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INTEGRATING DIGITAL TECHNOLOGIES IN OPTIMIZING PHYSICAL TRAINING FOR U18 HANDBALL PLAYERS

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ABSTRACT. *Introduction:* In contemporary sports, the integration of digital technologies into physical training has become increasingly relevant, particularly for youth athletes who are in sensitive stages of physical and functional development. For U18 handball players, the balance between maximizing performance and ensuring safe progression is crucial, making technology a valuable support for coaches and athletes. *Objective*: The purpose of this research was to analyse the effects of integrating digital monitoring tools into the physical preparation of U18 handball players. The hypothesis was that technology-assisted training would generate superior improvements compared to traditional approaches by enabling individualized workloads, objective feedback, and improved injury prevention strategies. *Material and Methods*: The study design included a sample of U18 handball players, divided into an experimental group trained with digital tools and a control group trained using conventional methods. Training was carried out over a full competitive cycle. Both groups were evaluated at baseline and after the intervention through standardized motor tests (strength, speed, agility, endurance, mobility) and physiological indicators such as heart rate (HR), heart rate variability (HRV), and accelerometery. Tools employed included GPS trackers for movement and load assessment, video analysis for technique evaluation, and sensor-based devices to measure landing forces and postural stability. *Results:* The experimental group showed faster and more consistent improvements in explosive strength, acceleration, and endurance, while also maintaining higher levels of recovery quality as

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measured through HRV. Digital feedback promoted greater motivation and awareness among athletes, while objective monitoring allowed coaches to adjust workloads more precisely, reducing signs of overload. In contrast, the control group demonstrated progress, but with higher variability and limited individualization. *Discussion*: The results supported previous literature that highlighted the benefits of integrating digital monitoring tools into sports training. The added value lay in the objectivity of data collection and the capacity to design personalized programs while minimizing injury risk. *Conclusions:* The integration of digital technologies into the physical preparation of U18 handball players proved to be more effective than traditional approaches, supporting both performance enhancement and safe athletic development. This hybrid training model represents a methodological innovation and a practical necessity in the cultivation of future elite athletes.

Keywords: digital technologies; physical training; handball; performance monitoring; injury prevention.

INTRODUCTION

Physical preparation represents one of the essential pillars of performance in team sports, and handball is among the disciplines with the most complex physical demands. Characterized by intermittent high-intensity efforts, rapid changes of direction, intense physical contact, and frequent alternations between sprint actions and active recovery, handball simultaneously requires high levels of strength, speed, agility, endurance, and coordination (Michalsik & Aagaard, 2015; Wagner et al., 2014). Match-analysis studies have shown that elite female handball players perform numerous accelerations, decelerations, jumps, and high-speed runs throughout a game, highlighting the multifactorial nature of physical performance in this sport (Póvoas et al., 2012).

For the Junior I category (female athletes aged between 16 and 18), these physical demands coincide with a critical stage of biological maturation and motor development. During this period, neuromuscular adaptations, coordination refinement, and strength development are still ongoing, making the systematic evaluation and optimization of physical preparation decisive for long-term athletic development and future performance at the senior level (Lloyd & Oliver, 2012; Myer et al., 2011).

Traditional assessment methods, such as manual timing, visual observation, or subjective evaluation of effort, offer limited accuracy and often fail to capture the true external and internal load experienced by the athlete (Impellizzeri et al., 2005). In the context of increasing digitalization in sport, modern monitoring technologies, particularly Global Positioning System (GPS) devices combined with inertial sensors, have become indispensable tools in performance analysis. These systems allow real-time and post-session monitoring of key movement parameters, including maximum and average speed, frequency and intensity of accelerations and decelerations, total and high-intensity distance covered, neuromuscular load (PlayerLoad), as well as multidirectional movements and ground impact forces (Cummins et al., 2013; Akenhead & Nassis, 2016).

By correlating GPS-derived data with the results of standardized physical tests, coaches and sports scientists can obtain a more comprehensive and objective assessment of physical preparation, identify individual strengths and weaknesses, and personalize training interventions accordingly (Buchheit & Simpson, 2017). Moreover, the integration of GPS technology into the testing process of Junior I handball players offers multiple advantages, including increased measurement precision through the reduction of human error, contextual interpretation of test performance by comparison with match demands, longitudinal monitoring across the competitive season, and injury risk reduction through early detection of neuromuscular overload or movement asymmetries (Gabbett, 2016; Malone et al., 2017).

Therefore, the present study aims to highlight the usefulness of integrating sports GPS technology into six standardized physical assessment tests (Countermovement Jump, 10–20 m Sprint, T-Test, Yo-Yo Intermittent Recovery Test Level 1, Y-Balance Test, and Landing Error Scoring System), in order to demonstrate the positive impact of digitalization on the objectivity, accuracy, and practical relevance of the data obtained within the training process of Junior I female handball players.

MATERIAL AND METHODS

Participants

The study was conducted on **20 Junior I female handball players**, aged between 16 and 18 years, registered with handball clubs and engaged in competitive preparation. The selection of this sample was justified by the fact that at this age athletes are in a transition stage towards senior-level performance, and optimizing physical preparation has a direct impact on future performance. Inclusion criteria required regular participation in training (minimum three sessions per week), absence of severe injuries in the past six months, and the consent of both athletes and their coaches for participation. The study was approved by the Ethics Committee, and informed consent was obtained from all participants prior to testing.

Equipment and technologies used

A Catapult Vector S7 sports GPS system or equivalent was employed, equipped with a triaxial sensor (accelerometer, gyroscope, and magnetometer) and a recording frequency ranging between 10 and 18 Hz. Monitoring was carried out using a special vest that fixed the GPS unit in the dorsal area without interfering with movement biomechanics. Data were downloaded and processed using Catapult OpenField software or equivalent. Auxiliary materials included manual stopwatches, measuring tapes, cones, and testing areas marked in accordance with standardized protocols.

Fig. 1. Catapult Vest
(CATAPULT, n.d.)

Applied tests

The testing battery included six standardized physical assessment protocols. The Countermovement Jump (CMJ) was performed through three maximal jumps by each athlete, with 30-second rest intervals between attempts. GPS parameters analysed included vertical acceleration, impulse force, and jump consistency, which are relevant to lower limb explosiveness. The 10–20 m Sprint involved starting from a static position and running distances of 10 and 20 m, measured through both traditional timing and GPS recording. The parameters analysed were maximum speed, initial acceleration, and deceleration at stopping, relevant for short-distance acceleration and speed, typical in handball.

The T-Test for agility consisted of running a T-shaped route, including forward, lateral, and backward movements. GPS recorded multidirectional accelerations and decelerations, as well as neuromuscular load (PlayerLoad), indicators relevant to agility and the ability to change direction rapidly. The Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1) involved repeated 20 m runs with 10-second recovery intervals until exhaustion. Parameters analysed included total distance covered, number of sprints, and effort intensity, relevant for intermittent endurance and recovery capacity.

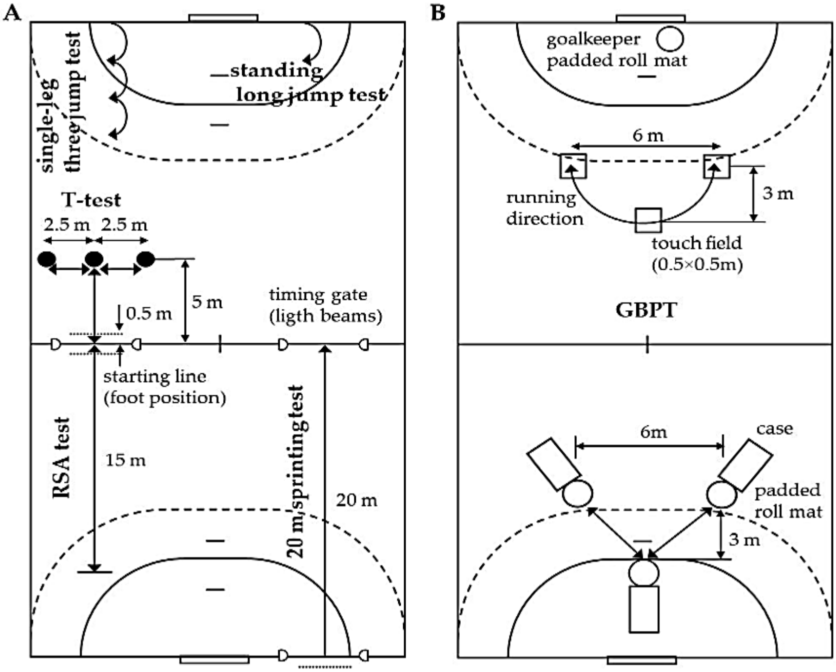

Fig. 2. Battery tests
(Wagner & Hinz, 2023)

The Y-Balance Test required the athlete to maintain balance on one leg while performing reach movements in anterior, posteromedial, and posterolateral directions. GPS recorded accelerometer variations and postural deviations, providing information about functional balance and injury risk. Finally, the Landing Error Scoring System (LESS) involved jumping off a low platform followed by ground landing, with motion recording. Parameters analysed included vertical impact force, lateral accelerations, and PlayerLoad upon landing, indicators relevant to the identification of landing technique deficiencies and the risk of knee and ankle injuries.

Fig. 3. Illinois Agility Test
(Reyes, 2023)

Data collection procedure

The tests were administered in a single session following a standardized 15-minute warm-up. The order of application was: CMJ, Sprint, T-Test, Yo-Yo IR1, Y-Balance, and LESS. The GPS system was activated before the session began and data were downloaded immediately after completion. Each test was performed at least twice, whenever the protocol allowed, to ensure reliability of the results.

Data analysis

Traditional data obtained through manual timing and visual observation were compared with GPS-derived data. The main indicators analysed included maximum speed, accelerations and decelerations, neuromuscular load (PlayerLoad), total distance covered, jump consistency, and balance deviations. Results were reported both individually and collectively in order to highlight overall performance as well as the specific characteristics of each athlete.

All data were processed using descriptive and inferential statistical methods. Descriptive statistics included the calculation of means, standard deviations, minimum and maximum values for all measured variables. Data normality was assessed using the Shapiro–Wilk test. Depending on data distribution, paired-sample t-tests or Wilcoxon signed-rank tests were applied to compare traditional assessment results with GPS-derived measurements.

The relationships between variables were examined using Pearson's or Spearman's correlation coefficients, as appropriate. Effect sizes were calculated to determine the magnitude of observed differences. The level of statistical significance was set at $p < 0.05$.

RESULTS

The application of the six physical tests provided a comprehensive evaluation of the physical preparation level of Junior I female handball players. The integration of GPS technology enabled a more objective and detailed analysis of performance compared to traditional assessment methods.

In the Countermovement Jump (CMJ) test, the mean jump height assessed through classical measurement was **32.4 ± 4.1 cm**. GPS-derived data revealed a mean peak vertical acceleration of **2.85 ± 0.37 g** and a mean PlayerLoad per jump of **0.42 ± 0.06 AU**. Although several athletes presented similar jump heights, GPS analysis identified notable differences in movement consistency, with coefficients of variation ranging from **4.8% to 11.6%** across repeated trials.

For the 10–20 m Sprint test, the average sprint time recorded using manual timing was **3.41 ± 0.18 s**, while GPS analysis indicated a mean maximum speed of **6.72 ± 0.54 m·s^{-1}**. Acceleration profiles showed that **35% of the athletes** achieved peak acceleration within the first 10 m but demonstrated a reduction in speed during the final segment, whereas others maintained a more uniform speed profile throughout the sprint distance.

In the T-Test, the mean completion time measured using traditional methods was **10.12 ± 0.63 s**. GPS data recorded a mean total PlayerLoad of **6.84 ± 1.12 AU**, with high inter-individual variability. Athletes with faster completion times exhibited significantly higher deceleration loads ($p < 0.05$), suggesting increased biomechanical stress despite superior performance outcomes.

During the Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1), the average total distance covered until exhaustion was **1240 ± 280 m**. GPS analysis revealed a mean of **42.6 ± 8.3 high-intensity runs** and a cumulative PlayerLoad of **312 ± 54 AU**. Notably, athletes who covered comparable distances displayed differences of up to **18%** in total neuromuscular load, indicating varying levels of movement efficiency.

In the Y-Balance Test, traditional measurements indicated anterior reach distances of **93.1 ± 6.4%**, **95.7 ± 5.8%**, and **94.3 ± 6.1%** of limb length for the three reach directions. GPS analysis identified center-of-mass deviations exceeding **3.5 cm** in **25% of the athletes**, revealing postural instabilities that were not evident through visual assessment alone.

In the Landing Error Scoring System (LESS), the mean visual score was **4.6 ± 1.3 points**, indicating acceptable landing technique. However, GPS-derived impact data showed peak vertical ground reaction proxies exceeding **5.2 ± 0.7 g** in **30% of the athletes**, suggesting elevated knee joint loading despite favorable visual scores.

Overall, the comparison between traditional and GPS-based assessment methods demonstrated that classical testing provides a general overview of physical performance, while GPS integration allows for a more precise evaluation of biomechanical load, movement quality, and injury-related risk factors. This combined approach enables a multidimensional assessment of athletes, extending beyond basic performance indicators such as time, distance, or jump height.

DISCUSSION

The results obtained from the applied tests confirm that the use of digital technologies, particularly sports GPS systems, provides a significant advantage in the evaluation of Junior I female handball players. Similar findings have been reported in the literature, where GPS-based monitoring has been shown to offer a more comprehensive representation of external load and movement demands compared to traditional assessment methods (Cummins et al., 2013; Akenhead & Nassis, 2016). While classical tests provide essential indicators such as time, distance, or visual scores, GPS technology introduces additional dimensions of interpretation, including accelerations, neuromuscular load (PlayerLoad), effort distribution, and movement quality.

The relevance of these findings for handball is evident, as the sport is characterized by intermittent high-intensity efforts, rapid changes of direction, and complex biomechanical demands. Previous match-analysis studies in female handball players have demonstrated a high frequency of short sprints, accelerations, decelerations, and jumping actions during competition, which are insufficiently captured by traditional evaluation alone (Michalsik & Aagaard, 2015; Póvoas et al., 2012). The present study supports these observations, showing that GPS monitoring allows a more detailed analysis of such sport-specific actions.

An important contribution of GPS technology, also highlighted in previous research, is its capacity to identify inter-individual differences among athletes with similar classical performance outcomes. Buchheit and Simpson (2017) emphasized that athletes with comparable sprint times or distances covered may exhibit substantially different acceleration profiles and mechanical loads. The results of the present study align with these findings, demonstrating that athletes achieving similar sprint performances differed in acceleration efficiency and neuromuscular load, with direct implications for individualized training prescription.

In terms of injury prevention, the present findings are consistent with studies indicating that excessive cumulative load, high deceleration demands, and repetitive impact forces are associated with an increased risk of injury in team sports (Gabbett, 2016; Malone et al., 2017). While traditional methods often fail to detect these risk factors, GPS combined with inertial sensors enables the identification of potentially harmful movement patterns, such as elevated landing impacts or asymmetrical loading, allowing for early preventive interventions.

Another advantage of GPS technology highlighted both in this study and in the literature is the possibility of continuous performance monitoring. Unlike classical testing, which provides isolated assessments at specific time points, GPS allows longitudinal tracking of workload and recovery across training sessions and matches (Impellizzeri et al., 2019). This approach supports better-informed decisions regarding training load management and recovery strategies, particularly in developing athletes.

Despite these advantages, the integration of GPS technology into the training process presents certain challenges. As noted by Bourdon et al. (2017), data interpretation requires specific expertise, and the information obtained must be carefully contextualized within the technical and tactical demands of the sport. Nevertheless, the consistency between the present results and those reported in the literature suggests that the benefits of GPS monitoring in terms of assessment accuracy, individualization, and injury prevention justify its implementation.

Overall, the discussion highlights that the transition from traditional to digital evaluation should not be viewed as a complete replacement of classical methods, but rather as a complementary approach. Traditional tests remain valuable due to their simplicity and accessibility, while GPS technology enhances scientific rigor through objective and multidimensional analysis.

In conclusion, when compared with existing literature, the findings of the present study reinforce the role of GPS technology in improving the physical assessment of Junior I female handball players. The integration of digital monitoring systems contributes to a deeper understanding of individual performance characteristics, a more precise evaluation of movement quality, improved injury prevention strategies, and the development of personalized training programs, thereby supporting long-term athlete development.

CONCLUSIONS

Specific physical preparation in handball for Junior I players proved essential for the development of sports performance, as strength, speed, agility, and endurance parameters influence the transition to senior-level competition. Classical evaluation methods provided a general overview, but they were limited by subjectivity and the lack of biomechanical detail. The integration of digital technologies, such as GPS systems, allowed for an objective and detailed analysis of performance, highlighting significant differences in execution and efficiency even among athletes with similar results obtained through traditional methods. The applied tests covered fundamental physical components for handball: explosiveness, speed, agility, endurance, balance, and biomechanical safety, thus providing a comprehensive tool for optimizing training and preventing injuries.

The integration of GPS technology into the evaluation of Junior I players should complement classical methods, offering coaches a more comprehensive view of athlete performance and allowing for the personalization of training programs according to individual needs, such as adjusting sprint or stability exercises. Monitoring parameters such as PlayerLoad and landing forces contributes to injury prevention through mobility programs, proprioceptive exercises, and corrective techniques. Periodic evaluations, for example on a quarterly basis, allow for tracking progress and adjusting preparation strategies. Furthermore, the integration of GPS technologies in educational and scientific contexts supports coach education and enhances the professional level in youth sport.

AUTHOR CONTRIBUTIONS

Ms. student PhD. Roxana-Nicoleta POPA, Mr. student PhD. Alex-Paul SECIU, Mr Prof. PhD. Virgil ENE-VOICULESCU and Ms Prof. PhD. Carmen ENE-VOICULESCU contributed in equal measure to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript. All authors have read and agreed to the published version of the manuscript.

CONFLICT OF INTEREST

The author declares that there is no conflict of interest regarding the publication of this doctoral report.

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