NORWEGIAN SCHOOL OF SPORT SCIENCES

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The response of different external load variables on session rating of perceived exertion training load in elite female team handball players

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Abstract

Purpose

To investigate the response of different external load variables on session rating of perceived exertion training load (sRPE-TL) in elite female team handball players.

Method

sRPE-TL and external load was collected from 21 players in 24 training sessions, during a period of 16 weeks. PlayerLoad™, PlayerLoad2D™, total distance, HSR distance (>15.52 km/h), sprint distance (>22.0 km/h), HIE >1.5 $m \cdot s^{-1}$, HIE >2.5 $m \cdot s^{-1}$ and HIE >3.5 $m \cdot s^{-1}$ was exported from the LPS system (Catapult Clearsky T6, Catapult Sports, Melbourne, Australia). The data was analyzed using Pearson`s correlation coefficient and a linear mixed-effect model that modeled the within-player and between-player effects of all the external load variables.

Results

All subjects showed a significant correlation between sRPE-TL and the variables PlayerLoad™ and PlayerLoad2D™. All external load variables showed a significant within-player effect on sRPE-TL, ranging from small to large ES (p = <0.01, ES: 0.59 - 1.38). The variables PlayerLoad™ and PlayerLoad2D™ had large, (37% and 35%) effect on sRPE-TL, respectively. Moreover, moderate individual responses to sRPE-TL to the variables PlayerLoad™, PlayerLoad2D™, total distance, HSRD, sprint distance, HIE >2.5 and HIE >3.5. Large, (17% - 26% coefficient of variation) between-session variability was observed with all external load variables. No significant between-player was observed.

Conclusion

This study demonstrated a large within-player effect on sRPE-TL in variables PlayerLoad™ and PlayerLoad2D™. The relationship becomes weaker when the intensity threshold increases. Total distance, PlayerLoad™ and PlayerLoad2D™ had a very strong correlation with sRPE-TL. Furthermore, individual response to external load observed indicates the importance to individualize the monitoring of training load. Finally, large between-session variability in sRPE-TL highlights the use of both sRPE-TL and external load when monitoring training load.

Contents

Preface

This thesis marks the end of my period as a student at Norwegian School of Sport Science (NIH). I have gained knowledge and experiences I truly appreciate, so thank you to both employees and students at NIH.

First of all, I want to express my sincere gratitude to my supervisor Live Luteberget, for your patience, valuable feedback and sharing of wisdom. This thesis could not have done without you! Additionally, I want to thank Håvard Wiig for your time helping me with the statistical analyses. Your help has been outstanding, and I really appreciate it!

Secondly, I need to thank the participating team in this study. I am very grateful for your time and effort. Without you, this thesis would not have been possible.

Finally, I want to thank my family and friends for the support throughout this entire process.

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1. Introduction

Team handball is an indoor team sport, played between two teams of seven players each on a 40m x 20m court (a goalkeeper and six field players). A match lasts 60 min (two halves, each of 30 min effective playing time), and the objective is to score the most goals. The sport is played worldwide, with many professional leagues, especially in Europe. Team handball has been an Olympic sport since 1972.

The training process is the application of physiological and biomechanical stress in order to achieve the desirable training outcome (Impellizzeri et al., 2005). Development or maintenance of physical fitness are important outcome to prepare athletes for the physical demands of competition (Iaia et al., 2009). These adaptions are determined by the combination of training volume, intensity and frequency (Coffey & Hawley, 2007), collectively referred to as training load (Foster et al., 2001). The term training load can be classified as external load, defined as the work completed by the athlete and internal load, defined as the athlete`s physiological response to this load (Akenhead & Nassis, 2016; Halson, 2014). Therefore, monitoring training load is essential to determining the individual responses to the training in team sports (Bourdon et al., 2017). It is known that excessive amounts of training can increase the risk of injury and illness, and insufficient training may annihilate the performance (Vanrenterghem et al., 2017). Therefore, monitoring the training load is an important aspect of athlete management (Bourdon et al., 2017; Halson, 2014; Schwellnus et al., 2016; Soligard et al., 2016).

Scientific research on team handball is limited in comparison of other team sports like football, Australian football and rugby (Karcher & Buchheit, 2014). Additionally, Costello et al. (2014) demonstrated that female athlete are under-represented in sports research. An understanding about the dose-response nature of external and internal load in team handball, can help to improve the training process and how to facilitate load monitoring in team handball players. The dose-response relationship may be influenced by individual characteristics (Impellizzeri et al., 2005), consequently sex may influence the relationship. Bourdon et al. (2017) clearly emphasized the importance of monitoring training load in order to determine the individual response to the training in team sports. In handball a high level of physical conditioning is required for players to be able to utilize their technical and tactical qualities (Manchado, Tortosa-Martínez, et al., 2013; Michalsik et al., 2014). Because there is a lack of research related to this field in team handball, and the effect sex may have on the dose-response relationship, there is a need for further research in order to understand the dose-response nature in elite female team handball players. Therefore, this thesis aims to investigate the relationship between internal load and external load in elite female team handball, using an individual approach.

2. Theory

2.1 Physical qualities in elite female handball

The game team handball has evolved substantially over the last few decades. The number of matches has increased considerably. With new rules changes such as quick throw-off, this has elevated the intensity of game-play, and led to an increased number of attacks during match-play (Ronglan et al., 2006). With the number of matches have increased it has led to an extension of the competition period now covering up to 10 months per year. During each game players must perform repeatedly different fast and dynamic types of locomotion. These activities can be powerful upper body movements such as tackle of opponents and maximal ball throwing as well as forceful lower limb muscle actions during jumping, running (sideways and backwards), sprinting and change of direction (CoD) (Michalsik, 2015).

Endurance is a general term and can be defined "as the capacity to sustain a given velocity or power output for the longest possible time" (Jones & Carter, 2000, p. 373). Total distance covered in female elite handball is reported to be between ≈2 and ≈5 km during a match (Manchado, Pers, et al., 2013). Playing position is account for some of the variation, where Michalsik et al. (2014) displayed that wing players cover more distance in matches. The amount of walking and jogging in total distance covered is reported to be 60-80% (Manchado, Pers, et al., 2013; Michalsik et al., 2014). This means that most of the total distance covered is performed with low intensity. Even though 60-80% of the total distance is walking and jogging, Michalsik et al. (2014) found that mean relative workload was 79,4% of maximal oxygen uptake (VO_{2max}) in elite females during periods of effective match-play. Different studies have measured the relative VO_{2max} in elite female handball players (Jensen et al., 1997; Michalsik et al., 2014). Average VO_{2max} values ranges from 50 to 53.5 $ml·kg^{-1}·min^{-1}$ (Jensen et al., 1997; Michalsik et al., 2014). These values are higher than the aerobic capacity of healthy female in the age group 20-29 years, which has an average VO_{2max} on 43.0±7.7 $ml·kg^{-1}·min^{-1}$ (Loe et al., 2013). There are also shown differences in endurance performance between elite and amateur female team handball players in Spain (Granados et al., 2007). This can suggest that to succeed in elite female team handball, it is necessary to achieve a minimum level of endurance performance. Even if endurance performance is not the decisive physical factor during an actual game, it improves the ability to tolerate high intensity. This means that players with a high level of aerobic capacity can play with a high tempo and tolerate high overall total training volume (Michalsik et al., 2014).

The limited amount of high intensity running and sprinting in elite female handball does not mean that work in high intensity is not important. To have a high intensity running and sprinting capacity can play a decisive factor in the match outcome, since it crucial for playing actions such as fast breaks, explosive fakes, side cuttings and fast retreats (Michalsik et al., 2014). Every time an acceleration (ACC) or deceleration (DEC) is performed, even if the speed remains low, a physiological strain is imposed on the player. Therefore, it is possible to underestimate the anaerobic energy yield in team handball if we only use metrics such as distance covered in varying speed (Michalsik et al., 2014). Luteberget and Spencer (2017) showed that all players combined performed on average 3,9±1,58 high-intensity events (HIE) per minutes. Backs had the highest number of HIE/min. This means that elite female team handball players perform multiple ACC, DEC or change of direction (CoD) per minutes (Luteberget & Spencer, 2017). This suggests high demands on the anaerobic glycolysis system during match play in team handball (Gastin, 2001; Glaister, 2005; Spencer et al., 2005).

If we also take into consideration physical confrontations with opponents during offense and defense, we understand that muscle strength and force development is an important part of the physical demands on elite team handball players. It is well known that it is physiological differences between men and women. In general are men taller, heavier with larger muscle mass, stronger, faster and have a higher VO_{2max} than women (Åstrand & Rodahl, 2003). This means that female players take up relatively less space on the court, since the court is identical for both sexes. This can be a reason that there are fewer physical strength-related confrontations in elite female team handball compared to elite male (Michalsik & Aagaard, 2015). Danish elite female players in match-play performed 5,0±4,0 hard tackles and 9,6±6,2 light tackles, and 6,2±3,8 hard tackles and 14,5±7,4 light tackles during offensive actions and defensive actions respectively (Michalsik & Aagaard, 2015). Additionally, elite females also perform high-intensity actions such as offensive breakthroughs, fast breaks, clasping, screening, blocking and shots. Michalsik et al. (2015) found that elite female players performed ≈75 high-intensity actions during a match. These findings indicating a high demand of muscle strength and rate of force development (RFD) for elite female players, even if there are fewer physical strength-related confrontations compared to elite male players. Great muscle strength and RFD are important factors during physical confrontations with a large amount of body contact with opponents in actions such as light and hard tackles and clasping (Michalsik et al., 2015). These factors are also important in actions as shots since a vertical jump is often performed immediately before a shot. Within a sport the players must encounter a wide variety of external forces, and overcome these to be successful (Wisløff et al., 2004). Vertical jumps demand a high level of force output, but also must be exerted with a rapid rate to induce the best performance (Bemben et al., 1990; Aagaard et al., 2002). This observation indicates that RFD is an important factor to explosive strength movements, such as vertical jump (Stone et al., 2003). In team handball the players also needs to avoid tackles, clasping and blocks from opponents.

In conclusion, team handball is an intermittent sport, and the physical demands seem to be a complex interaction between many types of activities. These activities include aerobic endurance, anaerobic work capacity, muscle strength and RFD. Since the players need to cover a total distance up to 5 km per match and perform multiple HIE per minutes and high-intensity actions in both offense and defense. The players need to master these categories in order to be successful (Michalsik, 2015).

2.2 Training load

Training load is a term that have received increased attention both from coaches and researchers in the last years, because it may assist to determine if an athlete is adapting to the training program and minimize the risk of fatigue, injury and illness (Halson, 2014). As aforementioned earlier, the term can be classified as external load, defined as the work completed by the athlete, and internal load, defined as the athlete`s physiological response to this load (Akenhead & Nassis, 2016; Halson, 2014). Athlete`s physiological response may be influenced by the individual characteristics of the athlete (Bouchard & Rankinen, 2001; Impellizzeri et al., 2005). Monitoring and managing training load may assist coaches and practitioners to achieve the desirable training outcome. Hard physical training is required to prepare the athletes for the physical demands of the competition. At the same time have research demonstrated that excessive loading can result in increased injury risk and insufficient training may annihilate the performance (Gabbett, 2016; McCall et al., 2018;

Vanrenterghem et al., 2017). Therefore, monitoring training load is essential to achieve the desirable training outcome with enhanced performance, understand the individual response to training, asses fatigue and minimize the risk of injury and illness (Bourdon et al., 2017).

There are multiple tools and methods to monitoring both external and internal load. It is now common practice to use global navigation satellite system (GNSS), local positioning system (LPS), heart rate monitoring, session rating of perceived exertion (sRPE) and wellness questionnaire to quantify training load in both individual and team sports (Akenhead & Nassis, 2016; Halson, 2014). Measures of external load in team sports can includes many variables. Distance covered or distance spent at varying speed are typically variables used in both research and for practitioner. Threshold values of speed are often to group distance into different categories (Luteberget, 2018). Such categories are often classified as high-speed running (HSR), very high-speed running (VSHR) and sprinting. While these different categories can be good indicators of the workload, in handball there are movements such as rapid changes of direction, tackles, accelerations and jumps (Michalsik et al., 2015; Póvoas et al., 2014). The development of GNSS and LPS system that have integrated inertial measurements units (IMUs) have made it possibly to quantify the intensity of these actions. IMUs are inertial sensors such as accelerometer, gyroscope, and magnetometer. These sensors detected actions such as acceleration, deceleration, change of direction and impacts. These actions are an important aspect of the training load that athletes are exposed to (Gastin et al., 2014; Varley & Aughey, 2013).

Various tools can be used to quantify the internal load, but sRPE and heart rate measures are the most commonly used (Akenhead & Nassis, 2016). It has been known for a long time that heart rate increases linearly with increased exercise intensity. Therefore, heart rate measures provide a good estimate of the exercise intensity during steady state. Team sports is known for its intermittent nature, which diverge from that of steady state exercise. Alexandre et al. (2012) concluded that since football is a multifactorial activity, heart rate measures should be analyzed with other internal load variables, such as sRPE. sRPE is a tool that players rate their perceived exertion during a session, with an integer scale from 1-10 developed by Foster et al. (2001). This method is as a modification of the Borg concept of rating of perceived exertion (RPE). It is designed to individual estimate the average intensity of the entire training session (Foster et al., 2021). It appears to be an accepted marker of internal training load in various types of exercise (Bellinger et al., 2019; Coutts et al., 2003; Impellizzeri et al., 2004; Lovell et al., 2013; Wallace et al., 2009). To assess the sRPE training load (sRPE-TL) the score is multiplied by the session duration. This method has proven to be a good indicator of internal load and shown a strong relationship with some external load variables in team sports, such as football, basketball, rugby and Australian football (Lovell et al., 2013; McLaren et al., 2018; B. R. Scott et al., 2013; T. J. Scott et al., 2013; Svilar et al., 2018; Wiig et al., 2020).

2.3 The relationship between internal and external training load in team sports

As aforementioned above, internal load variables have shown a strong relationship with external load variables in different team sports. To find the relationship between internal and external load is important in understanding the dose-response nature of team sports (McLaren et al., 2018). Since, external load is representing the physical work performed and internal load is the internal physiological response to this load, changes in the training outcome is ultimately the individual athlete`s accumulative internal load over a time period (Coffey & Hawley, 2007; Impellizzeri et al., 2005; Vanrenterghem et al., 2017). Therefore, monitoring internal load is important, since a greater external load will lead to increased metabolic energy cost and ultimately increase the internal physiological load (Vanrenterghem et al., 2017; Wallace et al., 2014). Knowledge of the relationship between internal and external load is important to understand the internal response associated with various quantities of external load. Further, it can give a detailed assessment of the training accuracy and efficacy, which can enhance training prescription, periodization, and athlete management, and ultimately enhance the training outcome (Bartlett et al., 2017; Burgess, 2017; Castillo et al., 2017).

Table 1*: Shows the correlation between internal and different external load variables in different activities and sports.*

Sport	Reference	Type of training	Internal	External	Correlation
Rugby					
	Lovell et al., 2013		sRPE-TL	Total distance (m)	0.73
				Body load (AU)	0.14
				Impacts (n)	-0.25
				Training impulse (AU)	0.05
	Weaving et al., 2014	SSG	sRPE-TL	Body load (AU)	0.43
				Impacts (n)	0.75
				High-speed distance (m)	0.70
		Conditioning	sRPE-TL	Body load (AU)	0.28
				Impacts (n)	0.34
				High-speed distance (m)	0.34
		Skills	sRPE-TL	Body load (AU)	0.24
				Impacts (n)	0.38
				High-speed distance (m)	0.32
		Speed	sRPE-TL	Body load (AU)	0.46
				Impacts (n)	0.46
				High-speed distance (m)	0.16
		Strongman	sRPE-TL	Body load (AU)	0.48
				Impacts (n)	0.29
				High-speed distance (m)	0.06
		Wrestle	sRPE-TL	Body load (AU)	0.45
				Impacts (n)	0.35
				High-speed distance (m)	0.04
	Weaving et al., 2017	Skills	sRPE-TL	PlayerLoad™ (AU)	0.47
				High-speed distance (m)	0.27
		Conditioning	sRPE-TL	PlayerLoad™ (AU)	0.56
				High-speed distance (m)	-0.21
Football	Gaudino et al., 2015		sRPE-TL	High-speed distance (m)	0.11
				Impacts (n)	0.45
				Accelerations (n)	0.37
	Scott et al., 2013		sRPE-TL	Total distance (m)	0.80
				Low-speed activity distance (m)	0.80
				High-speed distance (m)	0.65
				Very-high-speed distance (m)	0.43
				PlayerLoad™ (AU)	0.84
AF	Bartlett et al., 2017		RPE	High-speed distance (m)	0.69
				Total distance (m)	0.77
	Gallo et al., 2015		sRPE-TL	Total distance (m)	0.88
				High-speed distance (m)	0.51
				PlayerLoad™ (AU)	0.86
	T. J. Scott et al., 2013		sRPE (CR10)	Distance (m)	0.81
				High speed running (m)	0.71
				PlayerLoadTM (AU)	0.83
			sRPE (CR100)	Distance (m)	0.78
				High speed running (m)	0.69
				PlayerLoad™ (AU)	0.80
Team handball	Takegami et al., 2022		sRPE-TL	Total distance (m)	0.73
				PlayerLoad™ (AU)	0.73

Abbreviations: AU, arbitrary unit; SSG, small side games; AF, Australian football.

As mentioned earlier there are different methods and tools to measure internal load. McLaren et al. (2018) showed that sRPE-TL had a stronger correlation with various external load variables, compared to the correlation between other internal and external load variables. This can provide evidence for the validity of sRPE as a method to quantify the internal load in team sports. Table 1 shows an overview of studies in different team sports that have investigated the relationship between external and internal load. The main finding of those studies is that total distance has the strongest association with sRPE. This means that internal response is strongly associated with the amount of running completed. This association is logical, because in order to sustain muscle contraction during locomotion, oxygen consumption and cardiac output increases (Vanrenterghem et al., 2017). Wiig et al. (2020) showed that sRPE had the strongest relationship with external load variables with no threshold or low intensity-threshold in football, which is in line with other studies in team sports (Lovell et al., 2013; McLaren et al., 2018; B. R. Scott et al., 2013; T. J. Scott et al., 2013). These findings can suggest that sRPE and external load variables with no or low intensity-threshold are dependent on the session duration since all work is quantified regardless of intensity (Wiig et al., 2020). High intensity-threshold variables have a weaker relationship with sRPE, which can be logical since athletes only perform a small fraction of the total work in high intensity (Wiig et al., 2020).To the author knowledge there are only one studies that have investigated the relationship between internal and external load in elite female team handball. Takegami et al. (2022) observed a very strong correlation between sRPE-TL and the external load variables total distance and PlayerLoad^{TM}, which are similar result reported from studies done on other team sports (Table 1). The type of training is influencing the relationship as shown in Table 1. Different types of training have different output goals, which influences the structure of training activities and the work-rest ratio (McLaren et al., 2018). This may be the reason different types of training has different relationship between internal and external load.

3. Method

3.1 Participants

One handball team (n=21) playing in the women`s premier division in Norway, *Rema-1000 ligaen*, participated in this study (age: 21 ± 2 years). The goalkeepers (n=3) and players that did not participate in 10 or more training sessions (n=3) were excluded from the analysis. 15 players are included in the analysis (age: 21 ± 2 years).

This study was conducted according to the ethical principles of the Declaration of Helsinki, and the players were written informed about the purpose and procedures of the study and signed a letter of consent (Appendix I). The study was approved by the Norwegian Centre for Research Data, and the ethics committee at the Norwegian School of Sport Science. When conducting research on human participants, the aim is always to minimize the risk involved. The participants in this study followed their regular training scheme and did not receive any additional training. Therefore, we considered the risk of injury not to be different.

3.2 Design

To investigate the response of external load variables on sRPE-TL, data was collected from two training sessions per week over a period from November to March (16 weeks, 24 training sessions, 18 ± 4 per player). The data collection was carried out on the sports hall at The Norwegian School of Sport Science. The sports hall measuring 50 × 70 × 11 m, on an indoor surface (Pulastic SP Combi, Gulv og Takteknikk AS, Norway). The sessions contained a warmup routine which consisted of many exercises targeting strengthening the shoulders, back, knees and the ankles. It also contained jogging, passing in pairs, and shoots to warm up the goalkeepers. The remaining part of the session included a vary of game-based training conditions, which was everything in between 2v3 to 6vs6 on one goal, and 7vs7 on the full court. All sessions were planned and performed by the coaches with no interference from the researchers, besides that the players were wearing a vest with a mobile node.

The period when the data was collected, was during the Covid-19 pandemic. This may have influenced the number of participating players in training sessions because of restrictions in

Norway. If a player had been in close contact with someone with Covid-19 they had to be in quarantine for 10 days. If someone was infected, they had to be in isolation for 7 days.

3.3 Training load

3.3.1 External training load

Players external load was monitored using an LPS system (Catapult Clearsky T6, Catapult Sports, Melbourne, Australia). The LPS consists of anchor nodes, mobile nodes which is worn by the players, docking station and software from the manufacturer (both real-time monitoring application and a cloud-based web service). Twenty anchor nodes were installed around the handball courts, approximate 3m above the floor (Figure 1) to capture players movement. The LPS was calibrated before commencement of the study according to the manufacturer recommendation using a tachymeter (Leica Builder 509 Total Station, Leica Geosystems AG, Switzerland).

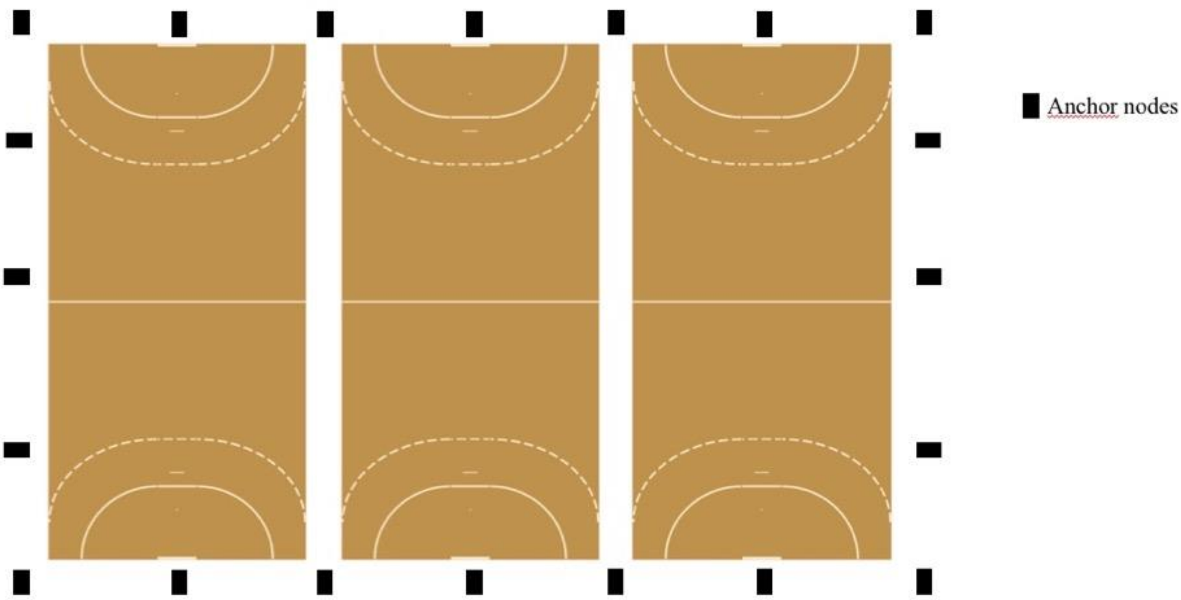

Figure 1: *Setup of anchor nodes. The study was conducted in a sports hall measuring 50 × 70 × 11 m, on an indoor surface (Pulastic SP Combi, Gulv og Takteknikk AS, Norway). The hall consists of three handball courts.*

For each training session, each player was equipped with a mobile node (Catapult Clearsky T6, Catapult Sports, Australia: firmware version: 5.6). The mobile node was placed between the shoulder blades, in a manufacturer supplied vest (Catapult Sports, Australia; Figure 2). To avoid inter-unit variability, each player was assigned a personal mobile node and used the same node for all training sessions. The devices were turned on 15 minutes before each training session.

Figure 2*: The mobile node was placed between the shoulder blades in the manufacturer supplied vest.*

The system has a capturing frequency of 20 Hz. The mobile nodes use ultra-wideband and Bluetooth to measure the distance between several anchor nodes (see Figure 1) at known location around the field. They are also integrated with IMU. This can provide additional information to quantify the training load (L. S. Luteberget, B. R. Holme, et al., 2018). The IMU in the mobile nodes consist of tri-axial accelerometer, tri-axial gyroscope, and magnetometer, which all sample at a frequency of 100 Hz. Tri-axial accelerometer is a tool measuring the rate of change of velocity in three axes (up/down, forward/backward and left/right). Tri-axial gyroscope is measuring the rotation around three axes (the coronal plane, the frontal plane, and the sagittal plane). Magnetometer is an electronic compass that provide information regarding the direction and orientation.

The manufacturer software application (OpenField, Version 2.5.0, Catapult Sports, Melbourne, Australia) was used in real time to mark the start and end of the training session. After each training session the devices was placed in the docking station for data import to the software application and recharging of the nodes.

3.3.2 Internal training load

The internal training load was monitored using the modified Borg CR10 scale (Foster et al., 2001). Players rated their perceived exertion during the session on an integer scale from 1-10, with verbal descriptions (Figure 3). The players were verbally informed how to rate the sRPE before the first training session. The sRPE questionnaire was send out with e-mail to all the participating players on the session using Microsoft Forms Office 365 (Microsoft Corporation, Redmond, WA, USA), approximately 30 minutes after the session ended. Response time on the questionnaire was (14.7±21.2 hours). sRPE-TL was calculated by multiplying sRPE with session duration in minutes. The session duration was defined as the start and stop by the manufacturer software application from the LPS system.

Rating	Description
0	Rest
1	Very, very easy
2	Easy
3	Moderate
4	Somewhat hard
5	Hard
6	
7	Very hard
8	
9	
10	Maximal

Note: Preparation phase in relation to game format (with one match day per week).

Figure 3*: Modified Borg CR10 integer scale with verbal descriptions. (Foster et al., 2001)*

3.4 Validity and reliability

There are multiple LPS system available, which has different technology and frequency rate. This can affect the validity of the data output (Malone et al., 2017; Varley et al., 2017). The system used in this project has shown acceptable validity of time-motion analysis in indoor team sports (L. S. Luteberget, M. Spencer, et al., 2018; Serpiello et al., 2018). PlayerLoad™ is an accelerometer-based measurement. Since the HIE variables are the sum of ACC, CoD and DEC, they are based on accelerometer, gyroscope and magnetometer data (IMU) (Luteberget & Spencer, 2017). L. S. Luteberget, B. R. Holme, et al. (2018) found that inertial movement analysis (IMA) metrics such as ACC, CoD and DEC from data collected by the IMU showed a good reliability in team handball.

sRPE-TL is a valid method to quantify training load during a wide variety of types of training and team sports (Foster et al., 2001; Impellizzeri et al., 2004).

3.5 Data processing

Once the external load data had been imported to the software application and synchronized to the cloud-based web service (OpenField Cloud, version 4.0, Catapult Sports, Melbourne, Australia), the data was exported as a CSV file to Microsoft Excel Office 365 (Microsoft Corporation, Redmond, WA, USA). The internal load data was exported from Microsoft Forms Office 365 as an XLSX file to Microsoft Excel Office 365, for further processing with the external load data.

The following variables were selected for analyses: total PlayerLoad™, PlayerLoad2D™, total distance (m), HSR distance (>15.52 km/h) (m), sprint distance (>22.0 km/h) (m), HIE >1.5 $m \cdot s^{-1}$ (n), HIE >2.5 $m \cdot s^{-1}$ (n) and HIE >3.5 $m \cdot s^{-1}$ (n). PlayerLoad™ is a vector magnitude expressed in arbitrary units (AU), developed by Catapult in conjunction with the Australian Institute of Sport (AIS). It is the sum of all the acceleration across all axes, and takes into account the instantaneous rate of change of acceleration and divided by 100, as described in more details by Boyd et al. (2011). PlayerLoad2D™ omits the vertical accelerometer from the calculation. HIE is the sum of ACC, CoD and DEC, and expressed as change in velocity ($m \cdot s^{-1}$). The direction of an event is relative to the mobile node's orientation at the time, and is based on the angle of the ACC. The magnitude of an event is calculated by integrating, based on the sum of anterior-posterior and medio-lateral ACC, described more comprehensive by L. S. Luteberget, B. R. Holme, et al. (2018). HIE variables was categorized into the manufacturer`s default intensity bands, which is 1,5 to 2,5 $m \cdot s^{-1}$, 2,5 to 3,5 $m \cdot s^{-1}$ and >3,5 $m \cdot s^{-1}$. The velocity bands for HSR distanse and sprint distance were based on earlier research on elite female team handball players by Michalsik et al. (2014). HIE thresholds are the same as used in the research by L. S. Luteberget, B. R. Holme, et al. (2018) on reliability of wearable IMU to measure physical activity in team handball.

3.6 Statistical analysis

Descriptive data in summary statistics are presented as average, standard deviation (SD), minimum (min) and maximum (max). The data was analyzed using both Pearson`s correlation coefficient and a linear mixed-effects model. Pearson`s correlation coefficient was calculated using Microsoft Excel Office 365. Linear mixed-effects model were performed with Ime4 package (Bates et al., 2015) in R version 4.1.2 (R Core Team, 2021).

3.6.1 Correlation coefficient

Correlation coefficient is statistical analysis often used in research on the relationship between internal and external load (Lovell et al., 2013; Paulson et al., 2015; T. J. Scott et al., 2013; Takegami et al., 2022). The analysis indicates if a change in one variable is associated with changes in other variables. Pearson`s correlation coefficient was used to examine the relationship between sRPE-TL and the external load variables. The correlation coefficient was calculated for each subject and subsequently presented as mean ± SD of all subjects, as done in other studies (Lovell et al., 2013; Paulson et al., 2015; T. J. Scott et al., 2013; Takegami et al., 2022). Correlation strength was classified as trivial ($r < 0.1$), weak ($0.1 < r < 0.3$), moderate ($0.3 < r < 0.5$), strong ($0.5 < r < 0.7$), very strong ($0.7 < r < 0.9$), almost perfect (>0.9), and perfect ($r = 1$). Statistical significance was set to $p<0,05$.

3.6.2 Linear mixed-effects model

Linear mixed-effects model analysis is useful when there are repeated measures on the same person since it accounts for both within-player and between-player variability. It also can accommodate missing data, and protects against inflated significance of data sets with the random effects structure (Baayen et al., 2008).The linear mixed-effects model analysis in this study was based on earlier research, on individual response to external training load in elite football players by Wiig et al. (2020). Like in Wiig et al. (2020) the external load variables were treated as predictor variables. Separate analyses were conducted on each external load variable. The fixed-effects in the model were within-player effect and between-player effect. The within-player effect was centered to the mean of each player. The between-player effect was the individual players mean external load of all sessions repeated for each sRPE-TL observation (Wiig et al., 2020). The random effects were playerID, playerID × predictor and sessionID. The random effects are presented as effect size (ES) and represent between-player variability and individual response to 2 SDs of the predictor. Within-player is 2 SDs of the predictor the difference between a low- and high-load training session. Between-player is 2 SDs of the predictor the difference between players with an average typical low and typical high external load (Wiig et al., 2020). The magnitudes of the effects are presented as standardized effect sizes where <0.2, 0.2 to 0.6, 0.6 to 1.2, 1.2 to 2.0, and >2.0 are regarded as trivial, small, moderate, large, and very large effects, respectively. For interpreting random effects, these thresholds are halved (Hopkins et al., 2009). Statistical significance was set to $p<0,05$.

We also tested the response time on sRPE questionnaire and time in season as random effects in the analysis. They did not significantly impact the results.

4. Results

A summary of training load variables is presented in Table 2. Significant correlations between sRPE-TL and total distance were found for 14 of 15 subjects, with moderate to very strong correlation coefficients (Table 3). All subjects showed a significant correlation between sRPE-TL and variables PlayerLoad™ and PlayerLoad2D™. We observed very strong mean correlation coefficients in all subjects in total distance, PlayerLoad™ and PlayerLoad2D™ with sRPE-TL.

Table 2: *Summary statistics of the training load variables grouped by all observations, mean of all players, and mean of all of sessions.*

Group	sRPE, AU	Duration, min	sRPE-TL, AU	PlayerLoad™, AU	PlayerLoad2D™, AU	Total distance, m	HSRD, m	Sprint distance, m	HIE > 1.5, n	HIE > 2.5, n	HIE > 3.5, n
All observations (n=274)											
Mean	4.6	91.5	425	501	327	4640	361	41	372	88	39
SD	1.6	9.3	169	83	55	738	223	67	106	30	20
Min	2.0	58.0	162	277	175	2477	0	0	167	32	9
Max	9.0	118.0	1062	728	492	7159	1224	505	682	188	122
Mean of players (n=15)											
Mean	4.5	91.4	420	499	325	4602	354	39	363	86	38
SD	0.8	2.1	73	36	27	311	129	34	84	23	16
Min	3.1	86.8	299	440	285	3948	152	6	279	54	20
Max	5.9	95.7	541	561	362	5161	525	111	541	144	85
Mean of sessions (n=24)											
Mean	4.6	91.3	421	500	326	4634	356	40	372	88	39
SD	0.9	8.4	118	58	37	517	159	42	41	11	6
Min	2.6	80.7	245	410	266	3908	10	0	281	70	31
Max	6.6	113.0	685	659	425	5867	710	205	461	110	51

Abbreviations: AU, arbitrary unit; HIE, high-intensity events; HSRD, high-speed running distance; min, minimum; max, maximum; sRPE, session rating of perceived exertion; sRPE-TL, sRPE training load.

Table 3*: Correlation coefficients between sRPE-TL and the external load variables.*

Subject	Total distance × sRPE-TL	P value	PlayerLoad™ × sRPE-TL	P value	PlayerLoad2D™ × sRPE-TL	P value	HSRD × sRPE-TL	P value	Sprint distance × sRPE-TL	P value	HIE_low × sRPE-TL	P value	HIE_med × sRPE-TL	P value	HIE_high × sRPE-TL	P value
1	0.79	<0.01*	0.73	<0.01*	0.69	0.01*	0.61	0.04*	0.40	0.20	0.67	0.02*	0.47	0.12	0.47	0.12
2	0.78	<0.01*	0.74	<0.01*	0.73	<0.01*	0.12	0.70	-0.12	0.69	0.74	<0.01*	0.77	<0.01*	0.20	0.52
4	0.57	<0.01*	0.67	<0.01*	0.69	<0.01*	0.52	0.01*	0.38	0.08	0.22	0.34	0.26	0.25	0.01	0.97
5	0.42	0.05	0.50	0.02*	0.51	0.02*	0.33	0.14	0.09	0.70	0.46	0.03*	0.49	0.02*	0.17	0.44
6	0.47	0.04*	0.51	0.03*	0.51	0.03*	0.37	0.12	-0.14	0.58	0.19	0.43	0.05	0.84	-0.26	0.28
9	0.71	<0.01*	0.76	<0.01*	0.75	<0.01*	0.67	<0.01*	0.59	<0.01*	0.50	0.02*	0.33	0.14	0.35	0.11
11	0.87	<0.01*	0.80	<0.01*	0.78	<0.01*	0.64	0.01*	0.23	0.39	0.62	0.01*	0.60	0.01*	0.68	<0.01*
12	0.79	<0.01*	0.75	<0.01*	0.74	<0.01*	0.46	0.06	0.12	0.65	0.43	0.08	0.66	<0.01*	0.49	0.04*
13	0.60	0.01*	0.61	<0.01*	0.59	0.01*	0.39	0.13	0.33	0.20	0.35	0.17	0.18	0.50	0.22	0.40
14	0.80	<0.01*	0.86	<0.01*	0.73	0.01*	0.71	0.01*	0.34	0.30	0.86	<0.01*	0.51	0.16	0.66	0.05
15	0.55	<0.01*	0.62	<0.01*	0.65	<0.01*	0.42	0.06	0.32	0.16	0.38	0.09	0.09	0.68	0.42	0.06
17	0.85	<0.01*	0.89	<0.01*	0.87	<0.01*	0.58	<0.01*	0.58	<0.01*	0.51	0.01*	0.58	<0.01*	0.62	<0.01*
18	0.81	<0.01*	0.82	<0.01*	0.81	<0.01*	0.65	<0.01*	0.37	0.07	0.53	0.01*	0.70	<0.01*	0.54	0.01*
19	0.85	<0.01*	0.79	<0.01*	0.79	<0.01*	0.64	<0.01*	0.27	0.22	0.59	<0.01*	0.35	0.11	0.09	0.70
20	0.80	<0.01*	0.71	<0.01*	0.70	0.01*	0.44	0.13	0.11	0.73	0.68	0.01*	0.42	0.15	0.45	0.12
All subjects	0.71 ± 0.15 very strong		0.72 ± 0.12 very strong		0.70 ± 0.10 very strong		0.50 ± 0.16 strong		0.26 ± 0.22 weak		0.52 ± 0.19 strong		0.43 ± 0.22 moderate		0.34 ± 0.27 moderate	

*Abbreviations: HIE, high-intensity events; HSRD, high-speed running distance; sRPE-TL, sRPE training load. *Significant (p = <0.05)*

Table 4*: The within-player and between-player effect of the specific external load variable on sRPE-TL.*

External load variable	Value of 2 SDs	Effect	90% CI	ES	ES low	ES high	P value
Within-player							
PlayerLoad^{TM}, AU	151	158.9	118.9 to 199.0	1.38	1.03	1.73	< 0.01 *
PlayerLoad2D^{TM}, AU	98	147.2	106.2 to 188.1	1.24	0.9	1.59	< 0.01 *
Total distance, m	1353	141.2	97.0 to 185.5	1.19	0.82	1.56	< 0.01 *
HSRD, m	374	141.7	91.6 to 191.9	1.16	0.75	1.56	< 0.01 *
Sprint distance, m	114	101	34.6 to 167.5	0.79	0.27	1.31	< 0.01 *
HIE >1.5, n	126	99.8	63.1 to 136.4	0.81	0.51	1.11	< 0.01 *
HIE >2.5, n	38	91.8	47.1 to 136.4	0.77	0.39	1.14	< 0.01 *
HIE >3.5, n	22.3	71.3	31.2 to 111.4	0.59	0.26	0.92	< 0.01 *
Between-player							
PlayerLoad^{TM}, AU	72	-44.8	-121.2 to 31.6	-0.39	-1.05	0.27	0.23
PlayerLoad2D^{TM}, AU	53	-33.5	-111.4 to 44.4	-0.28	-0.94	0.38	0.37
Total distance, m	622	24.8	-55.4 to 105.0	0.21	-0.47	0.88	0.52
HSRD, m	259	50.1	-32.4 to 132.7	0.41	-0.26	1.08	0.21
Sprint distance, m	68	57.2	-34.8 to 149.1	0.45	-0.27	1.16	0.2
HIE >1.5, n	169	23.4	-65.9 to 112.6	0.19	-0.53	0.91	0.58
HIE >2.5, n	47	59.2	-24.0 to 142.4	0.5	-0.2	1.19	0.15
HIE >3.5, n	32.8	71.1	-12.9 to 155.1	0.59	-0.11	1.28	0.09

*Abbreviations: AU, arbitrary unit; CI, confidence interval; ES, effect size; HIE, high-intensity events; HSRD, high-speed running distance; sRPE-TL, sRPE training load. The effect is quantified by 2 SDs of the external load variable. * Significant (p = <0.05) effect size.*

All external load variables showed a significant within-player effect on sRPE-TL, ranging from small to large ES (p = <0.01, ES: 0.59 - 1.38). The variables PlayerLoad^{TM} and PlayerLoad2D^{TM} had, 37% and 35% within-player effect on sRPE-TL, respectively. Total distance, HSRD, sprint distance, HIE >1.5 and HIE >2.5 showed a 33% - 22%, moderate within-player effect on sRPE-TL (Table 4). HIE >3.5 had a 17%, small within-player effect. Moreover, we observed no significant between-player effect (Table 4).

***Table 5**: Between-session variability and individual response in sRPE-TL that is not explained by the specific external load variable.*

External load variable	Between-session variability		Individual response	
	CV, %	**ES**	**CV, %**	**ES**
PlayerLoad™	17	0.62	10	0.37
PlayerLoad2D™	18	0.63	11	0.39
Total distance	18	0.64	13	0.44
HSRD	23	0.80	11	0.38
Sprint distance	26	0.86	15	0.50
HIE >1.5, n	24	0.81	8	0.28
HIE >2.5, n	25	0.89	13	0.47
HIE >3.5, n	26	0.91	9	0.31

Abbreviations: ES, effect size; HIE, high-intensity events; HSRD, high-speed running distance; sRPE-TL, session rating of perceived exertion training load. Thresholds for ES for random effects are: >0.1, small; >0.3, moderate; >0.6, large; >1.2, very large; and >2.0, extremely large.

Moderate individual responses to sRPE-TL to the variables PlayerLoad™, PlayerLoad2D™, total distance, HSRD, sprint distance, HIE >2.5 and HIE >3.5 (Table 5 and Figure 4). Large, 17% - 26% between-session variability was observed.

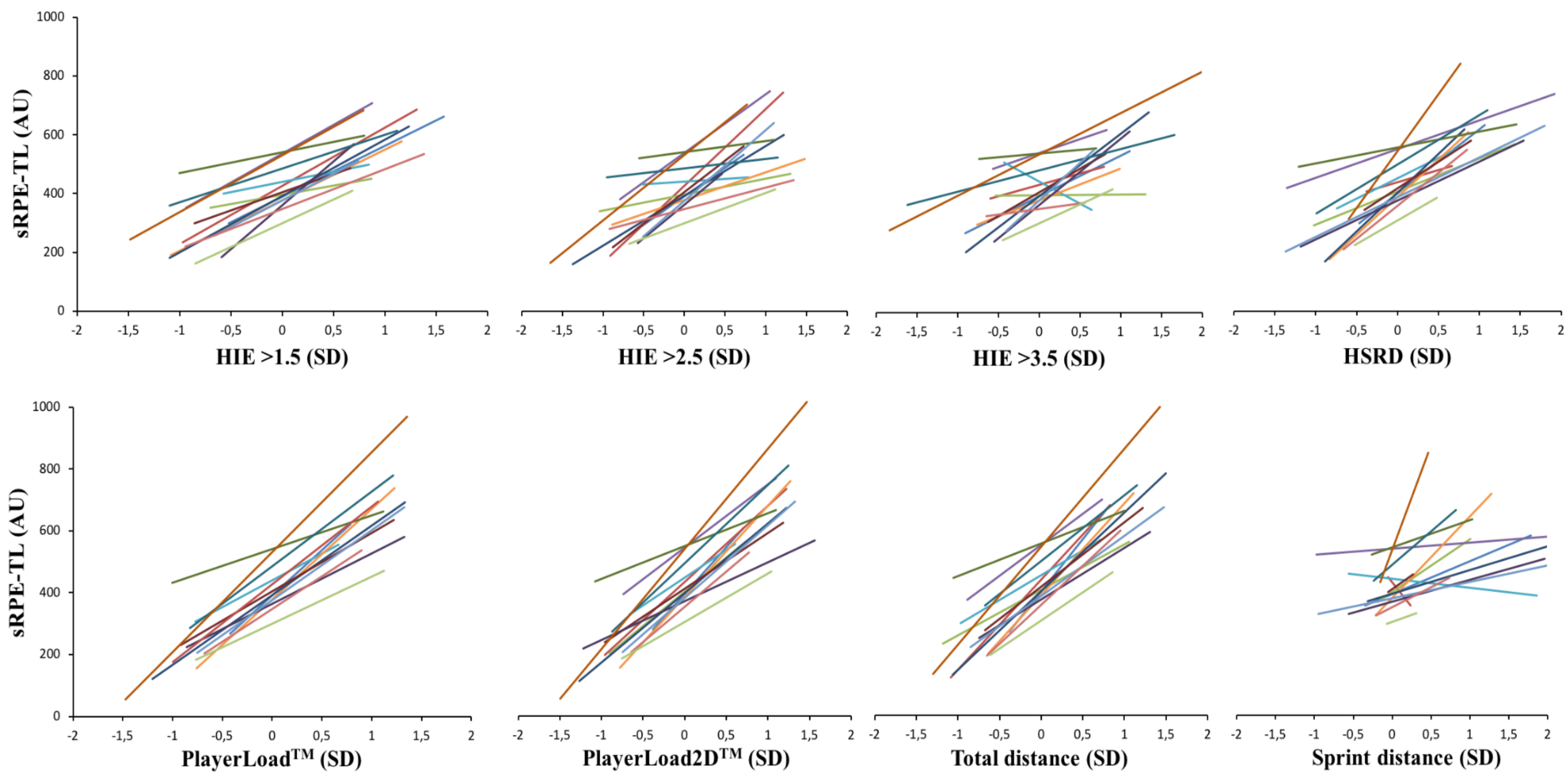

Figure 4*: Individual predicted sRPE-TL highlighting the individual response on the external load variables HIE >1.5, HIE >2.5, HIE >3.5, sprint distance, PlayerLoad^{TM}, PlayerLoad2D^{TM}, total distance and HSRD. The x-axis shows the external load in SDs.*

5. Discussion

This study aimed to clarify the relationship between sRPE-TL and external load variables in elite female team handball. We used an individual approach to model the effect of external load variables in sRPE-TL during training sessions in elite female team handball players. The results showed that external load variables with low intensity thresholds and HSRD had the largest effect on sRPE-TL, and the effect became reduced with increasing intensity thresholds. The low intensity threshold variables total distance, PlayerLoad^{TM}, PlayerLoad2D^{TM} also show very strong mean in all subjects' correlation with sRPE-TL. Furthermore, the data show moderate individual responses to PlayerLoad^{TM}, PlayerLoad2D^{TM}, total distance, HSRD, sprint distance, HIE >2.5 and HIE 3.5. Although external load had small to large within-player effect on sRPE-TL, there was still large between-session variability that could not be explained by external load variables.

5.1 Correlation

sRPE-TL had the strongest relationship with the external load variables PlayerLoad^{TM}, PlayerLoad2D^{TM} and total distance (Table 3). The only study published on female team handball players reported a very strong (0.73 ± 0.09 and 0.73 ± 0.08) correlation in all subjects between the variables sPRE-TL, total distance and PlayerLoad^{TM}, respectively (Takegami et al., 2022). The study was conducted on one team playing in the first division of the university league in Japan. They performed the daily training on an outdoor handball court, which vary from this study. It is possible to argue that performing handball on an outdoor court may influence the game. A harder surface may cause players to be more tentative in intense physical contact and tackles. There is also possible to argue the about the competitive standards in the first division of the university league in Japan compared to a top division in a European country. Even with these possible differences the results in this study are similar with a very strong (0.71 ± 0.15 and 0.72 ± 0.12) correlation with sRPE-TL in all subjects in total distance and PlayerLoad^{TM}, respectively. The relationship between sRPE-TL and external load variables have also been investigated in various team sports. In football, the correlation with sRPE-TL in total distance and PlayerLoad^{TM} is reported to 0.80 and 0.84 respectively (B. R. Scott et al., 2013). In Australian football, the relationship of sRPE-TL with total distance (r = 0.78 to 0.88) and PlayerLoad^{TM} (r = 0.80 to 0.86) were reportedly very strong (Gallo et al., 2015; T. J. Scott et al., 2013). Therefore, the very strong correlation coefficients between the sRPE and the external load variables total distance and PlayerLoad™ were found as in previous studies in other team sports. In line with previous research, we also observed a weaker correlation coefficient with external load variables when the intensity threshold increases (Table 3) (Gallo et al., 2015; McLaren et al., 2018; B. R. Scott et al., 2013).

Summarized, this study found that the external load variables total distance, PlayerLoad™ and PlayerLoad2D™ had the strongest relationship with sRPE-TL. These results are in line with previous research done in various team sports.

5.2 *Within-player effect*

The results from this study show that sRPE-TL could differentiate between a typical low- and high-load session (small to large effect size), in accordance with the study from Wiig et al. (2020) on the individual response to external training load in elite football players. These findings suggest that sRPE-TL is a valid tool to quantifying internal training load in team handball, since sRPE-TL can differentiate between different amounts of external load within the same player, which are in line with existing literature in team sports (Foster et al., 2001; Impellizzeri et al., 2004; McLaren et al., 2018; Takegami et al., 2022; Wiig et al., 2020). Other studies on team sports found that sRPE-TL had the strongest relationship with the variables with no threshold or low intensity-threshold, that is, PlayerLoad™, PlayerLoad2D™ and total distance (Casamichana et al., 2013; Gallo et al., 2015; Lovell et al., 2013; McLaren et al., 2018; B. R. Scott et al., 2013; T. J. Scott et al., 2013; Takegami et al., 2022; Wiig et al., 2020). In line with previous research, we observed a large within-player effect on the low-intensity-threshold variables PlayerLoad™ and PlayerLoad2D™, 37% and 35% effect on sRPE-TL respectively (Table 4). These results demonstrate that no threshold or low intensity-threshold variables also has the strongest relationship with sRPE-TL in team handball, as in other team sports. Wiig et al. (2020) stated that both sRPE-TL and low intensity-threshold variables probably are strongly dependent on the session duration since all work is quantified regardless of the intensity. This suggests that sRPE-TL primarily reflects the total work completed. A difference compared to Wiig et al. (2020) is the effect of total distance. We observed a moderate, 33 % effect on sRPE-TL, and Wiig et al. (2020) observed a very large effect. The higher effect of total distance on sRPE-TL observed in Wiig et al. (2020) may be due to higher amount of total distance between a low- and a high-load session. The weaker relationship with high intensity-threshold variables in this study can be due to the training session contained only a small part of the total work completed in high intensity (Table 2).

HSRD is classified as a high intensity threshold variable. In this study we observed that HSRD had a similar effect on sRPE-TL as total distance (33% effect) between a low- and a high-load session. As aforementioned above, research in other team sports reported the relationship between sRPE-TL and external load variables becomes weaker when the threshold increases (Gallo et al., 2015; McLaren et al., 2018; B. R. Scott et al., 2013; Wiig et al., 2020). A potential reason to the similar effect on sRPE-TL by both HSRD and total distance, is the variation of external load performed in the different training sessions. Variation in total distance performed in different training sessions is less than the variation in HSRD performed. We collected data from only two training sessions per week. Future research should try to include more training sessions per week, to investigate if the training load differentiate more between different training sessions.

Michalsik et al. (2014) reported that elite female team handball players in average perform 93 ± 65 meters in HSRD in a match. This is considerably less than average HSRD perform in the training sessions in this study (Table 2). Earlier studies have shown that the intensity in game-based training drills overload the intensity in official matches in team handball (Bělka et al., 2016; Corvino et al., 2014; Live S. Luteberget et al., 2018). The result of this study supports those findings. Altering the pitch size or number of players can increase the square meter per player, which can lead to higher intensity and increase the HSRD players most perform during a training session. Therefore, it is possible that HSRD has a smaller effect on sRPE-TL in an official team handball match, since the players perform less distance in this high intensity threshold. Further research should for that reason include matches when investigating the relationship between internal and external load.

The result from this study highlights that sRPE-TL could differentiate between a typical low- and high-load session and be a valid tool to quantify internal load in team handball. It also demonstrates that no threshold or low intensity-threshold variables has the strongest relationship with sRPE-TL, as in other team sports (Casamichana et al., 2013; Gallo et al., 2015; Lovell et al., 2013; McLaren et al., 2018; B. R. Scott et al., 2013; T. J. Scott et al., 2013; Takegami et al., 2022; Wiig et al., 2020). The lower effect of total distance observed in this study compared to Wiig et al. (2020) may be due to higher amount of total distance between a low- and a high-load session.

5.3 Between-player effect

The between-player effect describes the average differences between players with a low- and a high-load session. The variables showed no significant effect, which means that players doing more external training load do not report a higher average sRPE-TL on their individual average external load (Table 4). Wiig et al. (2020) found a small to moderate between-player effect on sRPE-TL in football. The effect observed in Wiig et al. (2020) compared to this study, is potential due to a higher amount of external load between players with a typical low and a typical high average external load.

The no significant between-player effect observed in this study may be due to that players with a high average external load have a greater maximal oxygen uptake, since athletes with a greater maximal oxygen uptake is reported to rate lower sRPE-TL (Garcin et al., 2004; Milanez et al., 2011). Gallo et al. (2015) found that experience, position, and time-trail performance influenced the sRPE-TL in Australian footballers. Both time-trail performance and a greater maximal oxygen uptake indicates a greater physical fitness. Therefore, it is logical to think that a greater physical fitness may influence the perceived exertion.

There is a possibility that other factors are relevant in team handball, such as playing position. It is known that playing position account for some of the variation in total distance covered in elite female during matches. Michalsik et al. (2014) have also reported that wing players perform more high intensity running than other positions. HIE/min is another external load variable which differs from different playing position. Backs is shown to have the highest values of HIE/min, followed by pivots, then wing players (Luteberget & Spencer, 2017). Takegami et al. (2022) reported different correlation between sRPE-TL and total distance and PlayerLoad^{TM} for backs and pivot (very strong), and wing players (strong). Therefore, it is possible that the no significant between-player effect observed in this study is influenced by a greater physical fitness on the players performing a higher average external load, and the variation in external load is caused by the different playing position.

Summarized, this study observed no significant between-player effect on sRPE-TL. A greater physical fitness may affect the athlete's perceived exertion and potentially rate lower sRPE-TL and playing position may influence the external load performed during a training session. More research is needed to further examine the between-player effect in team handball.

5.4 Between-session variability

The between-session variability indicates the variability in sRPE-TL that is not explained by specific external load. The high intensity variables had the highest between-session variability (Table 5), and the variability increases when the intensity threshold for the external load variables increases. Wiig et al. (2020) stated that high intensity-threshold are unsuitable as single predictors of sRPE-TL predictor in football when monitoring multiple training session since the high intensity variables show a poor ability to explain the between-session variability.

Previous research has demonstrated that type of training influences the relationship with internal and external load (Weaving et al., 2017; Weaving et al., 2014). Different types of training have different training output goals, and that influences the structure and work-rest ratio (McLaren et al., 2018). Reduction in work-rest ratio in small side games have been shown to reduce the total distance covered in high-speed running and sprint, but increased heart rate in hurling (Malone et al., 2019). Johnston and Gabbett (2011) reported a significantly increase in internal load for the same distance covered with the addition of physical collisions during repeated sprint exercise in rugby. Therefore, the variability in sRPE-TL between session may be due to that every session is different, and the load measures that best represent one type of training may not do so for others (McLaren et al., 2018).

In this study we observed a large between-session variability in sRPE-TL that is not explained by specific external load. The variability may be because every session is different and different types of training have different training output goals. We also observed that the variability increases when the intensity threshold increases. Further research should try to investigate how different types of training influences the relationship between internal and external load in team handball.

5.5 Individual response

The individual response in sRPE-TL is highlighted in Figure 5, as individual predicted sRPE-TL to different external load variables. Two SDs (different between low- and high-load session) of PlayerLoad^{TM}, PlayerLoad2D^{TM}, total distance, HSRD, sprint distance, HIE >2.5 and HIE 3.5 resulted in moderate variability in sRPE-TL response. HIE >1.5 resulted in a small variability in sRPE-TL response (Table 5). These differences underline the importance for coaches and practitioners to individualize the monitoring of training load and use both internal load in addition to external load variables (Wiig et al., 2020). As aforementioned above, sRPE-TL can be influenced by individual characteristics (Impellizzeri et al., 2005). In football Wiig et al. (2020) observed a lower individual response to total distance, and they stated that this makes total distance more uniformly related to sRPE-TL across different players. This can suggest that total distance is the most suitable variable when only using one measured variable in football (Wiig et al., 2020). It is a logical assumption since football is performed on a large pitch and session duration can be quite long, and both sRPE-TL and low intensity-threshold variables probably are strongly dependent on the session duration since all work is quantified regardless of the intensity.

We observed a lower individual response to HIE >1.5 on sRPE-TL in this study (Table 5). Luteberget and Spencer (2017) found a high occurrence of ACC events during match play for all playing positions in international female team handball. Therefore, all the players are performing high amount of ACC events despite different playing positions. This makes HIE >1.5 more uniformly across players. Team handball is performed on a smaller court, and the sports complex interaction between many different activities probably makes it not sufficient to only use one measured variable monitoring external load. PlayerLoad^{TM} is the variable with the highest within-subject effect (37%) on sRPE-TL in this study. As mentioned in method chapter, PlayerLoad^{TM} measure the instantaneous rate of change of ACC in all axes divided by a scaling factor. In this study PlayerLoad^{TM} had a very strong (0.80) correlation with total distance. This is because when a player is running it generate a vertical ACC. PlayerLoad^{TM} also showed a very strong correlation with sRPE-TL. This can suggest that PlayerLoad^{TM} is the most preferable training load measure when a single measure is used in team handball. Because it may consider both ACC and total distance. More research is needed to see if this finding is consistent.

The moderate individual response on sRPE-TL observed highlighting the importance of individualize the monitoring of training load. The lower individual response to HIE >1.5, makes HIE >1.5 more uniformly across players.

5.6 Limitations of the study

Some limitations need to be taken into consideration when reading and evaluating the results from this study. The currented study only considered one team. Despite a reasonable number of player and sessions analyzed, caution should be made when generalizing the results from this study. There could be very different training regimes in different countries and teams. If more teams participating, we could say more about the general handball population. The data was only collected from two training sessions per week. The lack of a gold standard to measure training load in team sports makes the criterion validity difficult to assess in both sRPE-TL and external load variables (Wiig et al., 2020). It is possible that external load variables and sRPE-TL is suboptimal measures of training load. Furthermore, as mentioned this study was conducted during the Covid-19 pandemic. That resulted in several players infected, which meant several days in isolation. We do not know if the infection or the isolation influenced the fitness level. It is possible it may have affected the players perceived exertion.

5.7 Practical applications

Considered the limited number of studies describing the relationship between internal and external load in elite female team handball players, this study has provided novel insights on the within-player effect on different external load variables on sRPE-TL in female elite team handball. These findings suggest that sRPE-TL is a valid tool to quantifying internal training load in team handball, since sRPE-TL can differentiate between different amounts of external load within the same player. Additionally, variables with high intensity threshold have a weaker relationship with sRPE-TL, and between-session variability increases when the intensity threshold increases. This makes external load variables with high intensity threshold not suitable alone to describe training load in team handball. The individual response on the external load variables on sRPE-TL shows the importance to individualize the monitoring of training load. Furthermore, team handball nature with a complex interaction with many types of different activities, the differences between players and individual response suggest that coaches and practitioners should monitor both sRPE-TL and external load.

6. Conclusion

This study demonstrated a large within-player effect on sRPE-TL in variables PlayerLoad^{TM} and PlayerLoad2D^{TM} in elite female team handball players. The relationship becomes weaker when the intensity threshold increases. Total distance, PlayerLoad^{TM} and PlayerLoad2D^{TM} had a very strong correlation with sRPE-TL. Furthermore, moderate individual response to sRPE-TL to external load variables was observed. Indicating the importance to individualize the monitoring of training load. Finally, we observed a large between-session variability in sRPE-TL that is not explained by specific external load, which highlighting the use of both sRPE-TL and external load when monitoring training load in elite female team handball.

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Table summary

Figure summary

Abbreviations

ACC	Acceleration
AIS	Australian Institute of Sport
AU	Arbitrary unit
CoD	Change of direction
CV	Coefficient of variation
DEC	Deceleration
ES	Effect size
GNSS	Global navigate satellite system
HIE	High intensity events
HSRD	High speed running distance
IMA	Inertial movement analysis
IMU	Inertial measurements unit
LPS	Local positioning system
Max	Maximum
Min	Minimum
RFD	Rate of force development
RPE	Rate of perceived exertion
SD	Standard deviation
sRPE	Session rating of perceived exertion
sRPE-TL	Session rating of perceived exertion training load
VO_{2max}	Maximal oxygen uptake
VSHR	Very high speed running

Appendix

I. Letter of consent

Appendix I: Letter of consent

Vil du delta i forskningsprosjektet

"Effekten av forskjellige eksterne belastningsvariabler på opplevd anstrengelse i håndball"?

Dette er et spørsmål til deg om å delta i et forskningsprosjekt hvor formålet er å undersøke forholdet mellom forskjellige eksterne belastningsvariabler og opplevd anstrengelse i håndball. I dette skrivet gir vi deg informasjon om målene for prosjektet og hva deltakelse vil innebære for deg.

Formål

Måling og overvåking av treningsbelastning har blitt en viktig del av moderne idrett. Formålet med å overvåke treningsbelastning er å få bedre innsikt i utvikling og vedlikehold av fysisk prestasjon, samt et ønske om å redusere skadeforekomst. Treningsbelastning kan deles inn i intern og ekstern belastning. Intern belastning er definert som den relative fysiologiske belastningen på utøveren, og er ofte representert som opplevd anstrengelse («Rate of Percieved Exertion»; RPE). Ekstern belastning er definert som det fysiske arbeidet utført av utøveren, og er ofte målt i variabler som distanse, hastighet og akselerasjon. I dette masterprosjektet vil vi undersøke effekten av forskjellige variabler som distanse og hastighet på opplevd anstrengelse på elite utøvere i håndball. Eksterne treningsbelastningsvariabler vil bli målt under trening, og opplevd anstrengelse vil bli samlet inn ~ 30 minutter etter hver økt. Informasjon om dette temaet vil kunne bidra til bedre overvåking av treningsbelastning, som kan føre til forbedring av de fysiske egenskapene til idretten, samt redusere skaderisiko.

Dette forskningsprosjektet gjennomføres i Idrettshallen ved Norges idrettshøgskole.

Hvem er ansvarlig for forskningsprosjektet?

Institutt for fysisk prestasjonsevne ved Norges idrettshøgskole er ansvarlig for prosjektet. Prosjektansvarlige er Live S. Luteberget og Merete Møller. I tillegg vil en master-student være ansvarlige for den daglige driften av prosjektet.

Hva innebærer det for deg å delta?

Hvis du velger å delta i prosjektet, innebærer det at du må ha på deg en GPS-enhet på trening 1-2 ganger i uken over sesongen 21/22. Dette innebærer at du har på deg en vest på trening (se bilde), hvor enheten er plassert. Du vil i forbindelse med øktene også bli bedt om å svare på en vurdering på hvor tung du syns treningen var (skala 1-10). Ellers vil ikke studien gripe inn i noen aspekter med treningene.

Mulige ulemper med deltakelsen i denne studien er at du må sette av tid til trening. Gjennomføring av trening innebærer alltid en viss risiko for skader, men det er ingen grunn til å anta at skaderisikoen er høyere ved deltakelsen i denne studien enn i egen trening.

Det er frivillig å delta

Det er frivillig å delta i prosjektet. Hvis du ønsker å skal delta, kan du når som helst trekke samtykke tilbake uten å oppgi noen grunn. Alle opplysninger om deg vil da bli anonymisert. Det vil ikke ha noen negative konsekvenser for deg hvis du ikke vil delta eller senere velger å trekke samtykket. Det vil for eksempel ikke påvirke spilletid eller forhold til treneren om du velger å ikke være med i studien, eller om du velger å trekke deg fra studien underveis.

Ditt personvern – hvordan vi oppbevarer og bruker dine opplysninger

Informasjonen som registreres om deg skal kun brukes slik som beskrevet i hensikten med studien. Du har rett til å se hvilke opplysninger som er registrert om deg og rett til å få rettet opp eventuelle feil i de opplysningene som vi har om deg.

Navnet ditt er det eneste direkte personidentifiserende opplysning som vil registreres. Navnet vil lagres separat fra dataene, og dermed er det kun en kode som knytter deg til opplysninger gjennom en navneliste. Dette betyr at informasjonen er avidentifisert. Det er kun autorisert personell knyttet til prosjektet som har adgang til navnelisten og som kan finne tilbake til deg. Det vil ikke være mulig å identifisere deg i resultatene av studien når disse publiseres

Hva skjer med opplysningene dine når vi avslutter forskningsprosjektet?

Opplysningene anonymiseres når prosjektet avsluttes/oppgaven er godkjent, noe som etter planen er 01.08.22. Vi er pliktet til å oppbevare data og separat navneliste i 5 år etter sluttdato for etterprøvbarhet og kontroll av resultatene. Etter dette, altså 01.08.27, slettes navneliste og dataene er deretter anonyme.

Hva gir oss rett til å behandle personopplysninger om deg?
Vi behandler opplysninger om deg basert på ditt samtykke.

På oppdrag fra Norges idrettshøgskole har NSD – Norsk senter for forskningsdata AS vurdert at behandlingen av personopplysninger i dette prosjektet er i samsvar med personvernregelverket.

Dine rettigheter
Så lenge du kan identifiseres i datamaterialet, har du rett til:

- innsyn i hvilke opplysninger vi behandler om deg, og å få utlevert en kopi av opplysningene
- å få rettet opplysninger om deg som er feil eller misvisende
- å få slettet personopplysninger om deg
- å sende klage til Datatilsynet om behandlingen av dine personopplysninger

Hvor kan jeg finne ut mer?
Hvis du har spørsmål til studien, eller ønsker å vite mer om eller benytte deg av dine rettigheter, ta kontakt med:

- Norges idrettshøgskole ved prosjektansvarlig Live S. Luteberget, på e-post: livesl@nih.no, eller telefon: 40043516, Merete Møller, på e-post: meretem@nih.no, eller masterstudent Gaute Mehus Lekve, på e-post: gauteml@nih.no eller telefon: 41215977
- Vårt personvernombud: Rolf Haavik (epost: personvernombud@nih.no)

Hvis du har spørsmål knyttet til NSD sin vurdering av prosjektet, kan du ta kontakt med:

- NSD – Norsk senter for forskningsdata AS på epost (personverntjenester@nsd.no) eller på telefon: 55 58 21 17.

Med vennlig hilsen

Live S. Luteberget Merete Møller Gaute Mehus Lekve

Samtykkeerklæring

Jeg har mottatt og forstått informasjon om prosjektet *«Effekten av forskjellige eksterne belastningsvariabler på opplevd anstrengelse i håndball»*, og har fått anledning til å stille spørsmål. Jeg samtykker til:

- ☐ at jeg vil delta i prosjektet som er beskrevet ovenfor
- ☐ at jeg vil delta i målinger av treningsbelastning og opplevd anstrengelse
- ☐ at mine opplysninger behandles frem til prosjektet er avsluttet 01.08.22, og at dataene kan lagres frem til 01.08.2027 for etterprøvbarhet og kontroll av resultatene

Jeg samtykker til at mine opplysninger behandles frem til prosjektet er avsluttet

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(Signatur, dato)