor for greater intensity (Corvino et al., 2014). Other factors such as coach encouragement and spare balls (more effective “ball in play” time) may also contribute to the training intensity. In addition, the fact that game-based training is a training task, and thus the outcome of the “match” is not as important as an official match may affect the tactical decisions and risk-taking in play, and again affect the intensity.

Even though game-based training is shown to mimic or overload the overall intensity of official matches, it has also been shown that the training is not sufficient to simulate the high-intensity repeated-sprint demands of high-standard matches in women’s soccer (Gabbett & Mulvey, 2008). Similarly, in the current study, the $\text{HIE} \cdot \text{min}^{-1}$ in game-based training drills does not seem to mimic official match demands to the same extent as $\text{PlayerLoad}^{\text{TM}} \cdot \text{min}^{-1}$. $\text{HIE} \cdot \text{min}^{-1}$ values are not substantially different from match mean data for backs in both conditions, and wings and pivots in the 6vs6 condition. When compared to MSP, backs showed lower values in both conditions, while wings and pivots showed lower values in 6vs6. These data suggest that while overloading the overall intensity in team handball players, game-based training conditions do not overload the specific HIE that is an important factor for performance in team handball (Michalsik et al., 2013). Wing players show a greater $\text{HIE} \cdot \text{min}^{-1}$ in the 3vs3 condition compared to both match mean and MSP. In a 3vs3 condition, wing players will have a different role than in a 6vs6 condition. They will be located more centrally on the court, and thus be more involved in the game, in both offence and defense. Over all, 3vs3 seems to be a good overload condition for wing players both for $\text{PlayerLoad}^{\text{TM}} \cdot \text{min}^{-1}$ and $\text{HIE} \cdot \text{min}^{-1}$. However, the fact that wing players change their role in the 3vs3 condition will affect the specificity of the drill in relation to their typical match role. This is also applicable to pivot players in the 3vs3 condition.

In the present study, GKs had lower $\text{PlayerLoad}^{\text{TM}} \cdot \text{min}^{-1}$ values in the game-based training conditions than in MSP. Thus, GKs may need a different training set-up for intensity overloading than the other playing positions. For tactical reasons, the frequency and type of shots could have been different during the game-based training than in official match play, especially in the 3vs3 condition. This could in turn affect the amount of HIEs that GKs execute.

Validity of LPS

As mentioned previously, the addition of time-motion variables to IMU variables may be beneficial in obtaining comprehensive overview of the physical demands imposed on team handball players. ClearSky T6 contains both LPS and IMU, and could thus be used for this purpose. The current study show that the mean difference between the reference system and the LPS was below 0.35 m for position and below 2% for distance in all task and, for the optimal condition. Thus, these variables can confidently be used for time-motion analyses in indoor sports.

Due to lack of a reference system that allows instantaneous position comparisons in motion, position error of LPSs is often investigated with static measurements. Static measurements of the validity of LPSs have shown an error range of approximately 1 to 32 cm (Frencken et al., 2010; Rhodes et al., 2014; Sathyan et al., 2012). This large range can partly be attributed to the different methodological setups and LPS technologies used. The environment could also contribute to the results; the largest error was found in an indoor environment (Rhodes et al., 2014), while the smallest error was found in an outdoor environment (Frencken et al., 2010). Only one previous study reported errors in position using LPS measurements in dynamic tasks, with a mean error of 0.23 m (Ogris et al., 2012). The similarity in error between the outdoor study by Ogris et al. (2012) and the current indoor study could indicate that measurements in large halls with no obstructions may create measurement conditions that are not much different from outdoor conditions. However, the current study also seems to indicate that small distances to walls and corners of halls, along with the anchor node setup, have a major impact on position accuracy. Position measurements are mainly used for time-motion analyses in sports, and thus our results (optimal condition) seem acceptable for this purpose. The players' position could also be used for tactical analyses purposes, such as understanding the movements performed in the lead up to a goal attempt. However, for other applications, such as tactical analyses, the lack of information regarding the accuracy level needed makes it difficult to confidently state that the LPS is either acceptable or not.

Previous studies on LPS in indoor conditions show mean errors in total distance ranging from 2.0 to 6.3% (Leser et al., 2014; Sathyan et al., 2012; Serpiello et al., 2017), while studies in outdoor conditions have shown errors ranging from 0.2 to 3.9% (Frencken et

al., 2010; Sathyan et al., 2012; Stevens et al., 2014). Presumably, previous studies optimized the setup of the LPS when investigating the accuracy of the systems, resembling the optimal condition in the current study. The results of the current study showed a mean difference in distance from the reference system of between 0.5% and 1.8% in the optimal condition, which is lower than previously reported for indoor conditions. However, error in total distance travelled in sub-optimal conditions was of a critically large magnitude, and not useful for quantifying the distance covered for training load purposes. Hence, for quantification of distance, only data from the optimal condition can be used with confidence.

To my knowledge, very few studies have investigated the validity of instantaneous speed measurements in team sports (Varley, Fairweather, & Aughey, 2012). It has been previously shown that peak speed in LPS is less accurate than mean speed (Ogris et al., 2012; Rhodes et al., 2014; Serpiello et al., 2017; Stevens et al., 2014); however, no previous study has assessed the accuracy of instantaneous speed as determined with an LPS over the whole range of dynamic tasks in team sports. The current study shows that instantaneous speed differed substantially between the LPS and the reference system in both the optimal and sub-optimal conditions (Table 11), and that the differences were speed-dependent (Figure 15). Our study shows considerably higher errors than those previously shown in a GNSS study (Varley et al., 2012). However, the GNSS-based study investigated straight line running only, which could contribute to these results. In addition, time synchronization and filtering of raw data could play a significant role in error reduction for instantaneous speed (Ogris et al., 2012; Stevens et al., 2014), and the filtering techniques and time synchronization method used in the aforementioned study (Varley et al., 2012) were not disclosed. Mean speed has been investigated in several studies (Frencken et al., 2010; Ogris et al., 2012; Rhodes et al., 2014; Serpiello et al., 2017; Stevens et al., 2014), and is often used as an overall indicator of the intensity of an activity. Compared to previous studies, the current study shows similar results in terms of mean speed errors (Frencken et al., 2010; Ogris et al., 2012; Rhodes et al., 2014; Stevens et al., 2014), thus, the LPS can give an overall indication of the intensity of the activity. Serpiello et al. (2017) investigated the validity of the same LPS as in this study, but with a lower sampling frequency (10 Hz vs ≈ 17 Hz in the current study). They found

higher errors in both mean speed and distance, which could be attributed to the lower sampling frequency used.

The current study shows that changes in the placement of anchor node positions relative to the field of play and the distance between the side walls and corners of the hall to the field of play can affect the accuracy of data. Placement of nodes has an effect on the geometry of the anchor nodes relative to each other and the mobile node. In addition to changes in geometry, close proximity to the edge of the field and the walls may cause the mobile nodes to go undetected by multiple anchor nodes, thus producing a higher error rate. Close proximity between the edge of the field and the walls may also increase multipath propagation (Muthukrishnan, 2009), which will reduce the accuracy of data. The current study was not designed to isolate the different contributors (geometry, undetected nodes, and multipath propagation), thus the results of this study show the sum of errors accumulated from all sources. Further investigations are needed to understand the impact of the different contributors and how this could contribute to the optimization of anchor node placement.

Perspectives and implications for Future Research

Players may perform isometric actions that will not be registered by the IMU-unit (or by previous studies using time-motion analyses). This may be especially pronounced in pivot players, because of their tactical role in both defense and offense. Thus, an underestimation of the intensity of players, especially of pivots, may be present in the current study. However, this study shows that IMU data can provide a different approach to quantify match and training loads in team handball. The metrics provide valuable information in sports like team handball where players perform a high number of non-running-based actions. Further research should seek better understanding of these metrics, and their applicability for training load quantification, performance outcomes and injury risk. Especially, the development of variables detecting passes and shots may be beneficial to be able to monitor the amount of load put on shoulders of team handball players, as there is a high prevalence of shoulder pain among handball players (Myklebust, Hasslan, Bahr, & Steffen, 2013). In addition, the combination of LPS and IMU could give a more comprehensive overview of physical demands in team handball, and should be investigated in future research.

In team handball, there are many defensive systems used (e.g. ball-oriented or player-orientated), with varying formations. Different tactical systems can also be applied in offence, which may impact the physical demands of players. In addition, players may change their role in offensive versus defensive phases. Unfortunately, the influence of such factors on physical demands has not yet been examined, and should be the subject of future research.

Performance in team handball is multifactorial, and the physical demands that are investigated in this study are only one of many factors. Technical and tactical factors are also important for performance, and contextualizing physical demands in relation to tactical and technical activities could provide practitioners a deeper insight into the physical demands in relation to the tactical roles of a team/player. Additional information regarding the physical demands in conjunction with variables such as where players are located on the field, possession status, and combinations/plays could be beneficial for the construction of training drills.

In the current study of the validity of LPS, no filters were applied to the data, in order to investigate the raw output from the LPS. Further investigations of the effect of filtering techniques on the validity of the current data could be interesting, as filtering techniques can affect the estimated position, distance and speed (Malone et al., 2016; Sathyan et al., 2012).

The study showed that changing the anchor node positions relative to the field of play and the distance between the side walls and corners of the hall to the field of play does affect the accuracy of the system. To optimize the measurement setup in small sport halls, future investigations should include tilting of nodes in the vertical direction to the field of play, and optimization of the geometry of anchor node positions relative to the field of play. Special attention should be given to multipath minimization to avoid mobile nodes going undetected by multiple anchor nodes close to corners, by adjusting the tilting and positioning of nodes close to corners. The inclusion of a dilution of precision measure would enhance the process of optimization of anchor node positions.

Practical applications

The results from this study demonstrate that elite female team handball players execute a considerable number of actions involving accelerations and decelerations, which underlines the intermittent nature of the game. Furthermore, the differences in HIEs between playing positions highlight the need for position-specific training programs. The reduction in PlayerLoad™ with consecutive periods on field is also relevant information for coaches, in order to apply effective training programs and rotation strategies. In addition, as the highest activity is observed in the first period of play (regardless of match time), coaches can use this information tactically; for instance by introducing rested “impact players” in certain periods of the game.

The results also demonstrate that coaches can manipulate physical demands in game-based training drills for female team handball players by modifying the number of players involved. However, coaches should be aware that the currently used games-based training drills did not facilitate the same overload in HIE as in PlayerLoad™. Thus, coaches can use game-based training drills, such as the ones used in this study, to overload the PlayerLoad™ of match situations. However, to overload the important HIE for backs and pivots, there is a need for additional or modified drills.

Both HIE count and PlayerLoad™ show good reliability, and can be used to detect differences in team handball. The findings in this study have produced a recommendation to use total count, or a combination of medium/high count when reporting HIE variables. The accuracy of LPS output is highly sensitive to relative positioning between the field of play and walls/corners and anchor nodes. Measures of position, distance, and mean speed from the LPS can be used confidently in time-motion analyses for indoor team sports, in conditions similar to the optimal condition in this study. In small sport halls or in conditions when the walls, and even more importantly, the corners of the room are close to the field of play, accuracy is relatively poor and caution required if measuring and interpreting data under these conditions.

Conclusion

In conclusion, the present studies demonstrated:

1. HIE count was reliable when it was displayed as total, high, or medium/high counts. PlayerLoadTM also displayed a good level of reliability.
2. There are differences between playing positions and between playing standards in the number of HIEs executed in match play. Backs display the highest numbers of HIEs, followed by pivots and wings. International-level players display higher values of HIE compared to national-level players.
3. High initial PlayerLoadTM·min⁻¹ was observed for team profiles and for players with ≥ 2 consecutive periods of play. Substantial declines in PlayerLoadTM·min⁻¹ were observed throughout matches for the team and for players with several consecutive periods on the field.
4. The number of players involved in game-based training drills can affect the intensity of the drill. A lower number of players resulted in an increase in both PlayerLoadTM·min⁻¹ and HIE·min⁻¹. Positional differences were apparent when comparing the intensity of game-based training drills with official matches.
5. Measures of position, distance, and mean speed from the investigated LPS can be used confidently in time-motion analyses for indoor team sports, in conditions similar to the optimal condition in this study. However, the accuracy was highly sensitive to positioning between field of play and walls/corners and anchor nodes.

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Paper I

“Reliability of Wearable Inertial Measurement Units to Measure Physical Activity in Team Handball”
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Title: **Reliability of wearable inertial measurement units to measure physical activity in team handball**

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Abstract

Purpose: The purpose of this study was to assess the reliability and sensitivity of commercially available inertial measurement units (IMU) to measure physical activity in team handball.

Method: Twenty-two handball players were instrumented with two IMUs (OptimEye S5, Catapult Sports, Australia) taped together. They participated in either a laboratory assessment (n=10), consisting of seven team handball specific tasks, or field assessment (n=12) conducted in twelve training sessions. Variables, including PlayerLoad™ and inertial movement analysis (IMA) magnitude and counts, were extracted from the manufactures software. IMA count was divided into intensity bands of low ($1.5\text{-}2.5\text{m}\cdot\text{s}^{-1}$), medium ($2.5\text{-}3.5\text{m}\cdot\text{s}^{-1}$), high ($>3.5\text{m}\cdot\text{s}^{-1}$), medium/high ($>2.5\text{m}\cdot\text{s}^{-1}$), and total ($>1.5\text{m}\cdot\text{s}^{-1}$). Reliability between devices and sensitivity was established using coefficient of variation (CV) and smallest worthwhile difference (SWD). **Results:** *Laboratory assessment:* IMA magnitude showed a good reliability (CV: 3.1%) in well-controlled tasks. CV increased (4.4-6.7%) in more complex tasks. *Field assessment:* Total IMA count (CV: 1.8%, SWD: 2.5%), PlayerLoad™ (CV: 0.9 % SWD: 2.1%), and its associated variables (CV: 0.4-1.7%) showed a good reliability, well below the SWD. However, the CV of IMA increased when categorized into intensity bands (2.9-5.6%).

Conclusion: The reliability of IMA count were good, when data was displayed as total, high or medium/high counts. A good reliability for PlayerLoad™ and associated variables was evident. The CV of the aforementioned variables was well below the SWD, suggesting that OptimEye IMU and its software are sensitive for use in team handball.

Keywords: *team sport, accelerometer, gyroscope, inertial sensors, training analyses*

Introduction

Analyses of physical demands in team sports can provide a better understanding of physical performance. This may help to improve the practice of training and the physical development of players¹⁻³, in addition to load management^{4,5}. GPS technology is one of the most used methods to measure physical demands in team sports. Such technology is used to measure distance travelled and speed, however, GPS technology alone may not accurately measure short duration movements (e.g. changes of direction). In addition, GPS signals are typically not obtainable indoors, thus not useable for indoors sports such as team handball. In recent years, inertial measurement units (IMU) have been integrated into GPS devices, to provide additional information relating to physical loads during games and training. IMUs consist of the interial sensors accelerometers and gyroscopes. In addition, magnetometers are also imbeded in many IMUs. Information from IMUs are independent of GPS signals, and can thus be used in indoor enviroments, as well as outdoors.

IMU technology has been used by various team sports in training and games⁶⁻⁹. By using specific software algorithms the technology can detect important activities and facets of the play¹⁰⁻¹². There are several different manufactures of IMUs (integrated with GPS) designed for monitoring team sport athletes, including Catapult Sports, Australia (MinimaxX and OptimEye), VX Sports, New Zealand (VX) and STATSports, Ireland (Viper pod). In addition to their respective hardware technology, these manufactures have developed specific algorithms within the software to automatically convert the raw IMU data into readily usable metrics for physical demand analysis in team sports. In general, these variables can be categorized into so-called workload variables or event detection variables. Workload variables have been used as a general measure of physical activity, and aim to measure both

the running-based activity and the non-running-based activity. PlayerLoad™ from Catapult Sports is an example of a workload variable¹³. Event detection variables registers the frequency and magnitude, and distinguish between different non-running-based activities, such as changes of direction (CoD)^{6,14} and tackles/collisions¹⁰. Workload variables are based on accelerometer data only, while event detection variables include gyroscope data.

The validity and reliability of accelerometer data are dependent on the variable/metric and device/manufacture that has been investigated¹⁵. Studies investigating IMUs in team sports primarily focus on devices from two manufactures; Catapult Sports and GPSports. Most previous studies have focused on raw accelerometer data, or workload variables. For example, it has been shown that IMUs are capable of accurately^{16–19} and reliably^{13,20} measuring a variety of team sports movements. In addition, there are a number of more recent studies validating novel or commercial (i.e. Catapult) event detection variables^{14,21–25}. For example, Gabbett²⁵ showed that MinimaxX is able to identify tackles in Rugby. Meylan, Trewin and McKean¹⁴ showed that MinimaxX is able to accurately detect acceleration, deceleration and CoD in soccer. However, the reliability of these variables have not yet been investigated. Further, to the authors knowledge, the variables in some of the published research^{22–24} is not currently commercially available. Therefore, the purpose of this study was to assess the between-device reliability of a commercially available IMU to measure physical demands in team handball. The current study is, to our knowledge, the first to investigate the between-device reliability of IMA variables, and the different variations of PlayerLoad™.

Methods

Subjects:

The reliability of PlayerLoad™ and IMA variables was evaluated via a laboratory (outfield players only) and field assessment (all playing positions included). Five male and five female handball players (age, 21.2 ± 1.3 years; body mass, 73.9 ± 12.3 kg; height, 175.1 ± 7.4 cm; mean \pm SD) participated in the laboratory assessment. The subjects competed in elite ($n = 5$) or first division ($n = 5$) in Norway. Twelve male handball players (age, 23.8 ± 4.6 years; body mass, 92.4 ± 9.7 kg; height, 192.3 ± 9.1 cm) from an elite handball team in Norway participated in the field assessment. All data was collected throughout the first half of the in-season period (October to December). The research was completed in accordance to the Helsinki declaration. The subjects were verbally informed about the purpose and procedures of the study, and signed consent forms prior to participation. Data storage was approved by the Norwegian Social Science Data Service.

Methodology

Subjects were instrumented with two IMUs (Optimeye S5, Catapult Sports, Australia) that were worn in the manufacturer-supplied vest (Catapult Sports, Australia), placed in a pouch on the posterior side of the upper trunk. The two devices were taped together, to align the accelerometer, and gyroscope axes. The position of the devices (proximal or distal to the body) was swapped between sessions, thus each device was applied at both sites. A total of seven pairs of devices were randomly assigned to the subjects. The same subject used the same two devices during all testing.

Laboratory Assessment

The assessment was conducted on a indoor surface (Pulastic SP Combi, Gulv og Takteknikk AS, Norway). Subjects were tested on two separate days, and the same protocol was completed in both sessions. The subjects underwent a warm-up of 10 minutes, consisting of dynamic stretching and sport specific running exercises (e.g., jogging, accelerations and CoD). Warm-up intensity was regulated individually. Familiarisation trials were undertaken prior to each movement task until the subject was confident in executing the tasks (range 2 to 5 trials).

The subjects completed a total of seven movement tasks (Figure 1). Four tasks consisted of a single one-step movement action (one-step action), performed in different force directions. These efforts are described as a start action (T1), stop action (T2), left CoD (T3) and right CoD (T4). Three tasks involved repeated CoD (T5), start and stop actions (T6), and multidirectional CoD (T7). In T1-T6 the subjects were instructed to face forward throughout the duration of the task (Figure 1). Thus, T3-5 includes cutting movements, while T7 includes turning movements. All tasks were completed with maximal intensity, and repeated four times. The subjects were given a two minute recovery between trials.

Field Assessment

A total of 12 handball-training sessions were undertaken on three different indoor courts during the analysis period. All sessions were performed as planned by the coach, without any intervention from the analyst. The training drills, intensity and volume of each session were adjusted according to the game schedule. The training sessions consisted of a warm-up, technical and tactical drills, transition games and game simulations. A separate period was created for each drill in the software. Rest periods and interchanges were

excluded. The analysis consisted, therefore of only active periods, which accounted for 63.8 ± 7.2 min.

Data processing

The Optimeye S5 (firmware 6.109, Catapult Sports, Australia) device is 96 x 52 x 13 mm and weighs 66.8 grams. It contains a tri-axial accelerometer, gyroscope and magnetometer, which all sample at a frequency of 100 Hz. The manufacture’s software (Catapult Sprint, v 5.14, Catapult Sports, Australia) was used to convert the raw data into IMA variables and PlayerLoad™. PlayerLoad™ is a vector magnitude derived from accelerometer data, and expressed in arbitrary units (au). Specifically, it is calculated as the square root of the sum of the instantaneous rate of change in acceleration from three vectors and divided by a scaling factor of 100¹³. PlayerLoad™ was expressed in its original formula, in addition to variations of this metric, including PlayerLoad 2D (PL_{2D}) and individual axes: anterior-posterior (PL_{AP}), medio-lateral (PL_{ML}) and vertical (PL_V).

IMA uses raw accelerometer and gyroscope data to create a non-gravitational acceleration vector (or data) based on Kalman filtering algorithms. These algorithms detect specific acceleration events (IMA event), which can be defined as an instant one-step movement effort (e.g., sudden CoD). The magnitude of an event is calculated as the area under the curve, based on the sum of anterior-posterior and medio-lateral accelerations. IMA magnitude is expressed as delta velocity (m·s⁻¹). The direction of an event is calculated relative to the device’s orientation at the time of the step, and is based on the angle of the applied acceleration and is measured in degrees (±180°). To exclude general running based activity from the analysis, only IMA events ≥ 1.5 m·s⁻¹ were included. Further, IMA counts were categorized into the manufactures default intensity bands; low (1.5 to 2.5 m·s⁻¹), medium (2.5

to $3.5 \text{ m}\cdot\text{s}^{-1}$) and high ($> 3.5 \text{ m}\cdot\text{s}^{-1}$). IMA count were also categorized within specific directional bands, based on IMA direction. These include forward (-45 to 45°), backward (-135 to 135°), left lateral (-135 to -45°) and right lateral (45 to 135°) counts. The directional values were changed to positive values prior to analysis in the laboratory assessment.

Statistical Analysis

Descriptive values from the two devices were presented as mean \pm SD. The mixed-linear-modeling procedure (Proc Mixed) in SAS[®] (SAS[®] Studio 3.5, SAS Institute Inc., Cary, NC, USA) was used for analyses. Separate analyses were conducted for each variable in the laboratory and field assessment. The fixed effects in the laboratory assessment model was device placement (2 levels: proximal, distal) and the direction of the event (4 levels: forward backward, right lateral, left lateral). The random effects were subject identity, device identity, and set identity*session identity*action identity. Set identity identifies each set the subjects completed, and action identity is a count of all different actions detected by the device. In the field assessment, the fixed effect was device placement. The random effects were subject identity, device identity, session identity and subject identity*session identity. Data presented as coefficient of variation (CV) were log-transformed to reduce bias from potential non-uniformity error²⁶. Measures of angles are interval data and not appropriate to convert, IMA directional values were therefore not presented as CV. The reliability between devices was established using the typical error of measurement (TE), expressed in absolute terms and as a percentage CV. The uncertainty was expressed as 90% confidence interval (CI). The CV was rated as good (CV < 5%), moderate (CV 5 to 10%) or poor (CV > 10%). The smallest worthwhile difference (SWD) was calculated as the $0.1 \times$ between-subject SD²⁶ and was used as a measure to identify *real* differences. When interpreting the magnitude of variance an

halvation of the usual magnitude thresholds for differences in means is appropriate, thus 0.1 was used instead of 0.2²⁶. Outliers were identified as ≥ 4.0 studentized residuals²⁶, but not removed from the dataset in any calculations.

Results

Laboratory Assessment

Reliability statistics from the laboratory assessment are displayed in Table 1. The CV of the magnitude of an IMA event was good (CV < 5%) in controlled movement tasks (T1-4) and in T5. However, the CV increased in more complex movement tasks (T6-7). Directional measurements showed a typical error of 2.4-3.6°. Figure 1 show the residuals of the different actions in the different tasks, and include plots of outliers. The figure displays the increased residuals with increasing complexity of the task, including a greater number of outliers.

The mixed model output showed that the device identity accounted for 0.1-0.4% of the variation in magnitude and 0.4-1.0° of the variation in direction.

Field Assessment

Total IMA count showed a CV of < 5%, which was less than the SWD (Table 2). The CV increased slightly when IMA count were categorized within intensity bands. IMA count within high, and medium/high (combined), and total intensity bands showed CVs that were less than the SWD. CV of IMA count within low and medium intensity bands were greater than the SWD.

The CV of total IMA count within direction bands was good to moderate (CV 3.9-6.6%, Table 3). However, CV was greater than the SWD in all cases. CV increased substantially when forward, backward, left and right counts were divided within intensity bands. The CV for these variables was greater than the SWD.

The CV of PlayerLoad™ and its associated variables was good (CV < 5%, Table 4), which was less than the SWD. The mixed model showed that the device placement (proximal or distal) accounted for 1.3-5.9% of the variation in the original data. The distal device showed higher values in all cases, with the exception of PL_{AP}, where the proximal device showed higher values. The device identity did not account for any of the variation in any of the PlayerLoad™ variables.

Discussion

To our knowledge, this is the first study to assess the between-device reliability of IMA variables from OptimEye S5 IMU. The main findings showed that IMA count was a reliable variable (Table 2), provided that it is displayed as total, high or high/medium counts. Furthermore, the study demonstrated a good level of reliability for PlayerLoad™, and associated variables (Table 4). IMA magnitude and direction showed good reliability in simple tasks, however an increase in CV (moderate) and TE with an increase in task complexity was observed (Table 1).

The laboratory assessment showed a good to moderate reliability for IMA magnitude values. The intensity and type of activity (or movement) are potential factors to affect the reliability of raw inertial signals²⁷. This may partially account for the variation that was observed in this study. The CV appeared to increase in more complex tasks (Table 1), possibly due to certain “outliers” in the data set (Figure 2). These “outliers” (or large variations) were likely to be a result of inconsistency in data filtering between devices. As such, a device could detect one large IMA event, whereas the other device could detect two small consecutive IMA events. This may appear in situations where several events within the same movement (e.g., instant left to right CoD) occur close together. Such findings may represent a

shortcoming for the IMA event detection algorithms, as team sports are highly complex in nature. One previous study¹⁴, investigating the MinimaxX IMU, has previously assessed the CV of IMA magnitude in a test-retest design, and found CVs of 13-21%, which is higher than reported in the current study. Different experimental designs of studies could affect the outcome, in addition it can be speculated that developments in the hardware and software have made this variable more reliable in the later version (e.g. MinimaxX vs OptimEye).

In the field assessment, total IMA count showed a CV of 1.8%, which was well below the SWD (2.5%). However, the reliability decreased when IMA count was categorized into intensity bands; low, medium and high (Table 2). Based on the current data it is recommended that IMA count should be categorized into wider intensity bands (such as combined medium/high), to reduce variation. In addition to overall IMA count, a categorization of IMA count within direction bands could provide a more detailed insight into players' movement patterns. However, this is a very challenging task given the chaotic nature of team sports and the individual variation of player movement characteristics. A moderate reliability was found for forward, backward, and left and right lateral counts for the OptimEye S5 devices in this study (Table 3). Further, when the direction bands were divided into intensity bands, the reliability decreased. Based on this, caution should be taken when interpreting IMA count with respect to directional bands, especially when categorising into intensity bands.

Similar to the current study, previous research has observed good between-device reliability of PlayerLoad™ when MinimaxX were tested via a calibration device and in Australian football games¹⁰. However, the current study showed a slightly lower CV, compared to the aforementioned study when devices were tested in a field setting. As both studies used a similar device set-up and design, it can be speculated that developments in the

hardware or software have made this variable more reliable. The current study showed greater reliability compared to previous studies in treadmill running²⁸ (CV 5.9%), team sport movements²⁹ (CV 4.9%), and simulated football matches³⁰ (CV 3.6-3.8%). However, large variations in the specific design (test-retest vs between-device) in these different studies may account for some of the variation reported.

The current study found no effect of the device identity on the data, thus the data is in line with previous research showing a nearly perfect relationship between devices for the PlayerLoad™ calculation, using the Pearson correlation coefficient statistic ($r = 0.99$)⁹. A nearly perfect relationship (ICC = 0.93) within devices has also been observed in a laboratory setting²⁸. These findings indicate that PlayerLoad™ can be used with confidence regardless of which devices are being used.

In agreement with previous research of Australian football¹⁰, the CV of PlayerLoad™ was well below the SWD (Table 4). This was also evident for PL_{2D} and the individual axes. PlayerLoad™ and associated variables may therefore be considered as sensitive to measure physical activity demands in team sports. However, practitioners should be aware that large between-athlete variability in accelerometer based loading metrics have been reported^{28,30,31}. Therefore, comparison between individual players may be difficult. Differences in loading patterns may partially be caused by differences in running economy, stride characteristics, and movement artefacts of the device dependent on the fixation on different athletes³². In fact, the current study shows that placement of the device affect the data output, thus emphasizing that small changes in fixation of the device can influence the output.

The literature specifies that inertial sensors should be tested in the type of activity and the specific intensity of that of the target population²⁷. The best practice would therefore

involve an assessment in real game situations. However, handball players land or fall frequently on their back, and using two devices would possibly affect their focus in games, and possibly increase the injury risk. The study therefore aimed to assess the reliability in training sessions, which was considered as the best available alternative for the OptimEye S5 devices to be tested in conditions representative for elite team handball demands. The devices were taped together during data collection and their positions were switched between sessions. This was considered as the best alternative to minimise variations between devices. Our data showed that the device placed distally to the body recorded greater values for most PlayerLoad™ variables (1.3-5.9%). A similar observation has also been reported by previous research in Australian football¹³. Therefore, the device setup could account for some of the observed variation in this study. Further, reliability of different placements of devices (e.g. centre of mass³⁰) could be of interest. However, the feasibility of this is unclear, due to considerations for GPS signal, fixation method, and safety.

Practical applications

- Both IMA count and PlayerLoad™ show a good reliability, and can be used to detect *real* differences in team handball.
- We currently recommend to use total count, or a combination of medium/high count when reporting IMA variables. However, band thresholds may need to be adjusted to individual sports and level of competition.
- Categorization of IMA into direction bands and intensity bands showed moderate to poor reliability, and should be used with caution.

“Reliability of Wearable Inertial Measurement Units to Measure Physical Activity in Team Handball”
by Luteberget LS, Holme BR, Spencer M
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Conclusion

The current study showed that IMA count is a reliable variable, when data were expressed as total counts (CV 1.8%) or within high and medium/high (combined) intensity bands (CV 3.1%). PlayerLoad™ and associated variables were also found to be a reliable (CV 0.9-1.7%) . The CV of these variables was well below the SWD, suggesting that Optimeye IMUs are sensitive to detect *real* differences in team handball activity. These findings may also be extended to other similar team sports with SWD greater than 3.1 and 1.7% for IMA count and PlayerLoad™ variables, respectively.

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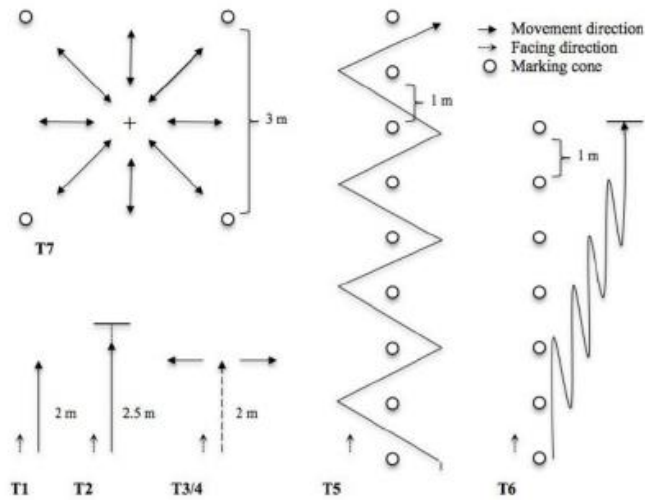


Figure 1: Illustration of the tasks executed in the laboratory assessment. Well-controlled one-step actions: start action (T1), stop action (T2), left CoD (T3), and right CoD (T4). Chaotic movement patterns: lateral CoD (T5), start-stop action (T6), and multidirectional CoD (T7). CoD = change of direction

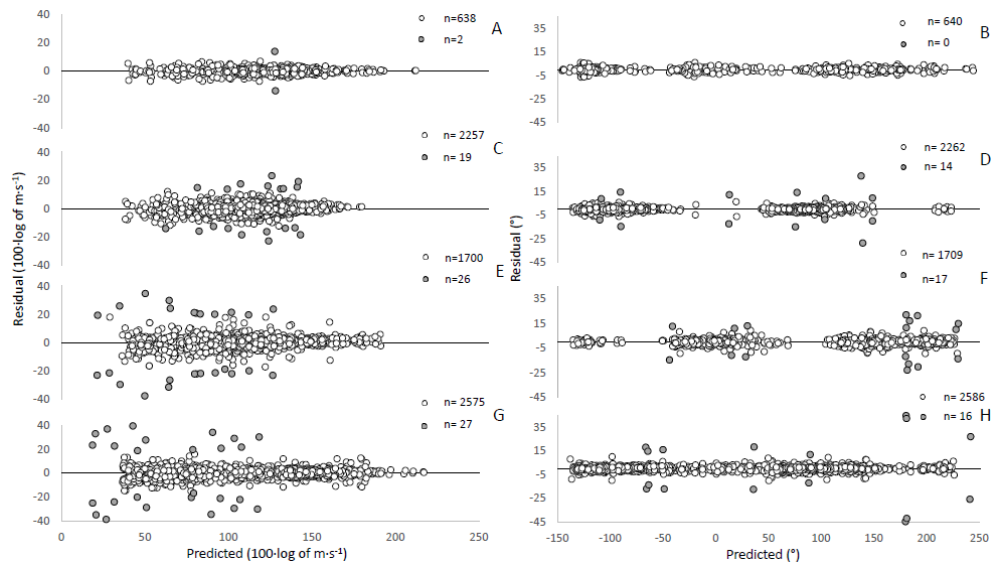


Figure 2: Residuals versus predicted plots for values from team handball specific movement tasks in the laboratory assessment. A-B: one-step actions (T1-T4), C-D: lateral CoD (T5), E-F: start-stop action (T6), and G-H: multidirectional CoD (T7).
CoD = change of direction

Table 1: Between-device reliability for magnitude and direction in the laboratory assessment.

Movement tasks	Acceleration	Device 1		Device 2		TE (Abs)	90% CI		CV (%)	90% CI (%)	Events (n)
		Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD		(Abs)	(%)			
One-step (n = 320)	Magnitude (m·s ⁻¹)	3.2 ± 1.0	3.2 ± 1.0	3.3 ± 1.0	3.3 ± 1.0	-	-	-	3.1	2.9 - 3.3	320
	Direction (°)	100.8 ± 50.1	100.8 ± 50.1	100.6 ± 50.4	100.6 ± 50.4	2.4	2.3-2.6	-	-	-	-
Lateral CoD (n = 80)	Magnitude (m·s ⁻¹)	3.1 ± 0.7	3.1 ± 0.7	3.0 ± 0.7	3.0 ± 0.7	-	-	-	4.4	4.3 - 4.6	1138
	Direction (°)	94.5 ± 19.0	94.5 ± 19.0	94.4 ± 18.9	94.4 ± 18.9	2.4	2.3 - 2.5	-	-	-	-
Start / stop (n = 80)	Magnitude (m·s ⁻¹)	2.9 ± 0.9	2.9 ± 0.9	2.9 ± 0.9	2.9 ± 0.9	-	-	-	6.7	6.4 - 7.0	863
	Direction (°)	86.6 ± 69.5	86.6 ± 69.5	86.9 ± 69.3	86.9 ± 69.3	3.4	3.3 - 3.5	-	-	-	-
Multi CoD (n = 80)	Magnitude (m·s ⁻¹)	3.4 ± 1.4	3.4 ± 1.4	3.4 ± 1.4	3.4 ± 1.4	-	-	-	5.9	5.8 - 6.1	1301
	Direction (°)	97.7 ± 33.6	97.7 ± 33.6	97.7 ± 33.5	97.7 ± 33.5	3.6	3.5 - 3.8	-	-	-	-

Note: Abs= absolute, TE= typical error, CV= coefficient of variation, CI= confidence interval.
 n= the number of trials, Events (n)= the number of events included in the analyses.

Table 2: Between-device reliability for inertial movement analyses (IMA) variables in the field assessment. IMA counts were categorized into intensity bands. n=83.

Intensity bands (n)	Device 1 Mean ± SD	Device 2 Mean ± SD	CV (%)	90% CI (%)	SWD (%)
Low	416.5 ± 97.7	417.2 ± 97.2	2.7	2.4 - 3.1	2.3
Med	120.3 ± 31.6	120.4 ± 31.7	4.6	4.0 - 5.3	3.0
High	68.9 ± 26.9	69.4 ± 28.2	5.3	4.7 - 6.2	5.6
Med/High	189.2 ± 55.8	189.7 ± 56.4	3.1	2.7 - 3.6	3.7
Total	605.8 ± 144.7	606.9 ± 144.8	1.8	1.8 - 2.1	2.5

Note: CV= coefficient of variation, CI= confidence interval, SWD= smallest worthwhile difference.

Low= 1.5-2.5 m·s⁻¹, Medium= 2.5-3.5 m·s⁻¹, High= >3.5 m·s⁻¹, Med/high= >2.5 m·s⁻¹, Total= >1.5 m·s⁻¹.

Table 3: Between-device reliability for inertial movement analyses (IMA) variables in the field assessment. IMA counts were categorized within direction bands, and divided further into intensity bands. n=83.

Direction bands	Device 1 Mean ± SD	Device 2 Mean ± SD	CV (%)	90% CI (%)	SWD (%)
Forward					
Low	48.7 ± 15.2	49.0 ± 15.2	10.1	8.9 - 11.8	3.2
Medium	18.2 ± 7.8	17.9 ± 7.9	20.6	17.9 - 24.1	4.9
High	17.4 ± 10.7	17.5 ± 12.1	21.5	18.8 - 25.3	7.9
Med/High	35.6 ± 17.2	35.3 ± 18.4	10.8	9.5 - 12.6	5.3
Total	84.2 ± 28.1	84.4 ± 29.6	6.6	5.8 - 7.6	3.5
Backward					
Low	59.0 ± 21.1	59.6 ± 21.7	7.7	6.8 - 9.0	4.0
Medium	22.6 ± 7.5	22.8 ± 7.3	11.7	10.3 - 13.7	3.6
High	14.0 ± 5.9	13.9 ± 5.8	13.7	12.0 - 16.0	5.5
Med/High	36.6 ± 11.4	36.6 ± 11.1	7.1	6.3 - 8.3	3.6
Total	95.6 ± 29.2	96.2 ± 29.5	5.5	4.8 - 6.3	3.5
Lateral - left					
Low	152.5 ± 51.3	152.7 ± 49.8	4.6	4.1 - 5.4	3.2
Medium	41.0 ± 16.0	40.3 ± 15.2	8.4	7.4 - 9.8	3.8
High	19.0 ± 9.5	19.1 ± 10.2	12.6	11.0 - 14.7	6.5
Med/High	60.0 ± 24.1	59.4 ± 23.9	6.4	5.6 - 7.4	4.1
Total	212.5 ± 71.0	212.1 ± 68.8	3.9	3.4 - 4.5	3.2
Lateral - right					
Low	156.4 ± 48.0	155.9 ± 47.2	4.8	4.2 - 5.6	3.0
Medium	38.5 ± 13.5	39.5 ± 14.0	9.8	8.6 - 11.4	4.7
High	18.6 ± 10.4	18.8 ± 10.7	16.6	14.6 - 19.5	6.3
Med/High	57.1 ± 22.2	58.3 ± 22.9	6.6	5.8 - 7.7	4.9
Total	213.5 ± 64.7	214.2 ± 65.2	4.1	3.7 - 4.8	3.1

Note: CV= coefficient of variation. CI= confidence interval, SWD= smallest worthwhile difference.

Low= 1.5-2.5 m·s⁻¹, Medium= 2.5-3.5 m·s⁻¹, High= >3.5 m·s⁻¹, Med/high= >2.5 m·s⁻¹, Total= >1.5 m·s⁻¹.

Table 4: Between-device reliability for PlayerLoad™, and its associated variables, in the field assessment. n=83.

Variables (au)	Device 1 Mean ± SD	Device 2 Mean ± SD	CV (%)	90% CI (%)	SWD (%)
PlayerLoad™	418.3 ± 78.9	418.9 ± 82.0	0.9	0.8 - 1.1	2.1
PlayerLoad™·min ⁻¹	6.6 ± 1.0	6.6 ± 1.0	0.9	0.8 - 1.1	1.5
PL _{2D}	260.3 ± 47.8	260.5 ± 48.6	1.0	0.9 - 1.1	2.0
PL _{AP}	154.2 ± 27.8	154.3 ± 27.8	0.4	0.3 - 0.5	2.0
PL _{ML}	175.9 ± 35.1	176.2 ± 35.9	1.7	1.5 - 1.9	2.1
PL _V	280.9 ± 56.9	281.5 ± 60.0	1.1	1.0 - 1.3	2.3

Note: CV= coefficient of variation, CI= confidence interval, SWD= smallest worthwhile difference, 2D=anterior-posterior and medio-lateral axes, AP= anterior-posterior axis, ML= medio-lateral axis, V= vertical axis.

Paper II

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Paper IV



Physical demands of game-based training drills in women's team handball

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ABSTRACT

Game-based training drills are popular in team sports. This study compared two game-based training conditions and official matches in team handball. Thirty-one women players wore inertial measurement units in five training sessions and five official matches. In training, 3vs3 and 6vs6 game-based training conditions were performed with a 5-min duration. PlayerLoad™ and high-intensity events (HIEs; $>2.5 \text{ m} \cdot \text{s}^{-1}$) were extracted from the raw data. Data were analysed using magnitude-based inferences and reported with effect sizes (ESs). PlayerLoad™ $\cdot \text{min}^{-1}$ from all positions combined was 11.37 ± 0.49 (mean \pm 90% confidence limits) and 9.71 ± 0.3 for the 3vs3 and 6vs6 conditions, respectively. Backs (ES: 1.63), wings (ES: 1.91), and pivots (ES: 1.58) had greater PlayerLoad™ in 3vs3 than 6vs6. Substantially greater HIE $\cdot \text{min}^{-1}$ in 3vs3 occurred for all positions. There was substantially greater PlayerLoad™ $\cdot \text{min}^{-1}$ in 3vs3 and 6vs6 than match play for backs, wings, and pivots. Wings (ES: 1.95), pivots (ES: 0.70), and goalkeeper (ES: 1.13) had substantially greater HIE $\cdot \text{min}^{-1}$ in 3vs3 than match play. This study shows greater PlayerLoad™ and HIE in 3vs3 than 6vs6. Both game-based training conditions investigated in this study provide an overload in overall PlayerLoad™; however, additional exercises might be needed to overload HIE, especially for backs and pivots.

ARTICLE HISTORY

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KEYWORDS

Female athletes; inertial movement units; match analyses; team sports

Introduction

Successful performance in team handball is dependent on several factors, including technical, tactical, social and physical characteristics (Luteberget & Spencer, 2016; Michalsik, Aagaard, & Madsen, 2012; Michalsik, Madsen, & Aagaard, 2014). The complexity of team handball requires economical training regimes to include all the important performance factors. The use of game-based training drills is a recommended technique that promotes physical performance enhancement and training effectiveness via a combination of the components of the game (Hill-Haas, Dawson, Impellizzeri, & Coutts, 2011). Indeed, game-based training drills are commonly used to improve technical and tactical skills in many team sports, and it has been shown that such skills provide an aerobic stimulus comparable with traditional interval-training methods (Buchheit et al., 2009; Iacono, Eliakim, & Meckel, 2015). Because of the incorporation of these training drills in team sports, several researchers have focused their attention on physical, physiological and technical activities of specific drills. There are a variety of factors that affect the intensity of game-based training in team sports, such as the field size (Corvino, Tessitore, Minganti, & Sibila, 2014; Kennett, Kempton, & Coutts, 2012; Rampinini et al., 2007), the number of players involved (Foster, Twist, Lamb, & Nicholas, 2009; Rampinini et al., 2007), rule modifications (Dellal, Logo-Penas, Wong, & Chamari, 2011) and coaches' encouragement (Rampinini et al., 2007). For example, number of players affects the

intensity of game-based training in team sports. There is an increase in heart rate, lactate concentration, rating of perceived exertion (RPE) and greater total distance covered with fewer players (Belka et al., 2016; Foster et al., 2009; Rampinini et al., 2007).

Game-based training mimics specific game demands and thus it is assumed that the training provides an effective transfer to match play (Aguar, Botelho, Lago, Maças, & Sampaio, 2012). In soccer, game-based training simulated the overall movement patterns of official matches (Gabbett & Mulvey, 2008). However, there are no studies comparing the intensity of game-based training to the intensity of official matches in team handball. Also, for soccer, playing position affects the intensity of game-based training, and different positions display differences in activity compared to match play (Dellal et al., 2012). In team handball, there are substantial differences in physical demands among the different playing positions in match play (Luteberget & Spencer, 2016; Michalsik et al., 2014). However, to our knowledge, no studies in team handball have investigated the intensity of game-based training in the context of playing positions.

Although there is a substantial growth in research related to game-based training in team sports, there is a lack of research specific to team handball. In light of this, the aim of the present study was to compare the intensity of game-based training drills with different player numbers (3vs3 and 6vs6). In addition, a comparison of these two training drills with official match intensity was important to specify game-based training for each playing position.

Methods

Experimental approach to the problem

In the present study, we investigated PlayerLoad™ and high-intensity events (HIEs) of game-based training drills lasting 5 min and compared them to periods of equivalent duration in official national-standard competition in high-level women team handball players. The study was conducted during the first half of the handball season (August–December) and consisted of monitoring 10 training sessions where the game-based training was conducted, in addition to the monitoring of 10 official matches in national leagues in Norway.

Participants

Thirty-one semi-professional female handball players (age: 22.2 ± 3.3 years, stature: 171.1 ± 6.4 cm, body mass: 68.5 ± 6.5 kg) volunteered and completed the study. The participants were from two teams: one playing in the second-highest division (1. division; $n = 15$) in Norway and one in the highest division (elite division; $n = 16$). All participants received verbal and written information about the procedures of the study and gave their written consent to participate in the study. The Norwegian Social Science Data Services approved the study.

Monitoring of game-based training

All participants were equipped with an inertial measurement unit (IMU; OptimEye S5, Catapult Sports, Australia) for monitoring of game-based training. The device was located in a padded pouch on the upper back in a custom-made vest (Catapult Sports, Australia). The device is integrated with a tri-axial accelerometer, a gyroscope and a magnetometer, all collecting data at 100 Hz. The device was fitted under the training jersey before training commenced. The monitoring of game-based training was conducted in a total of 10 training sessions (5 with each team). The players were monitored at their respective home-court arena and players were instructed to have a similar preparation to each of the monitored sessions, in terms of activity the days before and on the same day. Each session began with a general warm-up and a handball-warm-up. All participants for each session completed game-based training with 3vs3 and 6vs6 (Figure 1), with a duration of 5 min of each. Each participant completed one or two repetitions of the 3vs3 and 6vs6 game-based training conditions in each session, depending on the total number of players available for the session. Because of practical considerations, it was not possible to standardise the length of the rest period for each participant. The different game-based training drills began with a 5-min interval, meaning that in most cases the participants had a 5-min rest between conditions. However, in some cases, the rest period was doubled because of the large number of participants available for the session. Players were instructed to be active to stay warm between repetitions (e.g., light jog), but were not allowed to do any strenuous exercises. The 3vs3 condition consisted of 3 field-players on each team, in addition to a goalkeeper on

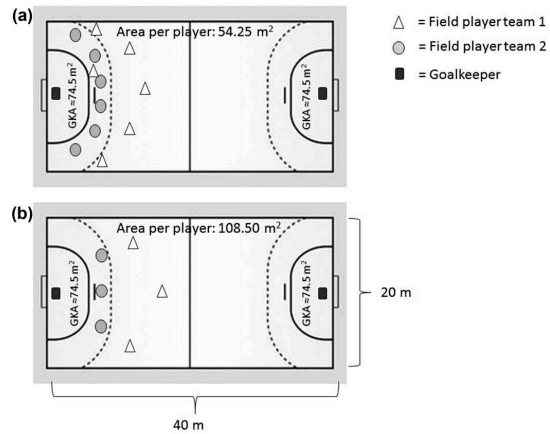


Figure 1. Setup for the two different game-based training conditions. 6vs6 (a) includes a total of 14 players, 6 field players and 1 goalkeeper on each team. 3vs3 (b) includes a total of 8 players, 3 field players and 1 goalkeeper on each team. The playing area was held constant with the area of a standard handball court (20×40 m) in both conditions. Note that the area per player refers to outfield players only; the goalkeeper area (GKA) is kept constant in both conditions.

each team. The 6vs6 condition consisted of 6 field-players on each team, in addition to a goalkeeper on each team. The playing area was held constant with the area of a standard handball court (20×40 m). The aim of the game-based training drills was to create a match-like setting; thus, the rules of the drills were kept the same as for official matches, with the exception that the goalkeeper was allowed to keep a ball by the goal for a rapid replacement of the ball after a missed shot. Verbal encouragement provided by the coach was allowed, and the coach was instructed to give encouragement similar to what they do in official matches. The order in which they performed the two drills was alternated between sessions. For players to be included in the analysis, they had to complete a minimum of three monitored training sessions where they were active in both 3vs3 and 6vs6.

Playing positions were set on the basis of the position the participants played in official matches. The positions in official matches and in 6vs6 were the same for all participants. In 3vs3, the specific positions change because of the increased area per player. Thus, the players are not necessarily playing in their assigned playing position in the 3vs3 condition.

Match monitoring

All participants wore the same IMU used in the monitoring of game-based training. The data collection was monitored live using the Catapult Sprint (Version 5.1.4, Catapult Sports, 2014) software. Interchanges were manually tracked using this software to ensure that only time spent on the field was included in the analyses. During team time-outs, all players were inactive. As interchanges were frequent and could involve several players, the interchange area was video-recorded and notes were taken. Thus, uncertainties and eventual errors in interchanges could be corrected in the software. Apart from players

wearing the IMU during matches, the study did not intervene with any other aspect of the normal match or match preparation. For players to be included in the analysis, they had to have a minimum of 5 min on-field time in three matches.

Data processing

PlayerLoad™, accelerations, changes of direction, and decelerations were extracted from the raw files using the Catapult Sprint software. Briefly, PlayerLoad™ is an accelerometer-based measurement of external physical loading of team sport athletes. Player Load™ was defined as instantaneous rate of change of acceleration divided by a scaling factor, expressed as the square root of the sum of the squared instantaneous rates of change in acceleration in each of the three vectors (X, Y and Z axes) and divided by 100 (Boyd, Ball, & Aughey, 2011). Acceleration, change of direction and deceleration events were based on accelerometer (magnitude), gyroscope and magnetometer (direction) data. All events >2.5 m · s⁻¹ were included as either an acceleration, change of direction or deceleration. The sum of all acceleration, change of direction or deceleration events was referred to as HIE. All variables of interest were normalised per min of on-field time to minimise the variability of absolute values with varying match length and individual on-field time in matches. Five-minute periods were calculated from the start of each half and continuously throughout the duration of the half. Because of stoppages during play, the duration of halves varied both in and among games and could be longer than the effective half-time of 30 min. The 5-min period with the highest value, for each individual player, was extracted and represented the most strenuous period (MSP) in match play. This serves as a “worst-case scenario”. Players had to be on field for the entire 5-min period (100%), and they had to have at least two 5-min periods in the match to be included in the analyses of MSP. The MSP was extracted individually for each variable, meaning that PlayerLoad™ · min⁻¹ and HIE · min⁻¹ were not necessarily extracted from the same period. There were no substantial differences between the two teams in any of the variables, and thus all results are reported from the two teams combined.

Statistical analyses

Data are presented as mean ± 90% confidence limits (CLs), both for the raw data and percentage change data. A linear mixed-model in IBM® SPSS® Statistics (Version 21, IBM Corp.) was used for analyses. The dependent variables were log-transformed before analysis, as this approach yields variability and differences as the percentage of the mean (Hopkins, Marshall, Batterham, & Hanin, 2009). The fixed effects in the model were playing position (4 levels: back, wing, pivot and goalkeeper (GK)), condition (4 levels: 3vs3, 6vs6, match, and MSP), position*condition and team ID. The random effects were athlete ID and Game ID. Separate analyses were performed for the dependent variables PlayerLoad™ · min⁻¹ and HIE · min⁻¹. Differences between the conditions were analysed using Cohen’s effect size (ES) statistics and ±90% CL. ESs of <0.20, 0.20 to 0.59, 0.60 to 1.19, 1.2 to 1.99 and ≥2.00 were

considered as trivial, small, moderate, large and very large (Hopkins et al., 2009), respectively. The percentage likelihood of difference between conditions was calculated (Hopkins, 2006) and considered almost certainly not (<0.5%), very unlikely (<0.5%), unlikely (<25%), possibly (25–75%), likely (>75%), very likely (>95%) or most likely (>99.5%). A percentage likelihood of difference <75% was considered a substantial magnitude. Threshold chances of 5% for substantial magnitudes were used, meaning a likelihood of >5% in both positive and negative directions was considered an unclear difference (Hopkins et al., 2009).

Results

The mean values of PlayerLoad™ · min⁻¹ for all players combined were 11.37 ± 0.49, 9.71 ± 0.3, 8.73 ± 0.25 and 9.85 ± 0.36 PlayerLoad™ · min⁻¹ for the 3vs3, 6vs6, mean match and MSP conditions, respectively. Data from all positions in the different conditions are displayed as mean data in Table 1. Mean values for HIE · min⁻¹, when combining all playing positions, were 4.27 ± 0.20, 3.03 ± 0.17, 3.29 ± 0.22 and 4.13 ± 0.27 HIE · min⁻¹ for the 3vs3, 6vs6, mean match and MSP conditions, respectively. Mean data from each playing position is presented in Table 1.

There were substantial differences between the 3vs3 and the 6vs6 conditions for all playing positions. Backs had greater PlayerLoad™ · min⁻¹ in the 3vs3 condition with a large ES (100%, ES: 1.63), and greater HIE · min⁻¹ with a small ES (85%, ES: 0.58). Wings had greater PlayerLoad™ · min⁻¹ in the 3vs3 condition with a large ES (100%, ES: 1.91) and a very large ES for HIE · min⁻¹ (100%, ES: 2.32). Greater PlayerLoad™ · min⁻¹ occurred in the 3vs3 condition for pivots, with a large ES (99%, ES: 1.58) for PlayerLoad™ · min⁻¹ and a moderate ES (90%, ES: 1.12) for HIE · min⁻¹. There were no clear differences in the 3vs3 and 6vs6 condition in PlayerLoad™ · min⁻¹ for GK, however, HIE · min⁻¹ was greater in the 3vs3 condition with a moderate ES (95%, ES: 0.93).

There was a greater PlayerLoad™ · min⁻¹ in the 3vs3 condition than match play for all playing positions. Similarly, with

Table 1. Mean and upper and lower confidence limits (CLs) for each playing position in each condition, for both PlayerLoad™ · min⁻¹ and HIE · min⁻¹. n is the number of observations in the respective condition and position.

Position	Condition	n	PlayerLoad™ · min ⁻¹				HIE · min ⁻¹			
			90% CL				90% CL			
			Mean	Upper	Lower	N	Mean	Upper	Lower	
Back	3vs3	63	13.24	12.45	14.07	63	4.50	4.03	5.01	
	6vs6	78	10.54	9.92	11.19	78	3.69	3.17	4.29	
	Match mean	39	9.27	8.71	9.87	39	4.08	3.61	4.61	
	MSP	25	10.84	10.13	11.60	25	5.36	4.67	6.15	
Wing	3vs3	56	13.87	13.02	14.79	56	4.36	3.89	4.90	
	6vs6	72	10.62	9.97	11.30	72	1.98	1.69	2.31	
	Match mean	32	8.79	8.23	9.38	32	2.24	1.97	2.55	
	MSP	20	10.46	9.73	11.24	20	3.01	2.59	3.50	
Pivot	3vs3	17	13.14	11.64	14.82	13	5.34	4.23	6.73	
	6vs6	22	10.52	9.36	11.84	17	3.64	2.57	5.14	
	Match mean	13	9.60	8.54	10.79	12	4.21	3.35	5.28	
	MSP	10	10.86	9.60	12.28	9	5.29	4.14	6.76	
GK	3vs3	47	4.90	4.47	5.37	47	2.83	2.42	3.31	
	6vs6	32	4.57	4.17	5.01	32	2.06	1.63	2.60	
	Match mean	9	5.17	4.67	5.73	9	1.92	1.54	2.40	
	MSP	9	6.01	5.40	6.69	9	2.88	2.31	3.60	

GK: goalkeeper; MSP: most strenuous period.

the exception of GK, the MSP was greater for all playing positions (Figure 2). Differences were also found between the 6vs6 condition and match mean and MSP (Figure 2). Wings, pivots, and GK had greater HIE · min⁻¹ in 3vs3 than matches. Conversely, there were no differences in the 6vs6

condition compared to mean match play for any playing position (Figure 3(a)) in HIE · min⁻¹. Backs had lower values in the 3vs3 condition than MSP, while wings had greater values (Figure 3(b)). All playing positions had lower HIE · min⁻¹ in 6vs6 than in MSP.

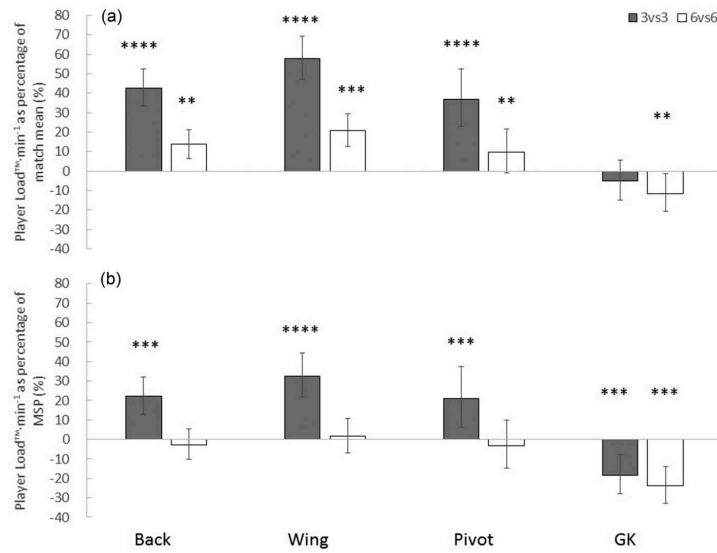


Figure 2. PlayerLoad™ · min⁻¹ mean ± 90% confidence limits for percentage differences from match mean (a) and MSP (b) for the 3vs3 condition and 6vs6 condition. Effect size (ES) between the different game-based training condition and match mean or MSP is indicated by the stated symbols. Only ESs with a substantial likelihood of difference (>75%) are shown. * = small, ** = moderate, *** = large, **** = very large. GK: goalkeeper; MSP: most strenuous period.

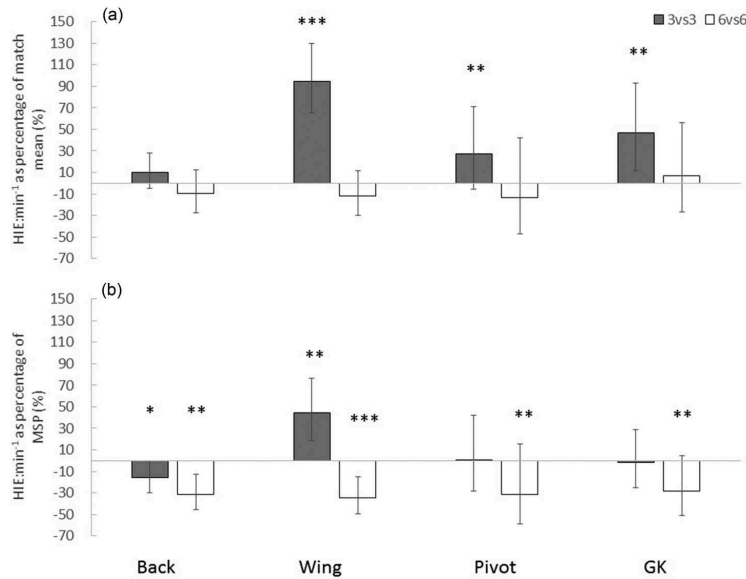


Figure 3. HIE · min⁻¹ mean ± 90% confidence limits for percentage differences from match mean (a) and MSP (b) for the 3vs3 condition and 6vs6 condition. Effect size (ES) between the different game-based training conditions and match mean or MSP is indicated by the stated symbols. Only ESs with a substantial likelihood of difference (>75%) are shown. * = small, ** = moderate, *** = large, **** = very large. GK: goalkeeper; HIE: high intensity events; MSP: most strenuous period.

Discussion

This study aimed to investigate the intensity ($\text{PlayerLoad}^{\text{TM}} \cdot \text{min}^{-1}$) and HIE of game-based training drills in team handball. The results of this study indicate that the number of players involved in the game-based training drills can affect the intensity of the drill with a lower number of players, resulting in an increase in both $\text{PlayerLoad}^{\text{TM}} \cdot \text{min}^{-1}$ and $\text{HIE} \cdot \text{min}^{-1}$. Moreover, to our knowledge, this is the first study to compare game-based training drills to official match intensity in team handball. The data shows that 3vs3 and 6vs6 game-based training conditions, with a duration of 5 min, show greater values compared to mean match intensity in $\text{PlayerLoad}^{\text{TM}} \cdot \text{min}^{-1}$ for backs, wings and pivots. However, the same pattern is not present in $\text{HIE} \cdot \text{min}^{-1}$ for backs and pivots.

The differences between the 3vs3 and 6vs6 conditions in the present study are in line with previous research in team handball and in other team sports. It has been reported greater RPE, greater heart rate and a greater total distance covered in 3vs3, compared to 4vs4 and 5vs5 (Belka et al., 2016) in youth male team handball players. It has also been shown that a decrease in player number increases the occurrence of technical actions, such as the number of contacts and number of dribbles in futsal (Duarte, Batalha, Folgado, & Sampaio, 2009). When the player number is changed and the pitch size is held constant, the area per player will be altered. The same is true if the pitch size is changed, while the player number is held constant. Studies altering the pitch size show similar results to the current study. Specifically, a greater intensity occurred with an enlargement of area per player. For example, a study on game-based training in team handball found differences in intensity when altering pitch size and holding the player number constant (Corvino et al., 2014). The greatest square metre per player (approximately 64 m^2) elicited greater values in total distance covered, RPE and heart rate (Corvino et al., 2014). In the current study, the 3vs3 condition resulted in an area of 108.5 m^2 while the 6vs6 resulted in an area of 54.3 m^2 per player, and again the largest square metre per player elucidated the highest intensity. When changing the number of players, while holding the area per player constant, heart rate and blood lactate is reported not to be different between conditions in soccer, although some differences in the activity profile have been reported (Castellano, Casamichana, & Dellal, 2013; Randers, Nielsen, Bangsbo, & Krstrup, 2014; Randers et al., 2010). Thus, some changes might occur by manipulating player number alone. However, it is also important to note that the changes in the current study might not be solely contributed to player number per se, as the changes in area per player might be of equal importance.

Game-based training is thought to mimic specific physical and physiological game demands, and thus it is assumed that it can be an effective and specific form of training for team sport athletes (Aguiar et al., 2012). In addition, an overload of physical components is often preferable to increase or maintain the players' physical conditioning (Casamichana, Castellano, & Castagna, 2012; Hill-Haas et al., 2011). In soccer, it has been reported that game-based training can simulate

the overall movement patterns of friendly matches of a domestic, national, and international standard of competition (Casamichana et al., 2012; Gabbett & Mulvey, 2008). However, there are, to our knowledge, no previous studies comparing the intensity of game-based training to the intensity of official matches in team handball. The current study shows a greater $\text{PlayerLoad}^{\text{TM}} \cdot \text{min}^{-1}$ for backs, wings and pivots in both game-based training conditions when compared to the mean of the match; this is in line with research in other team sports. The $\text{PlayerLoad}^{\text{TM}}$ values are also comparable to the values in MSP, and thus can be recommended as an effective training regime to mimic/overload official matches. The reduced duration of the game-based training compared to official matches is most likely a contributing factor for greater intensity (Corvino et al., 2014). Other factors, such as coach encouragement and spare balls (more effective play time), may also contribute to the training intensity. In addition, the fact that game-based training is a training task, and thus the outcome of the "match" is not as important as an official match, may affect the tactical decisions and risk-taking in play, and again affect the intensity.

Even though the game-based training is shown to mimic/overload the overall intensity of official matches, it is also shown that the training is not sufficient to simulate the high-intensity repeated-sprint demands of high-standard matches in women's soccer (Gabbett & Mulvey, 2008). Similarly, in the current study, the $\text{HIE} \cdot \text{min}^{-1}$ does not seem to mimic official match demands to the same extent as $\text{PlayerLoad}^{\text{TM}} \cdot \text{min}^{-1}$. $\text{HIE} \cdot \text{min}^{-1}$ values are not substantially different from match mean data and are lower in the game-based training compared to MSP. The lower $\text{HIE} \cdot \text{min}^{-1}$ might be a consequence of the greater $\text{PlayerLoad}^{\text{TM}} \cdot \text{min}^{-1}$, as the greater intensity might hinder the player's possibility for explosive actions and reduce their ability to execute HIE. In addition, motivation for the activity may play a role in the physical output, and thus, HIE could be greater in matches due to this fact. These data suggest that while overloading the overall intensity in team handball players, game-based training conditions do not overload the specific HIE, which is an important factor for performance in team handball (Luteberget & Spencer, 2016; Michalsik et al., 2012). Wing players show a greater $\text{HIE} \cdot \text{min}^{-1}$ in the 3vs3 condition compared to both match mean and MSP. In a 3vs3 condition, wing players will have a different role than in a 6vs6 condition. They will be located more centrally on the court, and thus be more involved in the game, in both offence and defence. Over all, 3vs3 seems to be a good overload condition for wing players for both $\text{PlayerLoad}^{\text{TM}} \cdot \text{min}^{-1}$ and $\text{HIE} \cdot \text{min}^{-1}$. However, the fact that wing players change their role in the 3vs3 condition will affect the specificity of the drill in relation to their typical match role. This is also applicable to pivot players in the 3vs3 condition.

In addition to the $\text{PlayerLoad}^{\text{TM}}$ and HIE investigated in this study, team handball players are also subjected to isometric actions. Such actions are not registered by the IMU, and thus an underestimation of the intensity of players is present in the current study, both in the game-based training and in match play. This might be more pronounced in pivot players due to their tactical role in both offence and defence. However, this issue of isometric actions should not have affected the

differences between game-based training conditions and matches in the present study.

During match play, GKs display lower PlayerLoad™ · min⁻¹ and HIE · min⁻¹ than the other playing positions (Luteberget & Spencer, 2016). In the present study, GKs had lower PlayerLoad™ · min⁻¹ values in the game-based training conditions than in MSP. Thus, GKs might need a different training setup for intensity overloading than the other playing positions. The fact that GKs had spare balls close to their goal might also affect the intensity for this position, as they do not have to move over larger areas to get the ball back in play. In both 3vs3 and 6vs6, the GKs' roles/tasks are the same; however, the results in this study show that the amount of HIE differs between the two conditions. For tactical reasons, the frequency and type of shots could have been different during the game-based training than official match play, especially in the 3vs3 condition. This could in turn affect the amount of HIE that GKs execute. The methods for monitoring handball players used in this study might not be optimal for measuring the load of GKs (Luteberget & Spencer, 2016), and different analysis methods might be more useful. However, this needs to be investigated further.

Conclusions

The results from this study demonstrate that coaches can manipulate physical demands in game-based training drills for women team handball players by modifying the number of players involved. The study shows that there are substantial differences in PlayerLoad™ and HIE when the number of players in game-based training drills is altered; fewer players resulted in higher values both in PlayerLoad™ · min⁻¹ and HIE · min⁻¹ for all outfield positions. In addition, both game-based training conditions facilitated a greater PlayerLoad™ than match data (both mean and MSP). However, HIE is not overloaded to the same extent for backs and pivots. Thus, coaches can use game-based training drills, such as the ones used in this study, to overload the PlayerLoad™ of match situations. However, to overload the important HIE for backs and pivots, there is a need for additional drills. Further research is required to fully understand all factors that influence the intensity and amount of HIE of game-based training drills in team handball. In addition, a technical comparison of game-based training drills and matches is required to underpin the specificity of the drills.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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Paper V



Validity of the Catapult ClearSky T6 Local Positioning System for Team Sports Specific Drills, in Indoor Conditions

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Aim: The aim of the present study was to determine the validity of position, distance traveled and instantaneous speed of team sport players as measured by a commercially available local positioning system (LPS) during indoor use. In addition, the study investigated how the placement of the field of play relative to the anchor nodes and walls of the building affected the validity of the system.

Method: The LPS (Catapult ClearSky T6, Catapult Sports, Australia) and the reference system [Qualisys Oqus, Qualisys AB, Sweden, (infra-red camera system)] were installed around the field of play to capture the athletes' motion. Athletes completed five tasks, all designed to imitate team-sports movements. The same protocol was completed in two sessions, one with an assumed optimal geometrical setup of the LPS (optimal condition), and once with a sub-optimal geometrical setup of the LPS (sub-optimal condition). Raw two-dimensional position data were extracted from both the LPS and the reference system for accuracy assessment. Position, distance and speed were compared.

Results: The mean difference between the LPS and reference system for all position estimations was 0.21 ± 0.13 m ($n = 30,166$) in the optimal setup, and 1.79 ± 7.61 m ($n = 22,799$) in the sub-optimal setup. The average difference in distance was below 2% for all tasks in the optimal condition, while it was below 30% in the sub-optimal condition. Instantaneous speed showed the largest differences between the LPS and reference system of all variables, both in the optimal ($\geq 35\%$) and sub-optimal condition ($\geq 74\%$). The differences between the LPS and reference system in instantaneous speed were speed dependent, showing increased differences with increasing speed.

Discussion: Measures of position, distance, and average speed from the LPS show low errors, and can be used confidently in time-motion analyses for indoor team sports. The calculation of instantaneous speed from LPS raw data is not valid. To enhance instantaneous speed calculation the application of appropriate filtering techniques to enhance the validity of such data should be investigated. For all measures, the placement of anchor nodes and the field of play relative to the walls of the building influence LPS output to a large degree.

Keywords: kinematics, position, instantaneous speed, accuracy, performance analyses, physical demands

INTRODUCTION

Analyses of physical demands can improve the understanding of physical performance and injury risk in sports. Such analyses are therefore conducted in many individual and team sports (Bangsbo et al., 2006; Montgomery et al., 2010; Gabbett, 2013; Gilgien et al., 2013; Luteberget and Spencer, 2017). In investigations of physical demands in team sports, the overall workload is often reported as a measure of athletes' total effort. Overall workload is dependent on the intensity and duration of the tasks, and is often reported using parameters such as total distance covered and distance covered in different speed zones. Sometimes high intensity events are also measured, which are characterized by inertia-based measures (Bangsbo et al., 2006; Michalsik et al., 2013; Luteberget and Spencer, 2017). High intensity events are reported using variables such as number of sprints, number of accelerations, or distances covered above a predefined speed threshold (Bangsbo et al., 2006; Michalsik et al., 2013; Luteberget and Spencer, 2017). To measure the parameters that describe these physical demands, Global Navigation Satellite Systems [GNSS; e.g., Global Positioning System (GPS)], inertial measurement units, a combination of the two, or video-based analysis systems are used. In outdoor sports, GNSS is one of the most frequently used methods for kinematic metrics in team sports (Malone et al., 2016). Total distance traveled, speed (e.g., time and distance in different speed zones), and number of sprints are calculated from position data, which can be obtained using GNSS technology, (sometimes integrated with inertial measurement units). The main drawback of GNSS is its restriction to outdoor facilities; therefore, indoor sports cannot use GNSS for tracking of players in competition and training. In indoor sports such as team handball, video-based analysis has been the main method used to analyze position-related variables (Sibila et al., 2004; Chelly et al., 2011; Michalsik et al., 2012, 2013; Póvoas et al., 2012, 2014; Karpan et al., 2015). However, in the past decade local positioning systems (LPSs) have been developed, which complement the role of hand operated and semi-automatic video based analysis systems in team sports (Leser et al., 2011). Most LPSs used in team sports are radio-frequency based (Muthukrishnan, 2009; Frencken et al., 2010; Ogris et al., 2012; Sathyan et al., 2012; Leser et al., 2014; Rhodes et al., 2014; Stevens et al., 2014), in which radio-frequency signals are used to measure the distance between several base stations (anchor nodes) at known locations distributed around the field of play, and mobile nodes worn by the athletes (Muthukrishnan, 2009; Hedley et al., 2010).

To allow meaningful analysis in sports, internal and external validity (Atkinson and Nevill, 2001) of systems used for data collection (e.g., LPS or GNSS) are important. External validity is related to the degree the data acquisition setting reflects the real sport setting. To maximize external validity, data acquisition should be conducted in a real-life sport setting, with minimal obstruction of the execution of the sport. Internal validity relates to the accuracy and repeatability of the measurements, and should be of a quality that allows quantification of small changes of practical importance within and between athlete activity profiles (Jennings et al., 2010). If the validity of a system is not

sufficient, the implementation of training or competition results based on the measurement system may cause harm to athletes in terms of prescription of inadequate training, leading to decreased performance and/or increased health risks (Foster, 1998; Gabbett, 2004). In turn, this can result in reduced team performance, thus affecting a team's structure and economic situation. Compared with investigating athletes in a laboratory setting, external validity has been improved to a large degree by systems such as GNSS and LPS, as these facilitate data acquisition in real-life training and competition. However, optimization of external validity can have a negative impact on internal validity (Atkinson and Nevill, 2001). Thus, investigations of the accuracy and repeatability of systems are important in order to be confident about the validity of data.

The accuracy of GNSS has been quantified for use in individual sports (Waegli and Skaloud, 2009; Gilgien et al., 2013, 2014, 2015; Supej and Cuk, 2014; Boffi et al., 2016; Fasel et al., 2016; Specht and Szot, 2016) and for team sports over a wide range of courses and velocities (Coutts and Duffield, 2010; Jennings et al., 2010; Cummins et al., 2013; Johnston et al., 2013, 2014; Scott et al., 2016). However, to our knowledge, only a small number of studies have investigated the accuracy of LPS for team sports (Frencken et al., 2010; Ogris et al., 2012; Sathyan et al., 2012; Leser et al., 2014; Rhodes et al., 2014; Stevens et al., 2014). The accuracy of LPS is mainly dependent on the signal type; environmental conditions, such as obstructions and materials in the surroundings of the field of play; the geometry between signal anchor nodes and the units on the athletes (Muthukrishnan, 2009; Malone et al., 2016); and the signal analysis and parameter calculation process. Indoor venues have been shown to elicit greater errors in LPS compared to outdoor venues, probably as a consequence of an increased multipath propagation compared to outdoor conditions (Sathyan et al., 2012). Thus, validation of a positioning system should be executed in the typical conditions in which it is used. In GNSS, the geometrical setup of the satellites (anchor nodes) is outside the user's control. In LPS, on the other hand, the geometry of the anchor nodes can be altered by the user in the installation process. To our knowledge, no studies have assessed the effect of the anchor node setup and the positioning of the field of play relative to the building's walls (signal multipath problem) on the accuracy of LPS.

In commercial positioning systems, data processing, such as derivation of kinematic metrics from position data, may vary between different LPS and GNSS systems, and even between different software in the same service product (Gilgien et al., 2014; Malone et al., 2016). However, the derivation of metrics is often not elucidated in the manufacturer's documentation, which complicates comparisons between different systems and software (Malone et al., 2016; Specht and Szot, 2016). Currently multiple LPS systems are commercially available, which differ in data acquisition technology, sampling rates and data processing steps; this affects the validity of the data output (Malone et al., 2016; Varley et al., 2017). Thus, the validity of one system does not apply to other systems, and individual validation of each system is required.

The aim of the present study was to (1) determine the validity of position, distance traveled and instantaneous speed

of a commercially available LPS (Catapult ClearSky T6, Catapult Sports, Australia) for indoor use; and (2) to investigate how the placement of the field of play relative to the anchor nodes and walls of the building affects the validity of the system. The study investigated these two questions in a typical indoor sport application, comparing the raw data from the LPS with a gold standard reference system (infrared light-based camera system).

METHOD

In the present study, we investigated the validity of an LPS system for monitoring movements in indoor team-sport athletes. Two male and two female active team handball players [age, 23.0 ± 2.2 years; body mass, 76.6 ± 11.4 kg; height, 172.3 ± 10.1 cm; mean \pm standard deviation (SD)] participated in the study. All participants received verbal and written information about the procedures of the study, and gave signed consent to participate in the study. The Norwegian Social Science Data Services approved the study.

Data Acquisition

The study was conducted in a sports hall measuring $50 \times 70 \times 11$ m, on an indoor surface (Pulastic SP Combi, Gulv og Takteknikk AS, Norway). The participants completed a total of five tasks, all designed to imitate team-sports movements, as shown in **Figure 1**. Task 1: a straight-line sprint and deceleration to a stop. Task 2: two diagonal movements, forward and back to the left and the right, with the paths separated by an angle of $\sim 75^\circ$. Task 3: a straight-line sprint, a 90° turn, and then deceleration to a stop. Task 4: a zig-zag (angle of turns $\approx 60^\circ$) course executed with sideways movements, and a 360° turn. Task 5: five continuous laps of the same course as in task 4, without the 360° turn. All tasks were commenced from a standing position. Each task was executed 5 times, with the exception of task 1, which was executed 9 times. Thus, a total of 116 trials were captured for each of the test conditions. Participants completed an individually selected warm-up before commencement of the tasks. All tasks were practiced during the warm-up. Participants were instructed to give maximal effort in all tasks. Subjects were tested on two separate days. The same protocol was completed in both sessions, on 1 day with an assumed optimal setup of the LPS (Optimal; **Figure 1**, field B), and on the other day with a sub-optimal setup of the LPS (Sub-optimal; **Figure 1**, field A). In the optimal setup, the LPS was arranged symmetrically, with a larger distance between the nodes and the testing area. In the sub-optimal setup, the LPS was asymmetrical, and the distance between the nodes and the testing area was small (**Figure 2**). This was done to replicate the effect of short distances between LPS anchor nodes and the field of play.

The LPS (Catapult ClearSky T6, Catapult Sports, Australia) and the reference system (Qualisys Oqus, Qualisys AB, Sweden) were installed around the field of play to capture the athletes' motion with both systems. During each trial 16 anchor nodes that were fixed around the handball court (**Figure 2**) collected LPS data, with a reported capturing frequency of 20 Hz. The LPS was set up to cover a field size of 20×40 m, the dimensions of an

official team handball court. Each participant was instrumented with a lightweight (≈ 28 g) mobile node (firmware version: 1.40), measuring L: 40 mm \times H: 52 mm \times D: 14 mm. The mobile node was positioned between the shoulder blades, in the manufacturer-supplied vest (Catapult Sports, Australia). At all times during the data acquisition, 14 mobile nodes were turned on to simulate the usual data load on the system. The spatial calibration of the LPS was conducted using a tachymeter (Leica Builder 509 Total Station, Leica Geosystems AG, Switzerland), according to the manufacturer's recommendations preceding the testing sessions. Reference data was collected using eight infra-red cameras mounted on tripods around the testing area (**Figure 2**), using a capture frequency of 100 Hz. The capture volume was 10×14 m. A reflective marker, 12 mm in diameter, was mounted on the mobile node's center to obtain a three-dimensional position. The reference system was spatially calibrated according to the manufacturer's recommendations prior to the testing sessions. Infra-red camera systems, such as the reference system in this study, can provide accuracy within a possible error range in a magnitude of millimeters (Chiari et al., 2005; Windolf et al., 2008; Jensenius et al., 2012). The accuracy is dependent on the number of cameras used, capturing volume, technical specifications and settings of system parameters (Windolf et al., 2008; Jensenius et al., 2012). In the current study, the calibration was carried out using a calibration wand, with the exact length of 749.2 mm. The calibration resulted in a 6.14 mm and 6.85 mm SD of the wand length, for optimal and sub-optimal condition, respectively.

Data Processing

To compare the LPS-based data with the reference system, the coordinate system of the reference system was transformed into the LPS's coordinate system using a Helmert transformation (Sheynin, 1995). The transformation between the coordinate systems was based on four reference points (12 mm reflective markers, positioned 1 m above floor level, in the four corners of the testing area). The positions of the reference points were measured with the reference system in all trials, and with a tachymeter (Leica Builder 509 Total Station, Leica Geosystems AG, Switzerland) in the LPS coordinate system. The Helmert transformation resulted in a mean position residual per calibration point of 2.3 cm for the optimal condition and 0.4 cm for the sub-optimal condition.

Raw position data (X and Y coordinates) was extracted, both from the LPS and from the reference system, using their respective software (LPS: OpenField, Catapult Sports, Australia. Reference system: Qualisys Track Manager, Qualisys AB, Sweden). All data analyses were conducted in MatLab (The MathWorks inc., USA). Due to incomplete LPS raw data (resulting from loss of signal during parts of the trials), 22 (sub-optimal condition) and 1 (optimal condition) trials were excluded from further data analyses. The capture frequency of the LPS system was not constant. The mean capture frequency was calculated to be 17.5 Hz. To overcome the issue of a variable capture frequency, the position data, from both the LPS and reference system, were resampled at the mean capture frequency of the LPS using a second order natural spline function. Trials

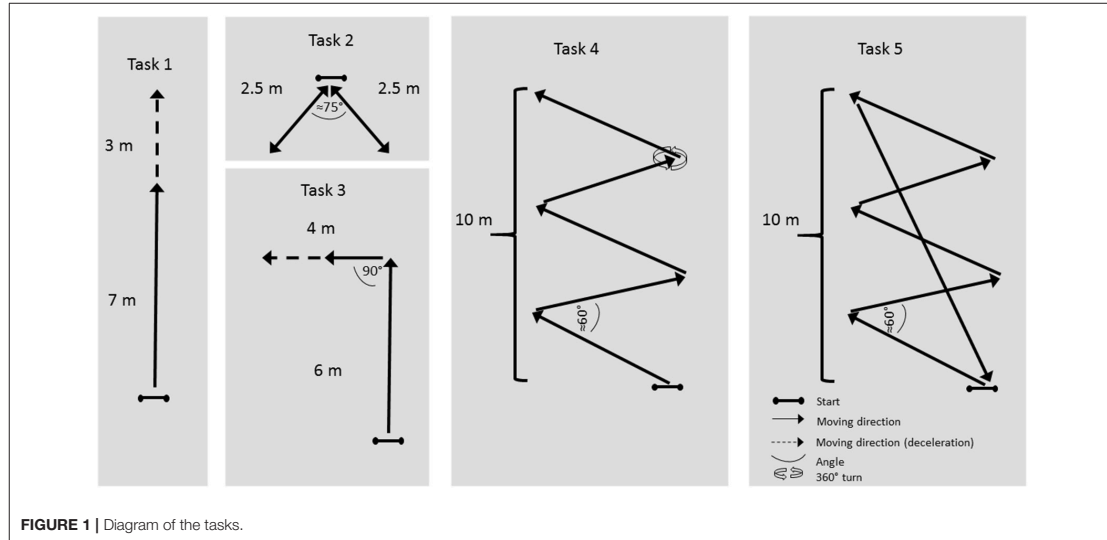


FIGURE 1 | Diagram of the tasks.

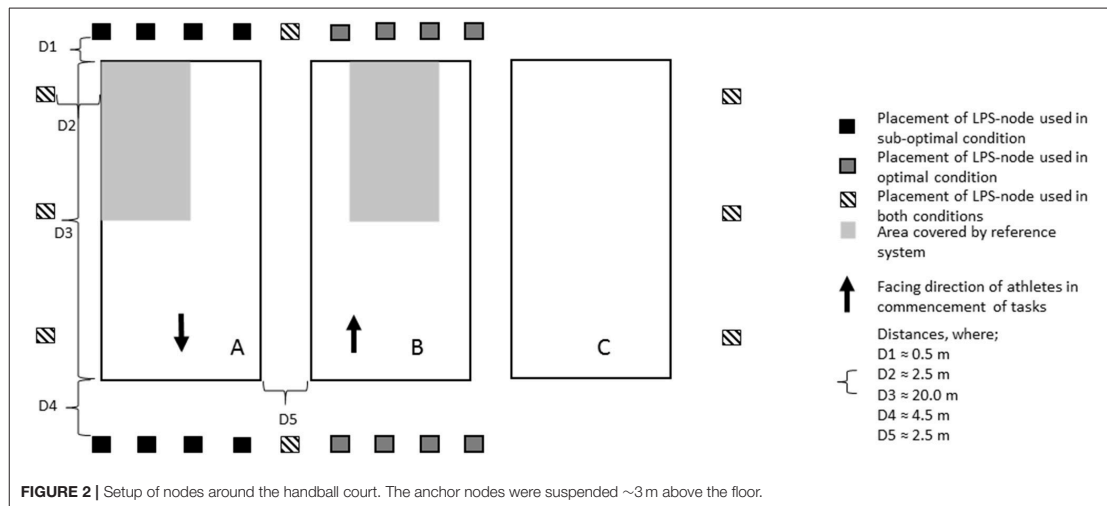


FIGURE 2 | Setup of nodes around the handball court. The anchor nodes were suspended ~3 m above the floor.

including data gaps > 1 s were excluded from the analyses. This resulted in the exclusion of 30 (sub-optimal condition) and 12 (optimal condition) trials from analysis. Thus, 64 (55%) trials (sup-optimal condition) and 103 (89%) trials (optimal condition) were available for analysis in this study. LPS and reference system data were time synchronized using cross-correlation of speed data. For that purpose the following steps were undertaken: (1) Position data in the horizontal plane (X and Y coordinates) were differentiated to obtain horizontal plane speed, for both LPS and reference system, using a four-point finite central difference formula (Gilat and Subramaniam, 2011). (2) LPS

and reference system data were time synchronized using cross-correlation (Buck et al., 2002) of horizontal plane speed data. After time synchronization, data was trimmed to reflect only the time athletes were performing the trials, by using a speed threshold of $0.5 \text{ m}\cdot\text{s}^{-1}$ (determined from the reference system). Two-dimensional position data at 17.5 Hz were used to calculate distance and speed. Distance traveled per trial was calculated as sum of the Euclidean distance between consecutive points. Speed in the horizontal plane (hereafter called speed) was calculated from position data, using a four-point finite central difference formula (Gilat and Subramaniam, 2011).

Method Comparison

The variables of position, distance and speed were compared for each task, using the norm of the differences between the LPS and the reference system. Mean difference, SD, and maximal difference in position were calculated. To express the results for position, the difference for each task from the reference system was assigned to bin limits in a histogram, and expressed as a percentage of the total number of raw data points, thus excluding the effect of duration of the task on the results. For distance, instantaneous and mean speed, the differences were characterized by mean, SD and maximal difference.

RESULTS

The mean difference between the LPS and reference system for all position estimations was 0.21 ± 0.13 m ($n = 30'166$) in the optimal setup, and 1.79 ± 7.61 m ($n = 22'799$) in the sub-optimal setup. Task 2 and task 5 showed the lowest mean (<0.20 m) and maximal differences (<1 m) in the optimal setup. In the sub-optimal condition, task 3 showed the lowest mean and maximal differences, but all differences in the sub-optimal condition were greater than in the optimal condition. Mean and maximum position differences for all tasks are displayed in **Table 1**. **Figure 3** presents the difference distribution in position in the five tasks, for both the optimal and sub-optimal condition.

With respect to distance, the mean differences between systems were 0.31 ± 0.40 m and 11.42 ± 26.21 m in the optimal and sub-optimal condition, respectively, for all tasks combined. The mean difference was well below 2% in the optimal condition, for all tasks (**Table 2**). Task 5 showed the lowest difference in the optimal condition. In the sub-optimal condition, all tasks showed higher differences, of $\geq 15\%$ in all tasks. The LPS overestimated the distance compared to the reference system for both the optimal and sub-optimal condition.

Instantaneous speed showed mean differences of $\geq 33\%$ for both the optimal and sub-optimal condition (**Table 3**). **Figure 4** displays all instantaneous speed measurements and reveals a direct association between speed and mean error. For mean speed, the mean difference was below 3% for all tasks (**Table 4**) in the optimal condition. The sub-optimal condition showed higher values across all tasks ($\approx 15\text{--}30\%$).

DISCUSSION

The aim of the current study was to investigate the validity of a commercially available LPS designed to track indoor team sports. The mean difference in position between the LPS and the reference system was below 0.35 m in all tasks in the optimal condition, while in the sub-optimal condition the difference was above 8 m in all tasks. Mean difference in distance was below 2% in the optimal condition, while it was below 30% in the sub-optimal condition for all tasks. Instantaneous speed showed the largest differences between the LPS and reference systems of all measures tested, both in the optimal ($\geq 35\%$) and sub-optimal condition ($\geq 74\%$). Further, the difference between instantaneous speed measurement in the LPS and the reference system was

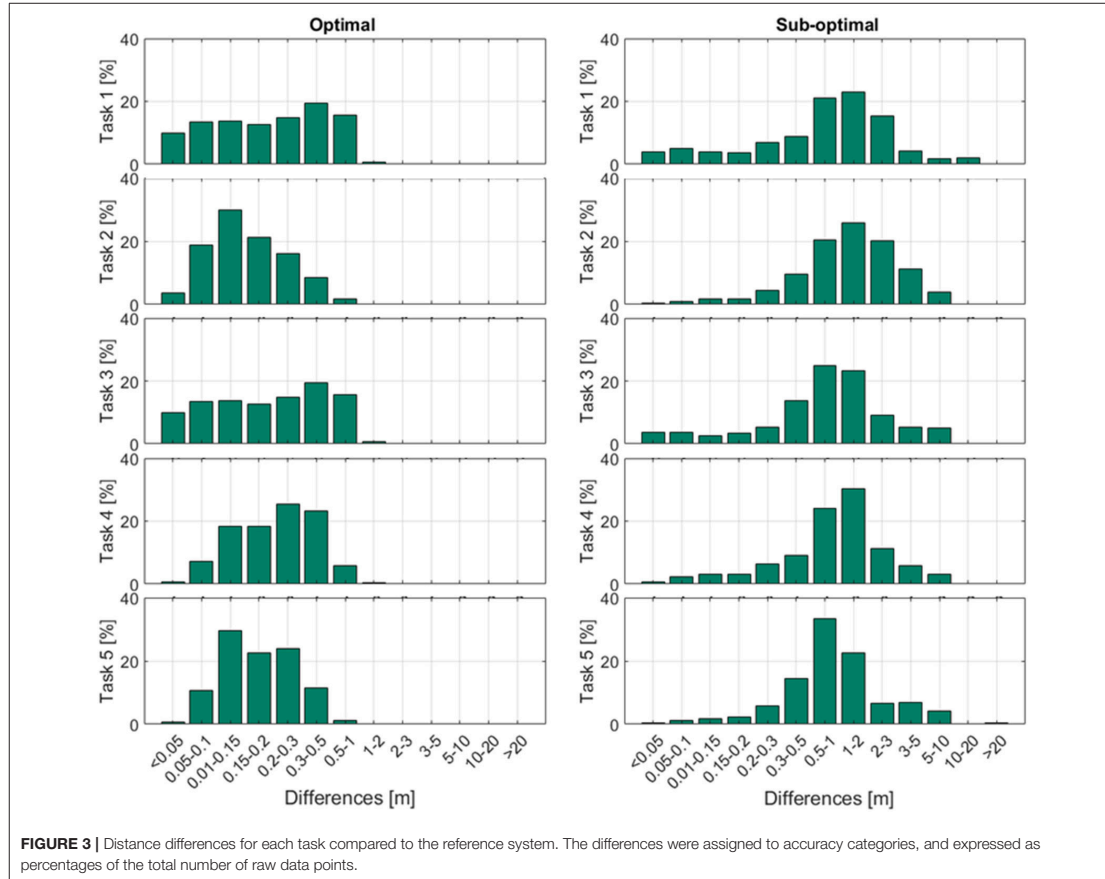
TABLE 1 | Difference between the LPS and reference system for position, for optimal and sub-optimal condition respectively.

	Optimal			Sub-optimal		
	<i>n</i>	Average (m)	Maximum (m)	<i>n</i>	Average (m)	Maximum (m)
Task 1	2468	0.27 ± 0.22	1.40	1449	1.46 ± 1.95	13.07
Task 2	4675	0.17 ± 0.11	0.81	2822	1.72 ± 1.42	8.24
Task 3	1190	0.34 ± 0.24	1.41	565	1.37 ± 1.72	9.60
Task 4	2379	0.26 ± 0.17	1.91	2118	1.41 ± 1.52	9.85
Task 5	19454	0.19 ± 0.10	0.96	15845	1.89 ± 9.10	194.64

dependent on the reference speed, with a higher speed yielding a higher difference.

The position error of LPS is often investigated with static measurements due to the lack of a reference system that allows instantaneous position comparisons in motion. Static measurements of the validity of LPS have shown an error range of ~ 1 to 32 cm (Frencken et al., 2010; Sathyan et al., 2012; Rhodes et al., 2014). This large range can partly be attributed to the different methodological setups and LPS technologies used. The largest error was found in an indoor environment (Rhodes et al., 2014), while the smallest error was found in an outdoor environment (Frencken et al., 2010). Only one previous study reported errors in position using LPS measurements in dynamic tasks, with a mean error of 0.23 m (Ogris et al., 2012). Although the previous reported value was from an outdoor environment, the results showed approximately the same error in position as in the optimal condition in the current study (0.21 m in the current study vs. 0.23 m in Ogris et al., 2012). Position measurements are mainly used for time motion analyses in sports, and thus our results seem acceptable for this purpose. However, for other applications, such as tactical analyses, the lack of information regarding the accuracy level needed makes it difficult to confidently state that the LPS is either acceptable or not. The similarity in error between the outdoor study by (Ogris et al., 2012) and the current indoor study could indicate that measurements in large halls with no obstructions may create measurement conditions that are not much different from outdoor conditions. However, the current study also seems to indicate that small distances to walls and corners of halls, along with the anchor node setup, have a major impact on position accuracy.

Previous studies on LPS in indoor conditions show mean errors ranging from 2.0 to 3.5% (Sathyan et al., 2012; Leser et al., 2014), while studies in outdoor conditions have shown errors ranging from 0.2 to 3.9% (Frencken et al., 2010; Sathyan et al., 2012; Stevens et al., 2014). Presumably, previous studies optimized the setup of the LPS when investigating the accuracy of the systems, resembling the optimal condition in the current study. The results of the current study showed a mean difference in distance from the reference system of between 0.5 and 1.8% in the optimal condition, which is lower than previously reported for indoor conditions. Some previous studies showed an underestimation of distance with LPS systems (Frencken



et al., 2010; Leser et al., 2014; Stevens et al., 2014), while others overestimated distance (Sathyan et al., 2012; Rhodes et al., 2014). The studies that showed an overestimation of distance were conducted indoors, as was the current study, leading to the speculation that indoor conditions may be a contributing factor to the overestimation. However, the differences could also be caused by differences in the filtering techniques applied in different studies (Sathyan et al., 2012). In the current study, no filters were applied to the data, in order to investigate the raw output from the LPS. Further investigations of the effect of filtering techniques on the validity of the current data could be interesting, as filtering techniques can affect the estimated distance and speed (Sathyan et al., 2012; Malone et al., 2016). Distance traveled might be less vulnerable to position error, since no amplification of error through position derivation of position was conducted, as was done with speed. However, error in distance traveled in sub-optimal conditions was of a critically large magnitude, and not useful for quantifying the distance covered for training

load purposes. Hence, for quantification of distance, only data from the optimal condition can be used with confidence. In addition, it might be reasonable to investigate whether filtering techniques could reduce the error in distance for sub-optimal conditions.

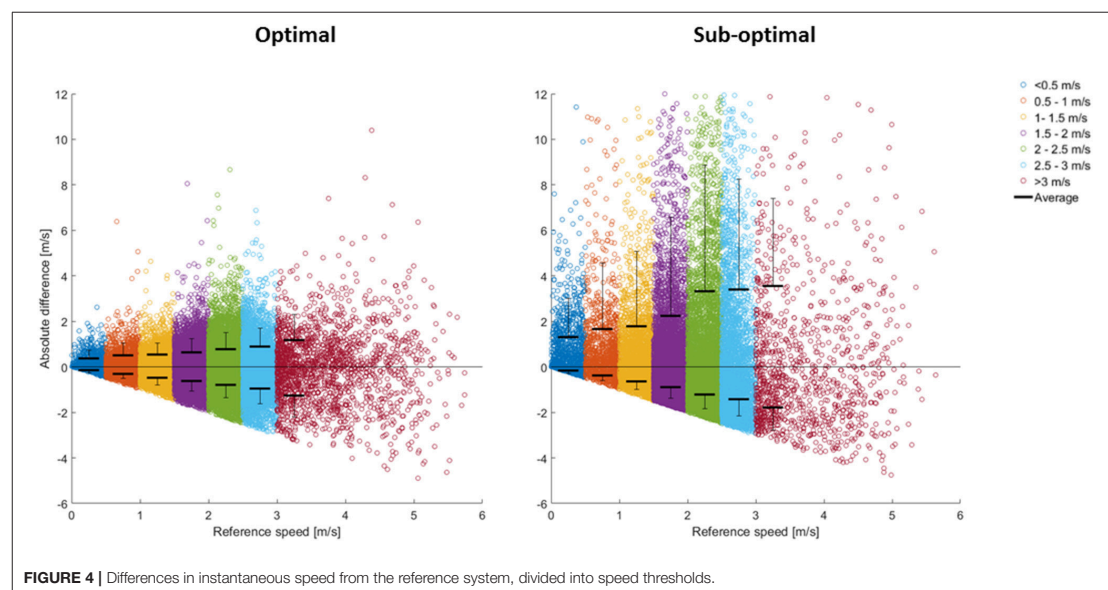
To our knowledge, very few studies have investigated the validity of instantaneous speed measurements in team sports (Varley et al., 2012). However, in match and training analyses, distance data are often categorized into speed zones in order to provide a more comprehensive metric for “intensity distribution” of the athletes external loading (Malone et al., 2016). Such categorization relies on instantaneous speed measurements. It has been previously shown that peak speeds in LPS are less accurate than mean speeds (Ogris et al., 2012; Rhodes et al., 2014; Stevens et al., 2014); however, no previous study has assessed the accuracy of instantaneous speed as determined with an LPS over the whole range of dynamic tasks in team sports. The current study shows that instantaneous speed differed substantially between LPS and the reference system in both

TABLE 2 | Difference between the LPS and reference system for distance traveled, for optimal and sub-optimal condition respectively.

	Optimal					Sub-optimal						
	<i>n</i>	Reference (m)	Average diff (m)	Max diff (m)	Average diff (%)	Max diff (%)	<i>n</i>	Reference (m)	Average diff (m)	Max diff (m)	Average diff (%)	Max diff (%)
Task 1	34	9.52 ± 1.40	0.14 ± 0.26	1.00	1.5	10.5	17	9.90 ± 0.16	2.46 ± 2.10	7.68	24.9	77.6
Task 2	16	33.31 ± 1.25	0.60 ± 0.57	2.18	1.8	6.5	13	23.88 ± 1.53	6.92 ± 5.07	17.37	29.0	72.7
Task 3	19	9.41 ± 2.36	0.15 ± 0.21	0.86	1.6	9.1	8	11.71 ± 0.29	2.45 ± 2.75	8.73	20.9	74.5
Task 4	18	15.97 ± 6.19	0.24 ± 0.18	0.64	1.5	4.0	13	21.38 ± 2.47	3.21 ± 3.35	9.43	15.0	44.1
Task 5	16	132.81 ± 3.92	0.64 ± 0.46	1.65	0.5	1.2	13	140.17 ± 4.95	41.38 ± 48.23	192.54	29.5	137.4

TABLE 3 | Difference between the LPS and reference system for instantaneous speed, for optimal and sub-optimal condition respectively.

	Optimal				Sub-optimal				
	<i>n</i>	Average diff (m/s)	Max diff (m/s)	Average diff (%)	Max diff (%)	<i>n</i>	Average diff (m/s)	Max diff (m/s)	Average diff (%)
Task 1	34	0.77 ± 0.86	10.40	34.8	375	1.43 ± 1.86	16.79	83.7	6101
Task 2	16	0.78 ± 0.70	7.56	33.5	237	1.60 ± 1.97	18.62	74.4	353
Task 3	19	0.92 ± 0.88	7.40	39.2	355	2.30 ± 2.94	31.25	87.7	982
Task 4	18	0.79 ± 0.71	8.10	35.3	477	1.64 ± 1.79	18.44	90.8	1175
Task 5	16	0.68 ± 0.58	8.67	37.0	197	1.73 ± 3.41	53.73	75.4	769

**FIGURE 4** | Differences in instantaneous speed from the reference system, divided into speed thresholds.

the optimal and sub-optimal condition (Table 4), and that the differences were speed-dependent (Figure 4). Our study shows considerably higher errors than those previously shown in a GNSS study (Varley et al., 2012). However, the GNSS-based study investigated straight line running only, which could contribute to these results. In addition, time synchronization and filtering

of raw data could play a significant role in error reduction for instantaneous speed (Ogris et al., 2012; Stevens et al., 2014), and the filtering techniques and time synchronization method used in the aforementioned study (Varley et al., 2012) were not disclosed. Mean speed has been investigated in several studies (Frencken et al., 2010; Ogris et al., 2012; Rhodes et al., 2014;

TABLE 4 | Difference between the LPS and reference system for average speed, for optimal and sub-optimal condition respectively.

	<i>n</i>	Optimal					Sub-optimal					
		Reference (m/s)	Average diff (m/s)	Max diff (m/s)	Average diff (%)	Max diff (%)	<i>n</i>	Reference (m/s)	Average diff (m/s)	Max diff (m/s)	Average diff (%)	Max diff (%)
Task 1	34	2.30 ± 1.38	0.05 ± 0.14	0.77	2.2	33.3	17	1.93 ± 1.46	0.50 ± 0.47	2.02	26.0	105.1
Task 2	16	2.00 ± 0.71	0.03 ± 0.03	0.08	1.4	4.1	13	1.82 ± 0.76	0.50 ± 0.34	1.12	27.6	61.4
Task 3	19	2.64 ± 1.25	0.07 ± 0.17	0.71	2.8	26.9	8	2.75 ± 1.47	0.55 ± 0.62	2.00	20.2	72.8
Task 4	18	2.12 ± 0.79	0.05 ± 0.07	0.30	2.3	14.0	13	2.18 ± 0.90	0.32 ± 0.33	0.94	14.7	43.4
Task 5	16	1.91 ± 0.56	0.01 ± 0.01	0.02	0.5	1.2	13	1.90 ± 0.54	0.55 ± 0.67	2.65	29.1	139.0

Stevens et al., 2014), and is often used as an overall indicator of the intensity of an activity. Compared to previous studies, the current study shows similar results (Table 3) in terms of mean speed errors (Frencken et al., 2010; Ogris et al., 2012; Rhodes et al., 2014; Stevens et al., 2014), thus, the LPS can give an overall indication of the intensity of the activity.

In the current study, the same measurement system was applied with the same measurement setting, but in two different conditions (optimal and sub-optimal condition). The factors that changed between the two conditions were the anchor node positions relative to the field of play and the distance between the side walls and corners of the hall to the field of play. The current study shows that changes in the placement of anchor node positions relative to the field of play and the distance between the side walls and corners of the hall to the field of play can affect the accuracy of data. Placement of nodes has an effect on the geometry of the anchor nodes relative to each other and the mobile node. In addition to changes in geometry, close proximity of the edge of the field and the walls may cause the mobile nodes to go undetected by multiple anchor nodes, thus producing a higher error rate. Close proximity between the edge of the field and the walls may also increase multipath propagation (Muthukrishnan, 2009), which will reduce the accuracy of data. The current study was not designed to isolate the different contributors (geometry, undetected nodes, and multipath propagation), thus the results of this study show the sum of errors accumulated from all sources. Further investigations are needed to understand the impact of the different contributors and how this could contribute to the optimization of anchor node placement.

LIMITATIONS

The method used in this study resulted in a position difference of 2.3 and 0.4 cm between the LPS and reference system, during optimal and sub optimal conditionings respectively. This is sufficient to detect the differences between the systems.

The effect of anchor node placement is especially important in smaller sports halls, when all distances to the walls are small. In the current study, both conditions were tested in a large sports hall, in order to keep variables such as distance to ceiling and material of walls and floors constant. The current results for the sub-optimal setup cannot be assumed to be true for smaller sports

halls, since small sport halls will have shorter distances between field of play and the walls on all four sides of the field, while in the current study only two side walls were close to the field of play. In small sports halls we might therefore expect even higher errors than in the sub-optimal condition of the current study. However, the study showed that changing the anchor node positions relative to the field of play and the distance between the side walls and corners of the hall to the field of play does affect the accuracy of the system. To optimize the measurement setup in small sport halls, future investigations should include tilting of nodes in the vertical direction to the field of play, and optimization of the geometry of anchor node positions relative to the field of play. Special attention should be given to multipath minimization to avoid mobile nodes going undetected by multiple anchor nodes close to corners by adjusting the tilting and positioning of nodes close to corners.

In the current study the raw positional data was examined. However, not all systems provide unfiltered raw positioning data for the user. In addition, practitioners will most likely not process data in independent software. Hence, validation of software-derived metrics is still needed, and should also be undertaken in future for the system investigated in this study. The current study provides insight into the raw positional data and the errors in the acquisition technology, without the possible influence of the manufacturer's software, which is important for researchers who want to process data using independent software. The export of raw positioning data from the systems allows filtering and processing of metrics independent of the manufacturer's software. Using manufacturer-independent software for raw data treatment and metric calculation may not only increase control of the process (Malone et al., 2016), but also avoid inaccuracies when collecting longitudinal data, which will be affected by software updates and other changes in the capture system. In addition, independent processing allows the user to provide details on the data processing in publications to facilitate appropriate interpretations and ease replication by other investigators. The positioning data (granted that it is not subjected to any filtering) is not affected by software updates, and thus could be used as a more stable measure of validity than software-derived metrics. In addition, raw position might be the most unaffected variable and should be used as the primary variable to compare measurements between different positioning systems' acquisition technology.

CONCLUSIONS AND PRACTICAL APPLICATIONS

The accuracy of LPS output is highly sensitive to relative positioning between field of play and walls/corners and anchor nodes. Measures of position, distance, and mean speed from the LPS can be used confidently in time-motion analyses for indoor team sports, in conditions similar to the optimal condition in this study. In small sport halls or in conditions when walls, and especially the corners of the room are close to the field of play, accuracy is relatively poor and caution is indicated.

The LPS is not valid in calculating instantaneous speed from raw data. Therefore the use of LPS systems for quantifying distance covered at different velocity bands is not recommended. The application of appropriate filtering techniques to enhance the validity of such data should be investigated.

Future studies should assess the relative contribution to total error of (1) signal multipath effects, which occur to a larger extent in close proximity to walls and corners; and (2) by the positioning and orientation of anchor nodes relative to the field of play. The inclusion of a dilution of precision measure would enhance the optimization of anchor node positions.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of Regional Committees for Medicine and Health Research Ethics with written informed consent from all subjects. All subjects gave written informed consent in

accordance with the Declaration of Helsinki. The study's data storage methods was approved by the Norwegian Social Science Data Service.

AUTHOR CONTRIBUTIONS

LL, MS and MG conceptualized the study design. LL and MG conducted the data acquisition. LL and MG contributed to the analysis of data, and all authors contributed to the interpretation of the data. LL drafted the manuscript, and all other authors revised it critically. All authors approved the final version and agreed to be accountable for all aspects of this work.

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Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Appendix I

Approval letter from the Norwegian Centre for Research Data



Matthew Spencer
Seksjon for fysisk prestasjonsevne Norges idrettshøgskole
Postboks 4014
0806 OSLO

Vår dato: 02.09.2014

Vår ref: 39602 / 3 / LT

Deres dato:

Deres ref:

TILBAKEMELDING PÅ MELDING OM BEHANDLING AV PERSONOPPLYSNINGER

Vi viser til melding om behandling av personopplysninger, mottatt 28.08.2014. Meldingen gjelder prosjektet:

39602 *Arbeidskravsanalyse av håndballspillere på nasjonalt/internasjonalt nivå -
fysiske krav og taktiske profiler*
Behandlingsansvarlig *Norges idrettshøgskole, ved institusjonens øverste leder*
Daglig ansvarlig *Matthew Spencer*

Personvernombudet har vurdert prosjektet og finner at behandlingen av personopplysninger er meldepliktig i henhold til personopplysningsloven § 31. Behandlingen tilfredsstillende kravene i personopplysningsloven.

Personvernombudets vurdering forutsetter at prosjektet gjennomføres i tråd med opplysningene gitt i meldeskjemaet, korrespondanse med ombudet, ombudets kommentarer samt personopplysningsloven og helseregisterloven med forskrifter. Behandlingen av personopplysninger kan settes i gang.

Det gjøres oppmerksom på at det skal gis ny melding dersom behandlingen endres i forhold til de opplysninger som ligger til grunn for personvernombudets vurdering. Endringsmeldinger gis via et eget skjema, <http://www.nsd.uib.no/personvern/meldeplikt/skjema.html>. Det skal også gis melding etter tre år dersom prosjektet fortsatt pågår. Meldinger skal skje skriftlig til ombudet.

Personvernombudet har lagt ut opplysninger om prosjektet i en offentlig database, <http://pvo.nsd.no/prosjekt>.

Personvernombudet vil ved prosjektets avslutning, 31.12.2018, rette en henvendelse angående status for behandlingen av personopplysninger.

Vennlig hilsen

Katrine Utaaker Segadal

Lis Tenold

Kontaktperson: Lis Tenold tlf: 55 58 33 77

Vedlegg: Prosjektvurdering

Dokumentet er elektronisk produsert og godkjent ved NSDs rutiner for elektronisk godkjenning.

Avdelingskontorer / District Offices

OSLO: NSD, Universitetet i Oslo, Postboks 1055 Blindern, 0316 Oslo. Tel: +47-22 85 52 11. nsd@uio.no

TRONDHEIM: NSD, Norges teknisk-naturvitenskapelige universitet, 7491 Trondheim. Tel: +47-73 59 19 07. kyrre.svarva@svt.ntnu.no

TROMSØ: NSD, SVF, Universitetet i Tromsø, 9037 Tromsø. Tel: +47-77 64 43 36. nsdmaa@svt.uit.no



Utvalget informeres skriftlig og muntlig om prosjektet og samtykker til deltakelse. Personvernombudet finner i utgangspunktet informasjonsskrivet tilfredsstillende, men forutsetter at det også oppgis dato for prosjektslutt og anonymisering av datamaterialet, her 31.12.2018. Revidert informasjonsskriv skal sendes til personvernombudet@nsd.uib.no før utvalget kontaktes (merk eposten med prosjektnummer).

Personvernombudet legger til grunn at forsker etterfølger Norges idrettshøgskole sine interne rutiner for datasikkerhet. Dersom personopplysninger skal sendes elektronisk eller lagres på mobile enheter, bør opplysningene krypteres tilstrekkelig.

Forventet prosjektslutt er 31.12.2018. Ifølge prosjektmeldingen skal innsamlede opplysninger da anonymiseres. Anonymisering innebærer å bearbeide datamaterialet slik at ingen enkeltpersoner kan gjenkjennes. Det gjøres ved å:

- slette direkte personopplysninger (som navn/koblingsnøkkel)
- slette/omskrive indirekte personopplysninger (identifiserende sammenstilling av bakgrunnsopplysninger som f.eks. bosted/arbeidssted, alder og kjønn)

Prosjektet gjennomføres i samarbeid med Norges håndballforbund Olympiatoppen. Norges idrettshøgskole er behandlingsansvarlig institusjon. Personvernombudet forutsetter at ansvaret for behandlingen av personopplysninger er avklart mellom institusjonene. Vi anbefaler at det inngås en avtale som omfatter ansvarsfordeling, ansvarsstruktur, hvem som initierer prosjektet, bruk av data og eventuelt eierskap.

