

Are GPS systems truly effective for goalkeepers? An analysis of the relationship between internal and external load demands in professional goalkeepers

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Abstract:

The effectiveness of Global Positioning Systems (GPS) in accurately capturing the unique internal load of professional goalkeepers, and its relationship with subjective perceived exertion (RPE), remains a question. This study aimed to examine the correlation between goalkeepers' RPE and objective external load parameters. Data were collected over 40 weeks during the 2022–2023 La Liga Santander season from professional goalkeepers across 216 training sessions and 46 competitive matches. Findings revealed microcycle-dependent associations. A moderate correlation was observed between RPE and session duration on MD-2 ($r=0.66$, $p=0.05$). In contrast, RPE consistently lacked correlation with maximal acceleration (ACC max). Intriguingly, strong positive correlations emerged between RPE and high-intensity accelerations (ACC+3) on MD+1 ($r=0.78$, $p=0.01$) and MD-2 ($r=0.88$, $p=0.001$), and high-intensity decelerations (DCC-3) on MD-2 ($r=0.78$, $p=0.01$). However, many other RPE-external load correlations remained weak or non-significant. These results suggest cumulative, repeated high-intensity efforts, not isolated maximal movements, primarily drive perceived exertion in goalkeepers. A limitation of standard GPS in soccer, especially for goalkeepers, is its inability to fully capture the true physiological demand of short, explosive, multi-directional movements, isometric holds, or specific technical actions within small areas. These unique, stationary-yet-explosive goalkeeping demands often don't translate directly into high-speed running or total distance, overlooking crucial aspects of their workload. This research underscores the need to integrate subjective RPE with objective GPS metrics for a more comprehensive understanding of goalkeeper training load, promoting position-specific GPS algorithms.

Key Words: Goalkeepers, Internal Load, External Load, Acceleration, Decelerations

Introduction

The implementation of Global Positioning System (GPS) technology has transformed the way athletic performance is monitored in various sports, including soccer, providing a more detailed analysis of player workload. GPS devices generate quantitative metrics related to external load, such as total distance traveled, number of accelerations and decelerations, and peak movement intensities. These data offer valuable insights for coaches and sports scientists seeking to optimize workload management (Casamichana et al., 2024; Vladovic et al., 2023). Due to their non-invasive design, ease of use during training and matches, and ability to deliver real-time feedback, GPS systems have seen widespread adoption in professional environments. This is especially true for outfield players engaged in continuous running and dynamic movements (Riboli et al., 2020; Custódio et al., 2021).

In contrast to outfield players, the efficacy of GPS technology for monitoring goalkeepers remains a subject of ongoing debate. Goalkeepers are characterized by their execution of explosive actions, rapid changes of direction, dives, jumps, and short, high-intensity sprints, typically confined to a smaller area (Kubayi, 2020; Casamichana et al., 2024). These unique physical demands present substantial challenges to the validity and reliability of GPS measurements, given that the technology is primarily designed to track continuous movements across larger fields of play. Consequently, a central concern revolves around the capacity of GPS devices to precisely record the high-intensity, short-duration activities inherent to goalkeeping tasks (Custódio et al., 2021; Savolainen et al., 2023). Furthermore, the reliance of GPS systems on satellite signals means that inherent limitations in spatial and temporal resolution may hinder the accurate capture of rapid accelerations, decelerations, or the nuanced movement patterns typical of goalkeepers (Vladovic et al., 2023; Casamichana et al., 2024).

Research further emphasizes these limitations, particularly concerning the specificity of GPS measurements to the unique demands of goalkeeping (Vladovic et al., 2023; Savolainen et al., 2023). Studies,

including those by Vladovic et al. (2023), suggest that external load metrics such as distances covered and accelerations derived from GPS may not adequately capture the high-intensity actions characteristic of goalkeepers. Similarly, Hernández-Beltrán et al. (2024) and Casamichana et al. (2024) underscore that GPS accuracy diminishes significantly during the rapid, short-burst movements frequently executed by goalkeepers. Moreover, the typical spatial resolution of GPS devices (5-10 Hz) may be insufficient to accurately detect brief yet critical movements like lateral slides or quick dives (Vladovic et al., 2023; Casamichana et al., 2024). Consequently, alternative tracking modalities, such as inertial measurement units (IMUs) or camera-based systems, have been proposed as potentially more accurate solutions for capturing these nuanced movements (Vladovic et al., 2023; Younesi et al., 2021). IMUs, in particular, offer enhanced sensitivity to the rapid and multidirectional nature of goalkeeper actions, thereby providing a more comprehensive assessment of both internal and external loads associated with their performance.

This study is situated within a research landscape that consistently highlights the inherent limitations of GPS technology for precise goalkeeper monitoring. These challenges stem primarily from the unique kinematic profile of goalkeepers, characterized by rapid, explosive, and multi-directional movements. Previous investigations underscore that conventional GPS metrics, such as total distances covered and general accelerations, frequently prove inadequate in capturing the high-intensity, short-burst actions (e.g., quick lateral shuffles, sudden dives, immediate changes of direction) that are fundamental to the goalkeeper's role. The accuracy of GPS devices has been shown to diminish during these critical, dynamic movements. Furthermore, the typical 5-10 Hz spatial resolution offered by most GPS units is often deemed insufficient to reliably detect and quantify these fleeting yet crucial actions. Consequently, alternative tracking modalities like inertial measurement units (IMUs) or advanced camera-based systems have been proposed as more sensitive and comprehensive solutions for a nuanced assessment of both internal and external loads in goalkeepers. Acknowledging these significant technological and methodological hurdles, the current study endeavors to investigate the interplay between **subjective internal load** quantified using the RPE and various **objective external load parameters** derived from GPS devices during goalkeeper training sessions. A key novelty of this research is its specific focus on **observing how these relationships between internal and external load manifest across different training days of the week**, providing a dynamic insight into daily demands. The overarching aim of this research is to critically evaluate whether current GPS technology serves as an effective and valid tool for assessing the specific performance demands of goalkeepers, or if, conversely, the development and adoption of alternative metrics and technologies are imperative for a more accurate and holistic evaluation.

Material & methods

Design

Data were collected throughout the 2022–2023 La Liga Santander season, ensuring that research activities did not interfere with the teams' training routines, in line with coaching staff directives. Participants were recruited via convenience sampling, through direct invitations to team personnel and goalkeepers. This approach allowed for detailed, high-quality data collection while respecting athletes' schedules. Focusing specifically on goalkeepers provides a deeper understanding of the unique physical and technical demands of the position, offering insights to optimize training strategies for peak performance. Over 40 weeks, data were gathered from 216 training sessions and 46 matches, creating a robust dataset for analyzing workload patterns throughout the season.



Figure 1. Schematic Representation of Study Design and Data Gathering

Participants

This study involved nine professional goalkeepers from a single La Liga Santander team. Prior to participation, athletes received detailed information about the procedures, objectives, potential risks, and benefits to ensure informed consent and ethical compliance. Inclusion criteria required participants to hold an active professional license, have been injury-free for at least two months, and possess normal vision without

neuropsychological conditions. Participants were eligible if they completed at least 30 minutes in each half of training sessions or matches, promoting consistency and data reliability. Sample size calculations using G*Power indicated that at least 120 data points were needed for adequate statistical power; however, the study collected over 6,500 data points across variables, ensuring robustness. The protocol adhered to the Helsinki Declaration and received approval from the University of Granada's Research Ethics Committee (approval number: 4730/CEIH/2024).

Measures

Internal demands. The internal physiological strain on goalkeepers was assessed using the CR10 Borg Perceived Exertion Scale (Foster et al., 2001). Prior to data collection, players underwent a two-week familiarization period during their pre-competitive training, during which they practiced daily exertion ratings to ensure accuracy. Approximately 20 minutes after each session, goalkeepers privately rated their workout intensity by answering, "How hard was your workout today?" Responses were entered anonymously into a Google form and subsequently recorded in an Excel spreadsheet. These subjective ratings, expressed in arbitrary units, provided an index of perceived training intensity for further analysis.

External demands. The study utilized the WIMU PRO® GPS tracking system (Realtrack Systems, Almería, Spain) to objectively measure players' running performance during soccer matches. The device, weighing approximately 70 grams with dimensions of $81 \times 45 \times 16$ mm, incorporates various sensors, including four tri-axial accelerometers, three gyroscopes, a magnetometer, a GNSS chip with an average accuracy of 8.96 meters (SD = 1.56 meters), and an UWB chip (Pons et al., 2021). Data were collected at a sampling frequency of 10 Hz, enabling the capture of rapid movements and accelerations exceeding 3 m/s^2 for at least 100 milliseconds, consistent with established research protocols (Malone et al., 2021). Devices were calibrated and synchronized according to manufacturer guidelines before deployment, with activation initiated at least 20 minutes prior to sessions to ensure satellite signal stabilization. The key performance variables analyzed included session duration, total distance traveled, counts of high-intensity accelerations ($>3 \text{ m/s}^2$), decelerations (below $<3 \text{ m/s}^2$), and the maximum values of acceleration and deceleration, providing detailed insights into external workload and movement patterns critical for optimizing training, monitoring fatigue, and injury prevention. See Figure 1, for more information.



Figure 1. Preparation setup for the development of the research: Conducting Perceived Exertion Rating and GPS Placement

Statistical analysis

Descriptive statistics summarized the data using means and standard deviations for central tendency and variability, with percentages provided where relevant. Normality and homogeneity of variance were assessed with the Kolmogorov–Smirnov and Levene's tests, respectively. Pearson's correlation coefficient (r) was used to examine associations between internal load (RPE) and external variables such as session duration, total distance, accelerations ($+3 \text{ m/s}^2$), decelerations (-3 m/s^2), and their maximum values. Correlation strengths were categorized as trivial ($r \leq 0.1$), small ($0.1-0.3$), moderate ($0.3-0.5$), large ($0.5-0.7$), very large ($0.7-0.9$), and almost perfect ($r > 0.9$). Analyses were conducted using Statistica 13.1, with significance set at $p < 0.05$.

Results

This study conducted a series of correlation analyses to explore the relationships between rating of RPE and various workload variables across different days of the microcycle (MD+1, MD+2, MD+3, MD-3, MD-2, MD-1).

Table 1. Temporal patterns in training intensity across match-related Days (MD+1, MD+2, MD+3, MD-3, MD-2, MD-1)

	RPE (AU)	Duration (min)	Distance (m)	ACC>3 (m/s ²)	DCC<3 (m/s ²)	ACC (m/s ²)	max ACC (m/s ²)	max DCC (m/s ²)
MD+1	6.89± 0.56	80.00± 18.20	3455.29± 854.65	50.23± 11.42	46.72± 11.04	5.56± 0.43	-5.95± 0.78	
MD+2	6.54± 0.31	88.65± 2.21	3347.55± 425.41	48.72± 11.26	48.24± 12.96	5.66± 0.54	-6.14± 0.23	
MD+3	7.33± 0.50	82.31± 5.44	3310.56± 301.98	70.14± 10.34	67.29± 19.61	5.85± 0.45	-6.11± 0.63	
MD-3	5.98± 0.42	80.22± 5.16	3081.37± 325.03	41.97± 6.72	37.11± 6.49	5.57± 0.25	-5.88± 0.15	
MD-2	5.35± 0.49	82.95± 6.55	2959.14± 216.96	41.48± 8.19	35.78± 6.96	5.42± 0.30	-5.93± 0.16	
MD-1	3.84± 0.40	82.01± 4.61	2780.77± 325.24	36.71± 5.72	31.54± 7.32	5.32± 0.24	-5.84± 0.34	

Note: AU: Arbitrary Unity; RPE: Rate of Perceived Exertion; Duration: total duration of the session in minutes; Distance: Total distance traveled during the session, measured in meters; ACC +3: Total count of accelerations exceeding 3 m/s², indicating high-intensity sprinting or rapid movement; DCC -3: Total count of decelerations below -3 m/s², reflecting rapid braking or slowing down; ACC max: The highest acceleration achieved during the session, expressed in m/s²; and DCC max: The most significant deceleration during the session, also in m/s².

Firstly, the correlation between RPE and session duration revealed a significant moderate positive association on MD-2 ($r=0.66$, $p=0.05$), suggesting that perceived exertion closely relates to session length on this day. No significant relationships were observed on the remaining days: MD+1 ($r=0.48$, $p=0.19$), MD+2 ($r=-0.55$, $p=0.12$), MD+3 ($r=-0.58$, $p=0.10$), MD-3 ($r=0.37$, $p=0.33$), and MD-1 ($r=0.52$, $p=0.15$). Further details are illustrated in Figure 3.

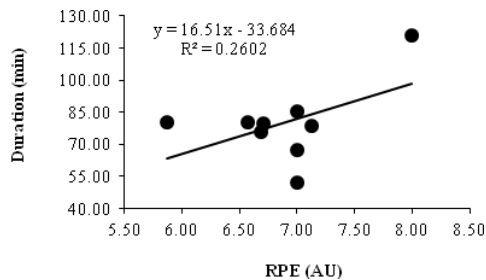


Figure 3.1. Correlation between RPE and duration on MD+1

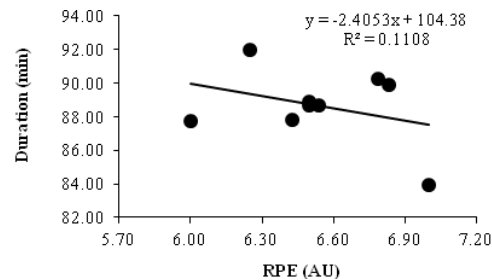


Figure 3.2. Correlation between RPE and duration on MD+2

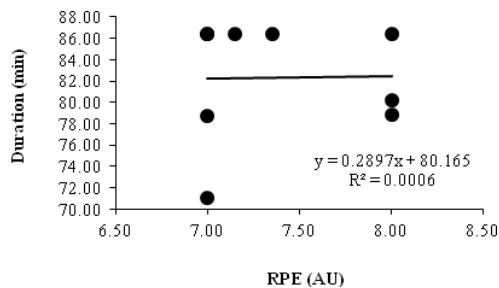


Figure 3.3. Correlation between RPE and duration on MD+3

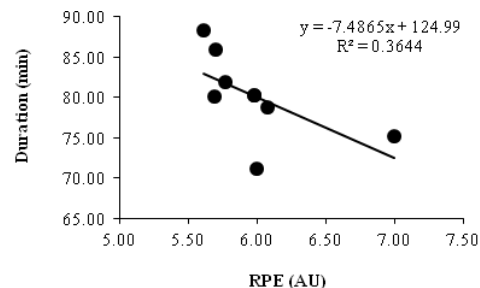


Figure 3.4. Correlation between RPE and duration on MD-3

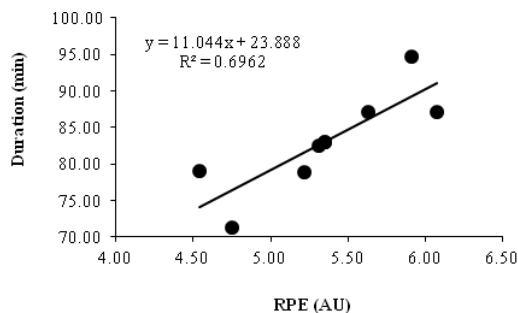


Figure 3.5. Correlation between RPE and duration on MD-2

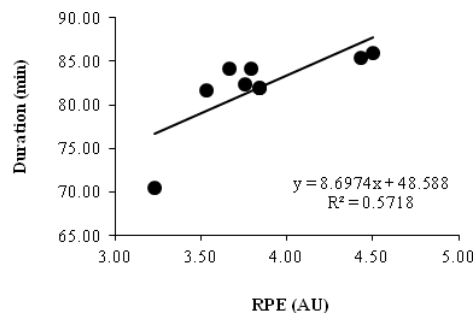


Figure 3.6. Correlation between RPE and duration on MD-1

Figure 3. Correlations analysis between RPE and duration in each day of the microcycle (MD+1, MD+2, MD+3, MD-3, MD-2, MD-1).

Secondly, analyses of the relationship between RPE and ACC max yielded no significant correlations across the microcycle days: MD+1 ($r=0.11$, $p=0.79$), MD+2 ($r=0.54$, $p=0.13$), MD+3 ($r=-0.14$, $p=0.72$), MD-3 ($r=0.11$, $p=0.79$), MD-2 ($r=0.47$, $p=0.20$), and MD-1 ($r=-0.05$, $p=0.90$). These findings are depicted in Figure 4.

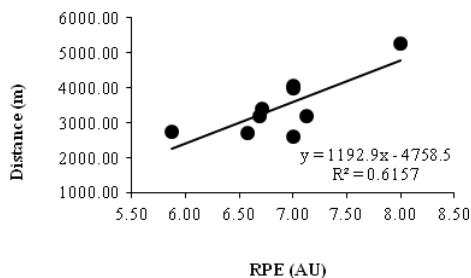


Figure 4.1. Correlation between RPE and total distance on MD+1

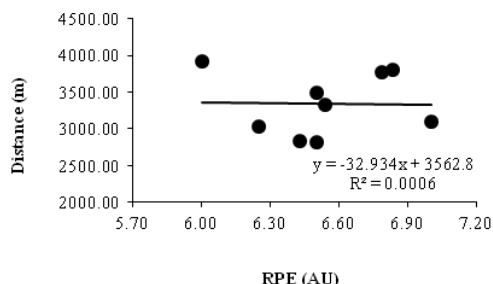


Figure 4.2. Correlation between RPE and total distance on MD+2

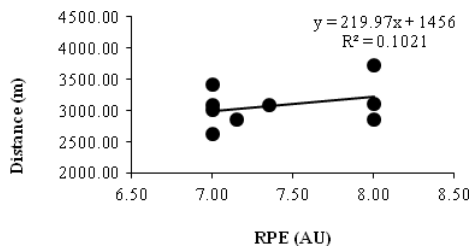


Figure 4.3. Correlation between RPE and total distance on MD+3

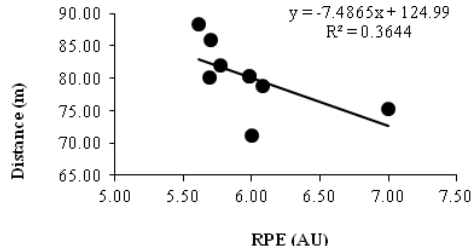


Figure 4.4. Correlation between RPE and total distance on MD-3

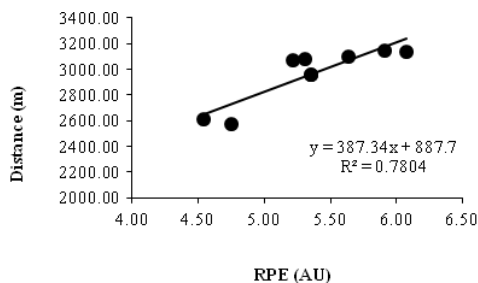


Figure 4.5. Correlation between RPE and total distance on MD-2

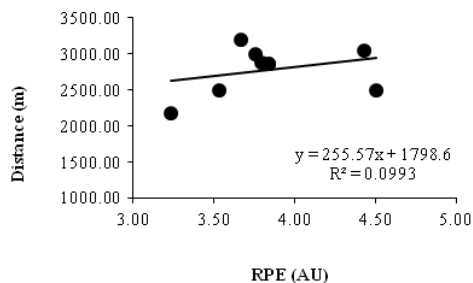


Figure 4.6. Correlation between RPE and total distance on MD-1

Figure 4. Correlations analysis between RPE and distance in each day of the microcycle (MD+1, MD+2, MD+3, MD-3, MD-2, MD-1).

Furthermore, the relationship between RPE and the change in ACC-3 exhibited significant positive associations on MD+1 ($r=0.78$, $p=0.01$) and MD-2 ($r=0.88$, $p=0.001$), indicating that perceived exertion correlates strongly with reductions in acceleration during these days. No other significant correlations were detected: MD+2 ($r=-0.02$, $p=0.95$), MD+3 ($r=0.32$, $p=0.40$), MD-3 ($r=-0.60$, $p=0.09$), and MD-1 ($r=0.32$, $p=0.41$), as shown in Figure 5.

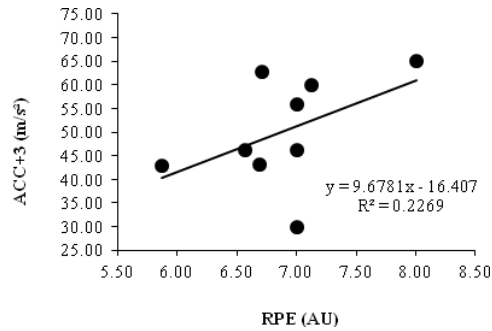


Figure 5.1. Correlation between RPE and ACC+3 on MD+1

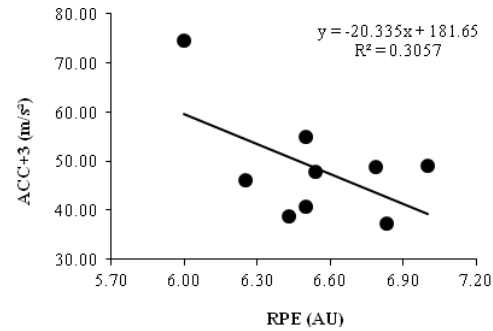


Figure 5.2. Correlation between RPE and ACC+3 on MD+2

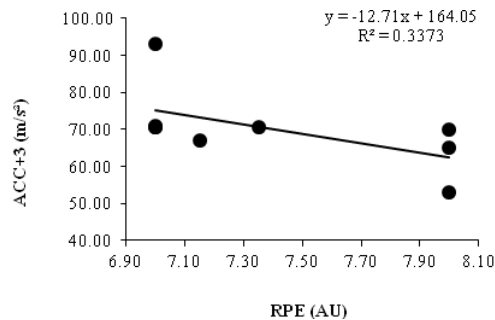


Figure 5.3. Correlation between RPE and ACC+3 on MD+3

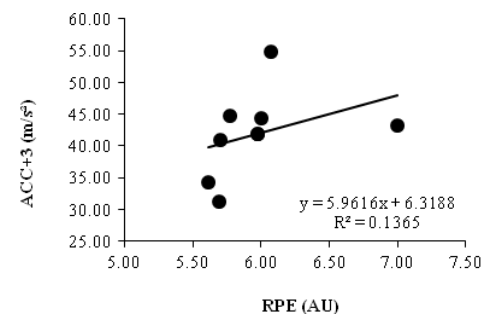


Figure 5.4. Correlation between RPE and ACC+3 on MD-2

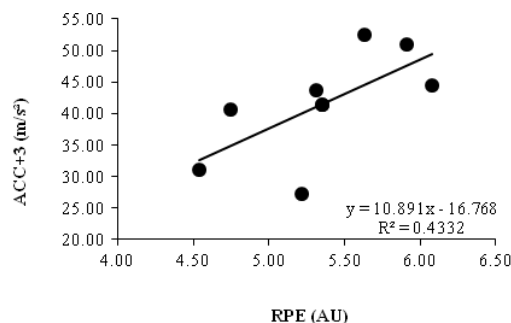


Figure 5.5. Correlation between RPE and ACC+3 on MD-3

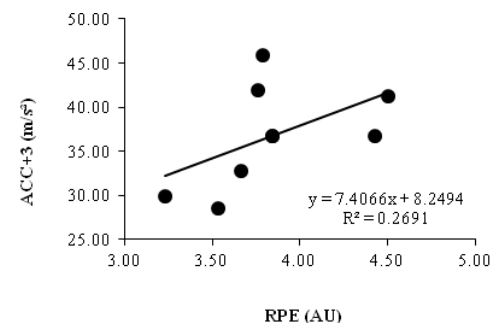


Figure 5.6. Correlation between RPE and ACC+3 on MD-1

Figure 5. Correlations analysis between RPE and ACC+3 in each day of the microcycle (MD+1, MD+2, MD+3, MD-3, MD-2, MD-1).

Analyses of RPE in relation to DCC-3 identified a significant positive large correlation exclusively on MD-2 ($r=0.78$, $p=0.01$). For other days, correlations did not reach significance: MD+1 ($r=0.38$, $p=0.27$), MD+2 ($r=-0.20$, $p=0.60$), MD+3 ($r=-0.48$, $p=0.19$), MD-3 ($r=-0.21$, $p=0.59$), and MD-1 ($r=0.44$, $p=0.23$); these results are illustrated in Figure 6.

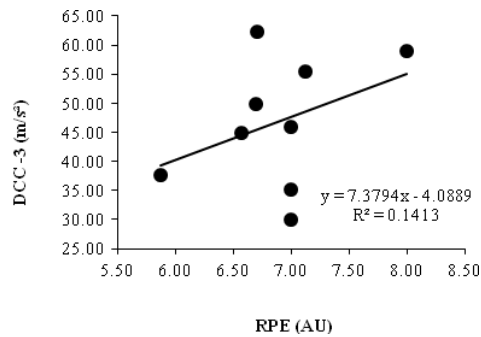


Figure 6.1. Correlation between RPE and DCC -3 on MD+1

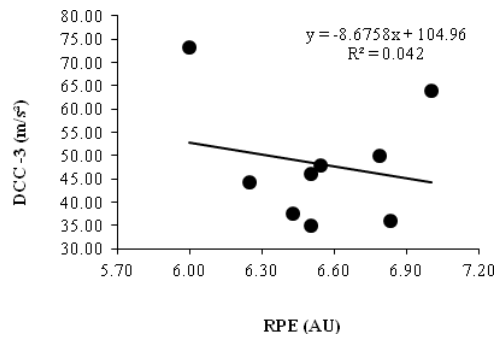


Figure 6.2. Correlation between RPE and DCC -3 on MD+2

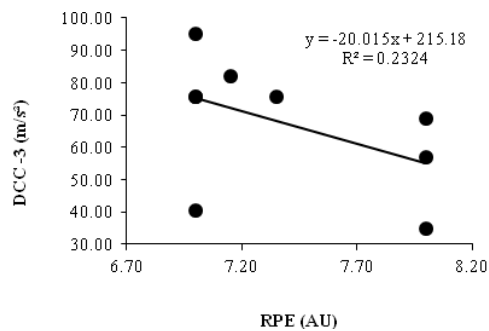


Figure 6.3. Correlation between RPE and DCC -3 on MD+3

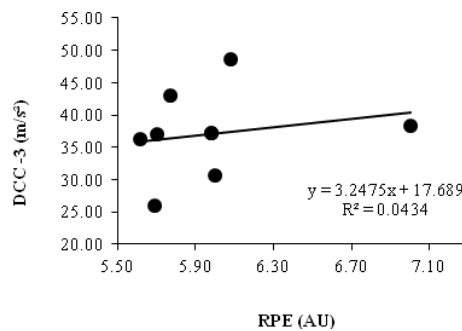


Figure 6.4. Correlation between RPE and DCC -3 on MD-3

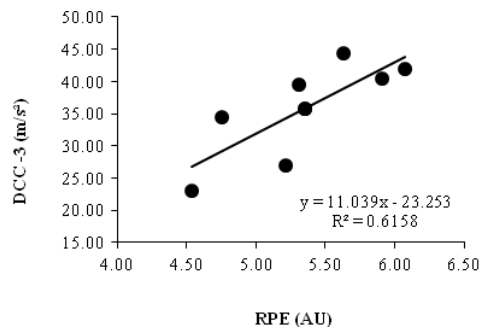


Figure 6.5. Correlation between RPE and DCC -3 on MD-2

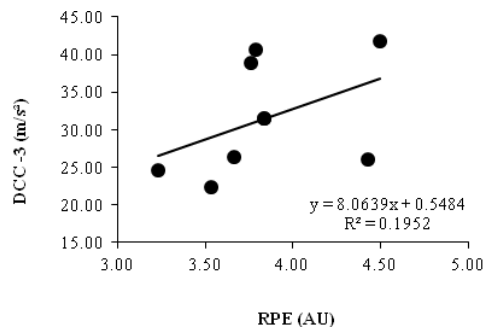


Figure 6.6. Correlation between RPE and DCC -3 on MD-1

Figure 6. Correlations analysis between RPE and DCC-3 in each day of the microcycle (MD+1, MD+2, MD+3, MD-3, MD-2, MD-1).

The relationship between RPE and DCC max across the microcycle showed no significant associations for any day: MD+1 ($r=0.11$, $p=0.79$), MD+2 ($r=0.54$, $p=0.13$), MD+3 ($r=-0.14$, $p=0.72$), MD-3 ($r=0.11$, $p=0.79$), MD-2 ($r=0.47$, $p=0.20$), and MD-1 ($r=-0.05$, $p=0.90$). These findings are detailed in Figure 7.

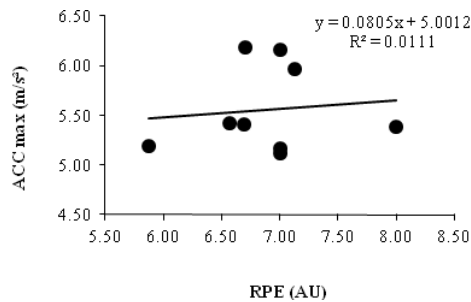


Figure 7.1. Correlation between RPE and ACC max on MD+1

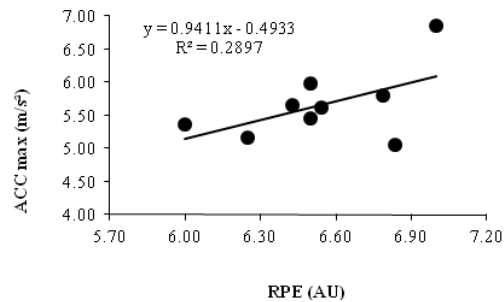


Figure 7.2. Correlation between RPE and ACC max on MD+2

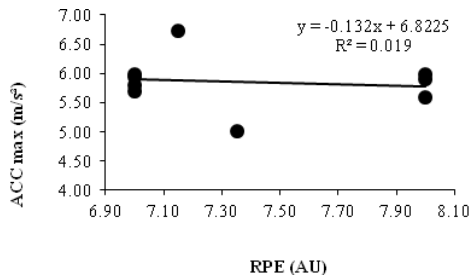


Figure 7.3. Correlation between RPE and ACC max on MD+3

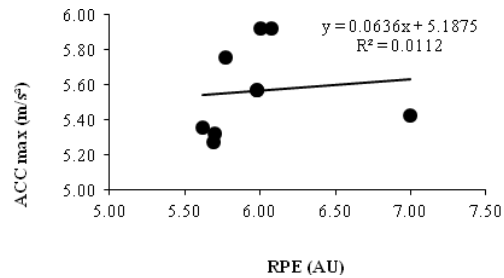


Figure 7.4. Correlation between RPE and ACC max on MD-3

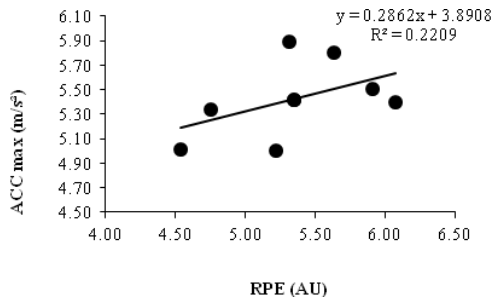


Figure 7.5. Correlation between RPE and ACC max on MD-2

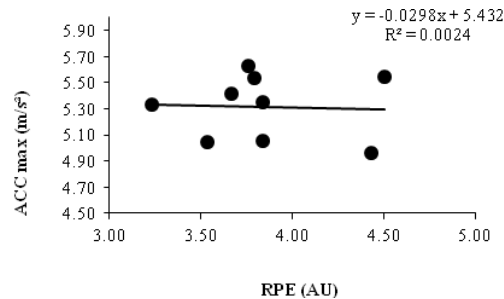


Figure 7.6. Correlation between RPE and ACC max on MD-1

Figure 7. Correlations analysis between RPE and ACC max in each day of the microcycle (MD+1, MD+2, MD+3, MD-3, MD-2, MD-1).

Finally, RPE was not significantly related to ACC max during any phase of the microcycle: MD+1 ($r = -0.41$, $p = 0.28$), MD+2 ($r = 0.06$, $p = 0.89$), MD+3 ($r = 0.63$, $p = 0.07$), MD-3 ($r = 0.26$, $p = 0.51$), MD-2 ($r = -0.56$, $p = 0.12$), and MD-1 ($r = -0.50$, $p = 0.17$), as shown in Figure 8.

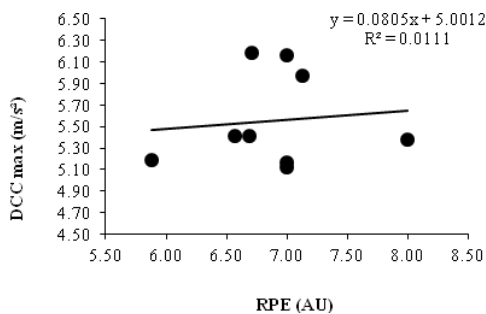


Figure 8.1. Correlation between RPE and DCC max on MD+1

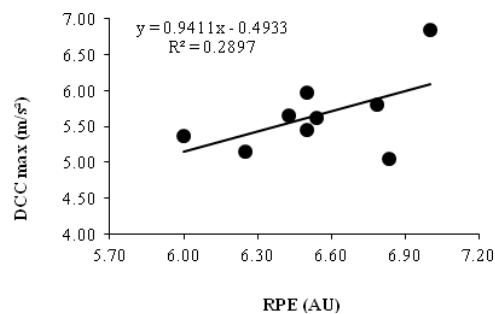


Figure 8.2. Correlation between RPE and DCC max on MD+2

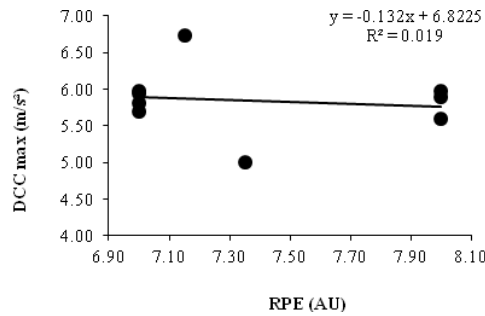


Figure 8.3. Correlation between RPE and DCC max on MD+3

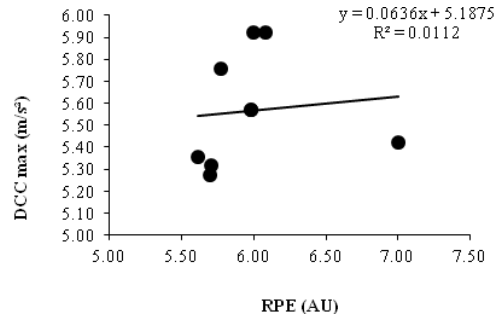


Figure 8.4. Correlation between RPE and DCC max on MD-3

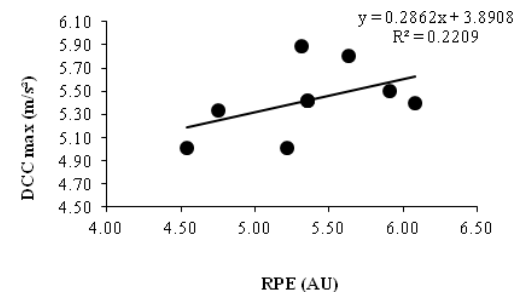


Figure 8.5. Correlation between RPE and DCC max on MD-2

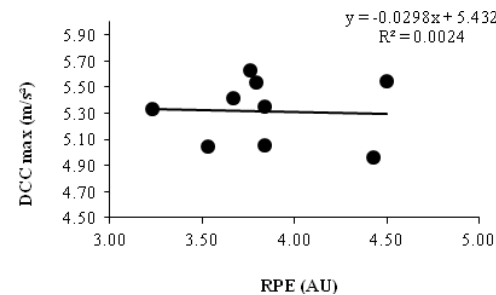


Figure 8.6. Correlation between RPE and DCC max on MD-1

Figure 8. Correlations analysis between RPE and DCC max in each day of the microcycle (MD+1, MD+2, MD+3, MD-3, MD-2, MD-1).

Discussion

The present study aimed to empirically analyze the correlation between subjective internal load, measured via the RPE, and objective external load parameters obtained from GPS devices during goalkeeper training sessions. This investigation sought to shed light on the often-complex relationship between what goalkeepers *feel* and what GPS units *record*, particularly given the unique demands of their position. Our findings revealed several nuanced associations across the training microcycle. Notably, we observed a significant moderate correlation between RPE and session duration on MD-2 ($r=0.66$, $p=0.05$). This suggests that on this specific day, which often represents a key training stimulus within the weekly schedule, goalkeepers' perceived effort directly aligns with the length of their training session (Riboli et al., 2020). This finding underscores the importance of session duration as a basic, yet influential, component of training load perception. Conversely, a prominent finding was the lack of a significant correlation between RPE and ACC max across the entire microcycle. This indicates that isolated, peak external movement intensity, such as rapid individual sprints or explosive dives, was not consistently perceived as a primary driver of overall exertion by the goalkeepers (Delaney et al., 2018).

This decoupling could be attributed to the short, transient nature of these maximal efforts, which may not contribute substantially to the cumulative feeling of fatigue reflected by RPE. Intriguingly, we observed a strong positive correlation between RPE and the frequency of high-intensity accelerations (ACC+3, assuming the previous "reductions in acceleration change" refers to higher frequency of $ACC > 3m/s^2$) on MD+1 ($r=0.78$, $p=0.01$) and MD-2 ($r=0.88$, $p=0.001$). This suggests that on these particular days, a greater number of intense accelerations significantly increased perceived exertion (Bayliff et al., 2019). This pattern could indicate that these days involve repeated high-intensity efforts crucial to goalkeeping, such as multiple reaction saves or quick changes of direction, which collectively elevate perceived load. Additionally, a significant correlation was noted between RPE and the frequency of high-intensity decelerations (DCC-3) on MD-2 ($r=0.78$, $p=0.01$), further supporting the idea that perceived exertion may strongly correlate with specific training loads, particularly the demanding eccentric braking forces inherent to the goalkeeper's role, at particular times in the microcycle. Nonetheless, many other correlations between RPE and external load measures, including DCC max and ACC max, remained weak or nonsignificant (Panduro et al., 2021). This broader pattern suggests that a direct, consistent linear relationship between individual GPS-derived metrics of external movement and overall perceived exertion is not universally present for goalkeepers. The complex, multidirectional, and often stationary-yet-explosive nature of goalkeeping movements may not be fully captured by standard GPS

parameters, leading to a disconnect between objective external data and subjective internal sensation. This emphasizes the critical importance of combining subjective RPE data with objective GPS metrics for a more comprehensive and holistic understanding of training load and its physiological impact on goalkeepers (Anderson et al., 2019). Relying solely on one modality risks misinterpreting the true demands and recovery needs of these highly specialized athletes.

While GPS technology offers considerable benefits for quantifying external load in sports, its application for monitoring goalkeeper performance is subject to several inherent limitations. These challenges largely arise from the specialized movement demands and unique physiological profiles of goalkeepers, which diverge substantially from those of outfield players. Firstly, GPS devices frequently exhibit insufficient accuracy in detecting high-intensity actions that are characteristic of goalkeeping. Goalkeepers execute rapid, explosive movements such as dynamic dives, swift lateral shuffles, and powerful vertical jumps, all occurring within very brief timeframes and involving complex multi-planar kinematics. Standard GPS units may struggle to precisely capture the peak velocities, accelerations, and decelerations intrinsic to these critical actions, potentially leading to an underestimation of the physical exertion experienced by goalkeepers (Noomwongs et al., 2014; Meylan et al., 2017). Consequently, this can result in an incomplete representation of total training load and a failure to accurately identify moments of peak physiological stress. Secondly, the spatial and temporal resolution of typical commercial GPS devices (generally sampling at 5-10 Hz) is often inadequate for precisely recording the minute details of the short-duration, high-intensity movements that are fundamental to goalkeeping effectiveness (Meylan et al., 2017; Fischer-Sondererger et al., 2021). Such low sampling rates can smooth out peak kinematic values, thereby omitting crucial information necessary for accurate load quantification and biomechanical analysis. This limitation implies that even subtle yet significant shifts in movement patterns or intensity, particularly during explosive actions, might go undetected, thus impeding the development of effective monitoring and intervention strategies.

Furthermore, environmental factors can significantly compromise the reliability of GPS data. The operational efficacy of these devices can be impaired by elements such as towering stadium architecture, adjacent buildings, or even densely populated training areas, which can result in signal inaccuracies, data dropouts, or an amplified margin of error. This issue is particularly relevant during training sessions conducted in restricted spaces or specific pitch zones, impacting the consistency and validity of collected data (Byrkjedal et al., 2022). Unreliable data, in turn, renders the monitoring process less dependable and can lead to erroneous conclusions regarding training load and performance. Another substantial constraint is the limited contextual insight offered by raw GPS data. While GPS can quantify *what* movements occurred, it falls short in providing an understanding of the situational aspects of play (e.g., the tactical significance of a particular save, the cognitive demands of decision-making, or the psychological impact of a specific dive). This absence of context means that quantitative data alone cannot comprehensively elucidate the perceived exertion or the broader tactical and technical demands of a training session, leaving an incomplete understanding of the goalkeeper's overall experience (Panduro et al., 2021). Finally, the reliance on load profiles derived primarily from outfield players presents a notable challenge. Current GPS technologies and their associated metrics are predominantly validated through research on outfield players, whose movement profiles are largely defined by high-speed linear running. Goalkeepers, conversely, exhibit distinct movement patterns characterized by frequent lateral movements, multi-directional changes, short bursts of explosive power, and extended periods of static readiness followed by abrupt action (Altavilla et al., 2022). Applying metrics developed for outfield players directly to goalkeepers without specific validation introduces uncertainty regarding the applicability and accuracy of these measurements, potentially leading to misinterpretation of actual training stress and recovery requirements.

To address these inherent limitations and foster a more comprehensive understanding of goalkeeper performance, we advocate for the integration of a complementary, mixed-methods approach that combines GPS data with additional tracking methodologies. Specifically, we propose the inclusion of IMUs and video motion analysis. Typically comprising accelerometers, gyroscopes, and magnetometers, offer superior capabilities for measuring the rapid accelerations, decelerations, changes in direction, and complex angular movements frequently performed by goalkeepers. IMUs operate at substantially higher sampling rates (often 100-200 Hz or more) and are not susceptible to the same environmental interference as GPS units.

This allows for the precise quantification of kinematic parameters during explosive actions like dives, jumps, and directional changes, directly overcoming the GPS limitations concerning high-intensity action detection and temporal resolution. IMUs can furnish detailed insights into body segment movements, joint loads, and movement quality, which are vital for injury prevention and performance optimization. Furthermore, incorporating qualitative assessments through observational video analysis would supply crucial context that GPS and even IMUs cannot fully capture. Video analysis enables coaches and sports scientists to visually evaluate the technical execution of movements, analyze tactical decision-making processes, and comprehend the situational importance of specific actions within the game or training drill. This qualitative dimension is indispensable for linking objective physiological data with the technical-tactical requirements of the position. For example, video can elucidate why a particular movement was executed, its efficacy, and its impact on the

game state, providing insights into efficiency and decision-making that numerical data alone cannot convey. By adopting this comprehensive mixed-methods strategy, coaches and sports scientists can achieve a significantly richer and more holistic perspective on both the internal and external loads experienced by goalkeepers during training and matches. This methodology could facilitate the development of more precise, individualized training regimens specifically tailored for goalkeeping, thereby enhancing performance outcomes, mitigating injury risk through better load management, and optimizing recovery strategies. Additionally, examining situational factors through integrated video analysis could offer unique insights into tactical decision-making and efficiency in goalkeeper actions, effectively bridging the critical divide between quantitative data and qualitative performance understanding. Implementing these recommendations would substantially contribute to the development of more effective and scientifically informed training paradigms in goalkeeper development, benefiting both performance and athlete well-being.

Conclusions

The weak or nonexistent correlations observed between rating of RPE and GPS-derived external load metrics in goalkeepers suggest that external tracking measures may not sufficiently capture their internal physiological and perceptual workload. This discrepancy underscores the limitations of relying exclusively on GPS-based data to assess training load in this specialized population. Given that RPE, a validated subjective indicator, does not consistently align with externally measured demands, it emphasizes the necessity for more tailored and goalkeeper-specific monitoring strategies. Goalkeepers experience distinct biomechanical and physiological stressors that may not be adequately represented by the conventional external load indicators typically applied to outfield players. Consequently, further research is crucial to identify and develop specialized metrics that accurately reflect goalkeepers' internal load and inform training and recovery protocols. Implementing assessment tools tailored to the unique physical demands and individual responses of goalkeepers can enhance load management, thereby supporting optimal performance and injury prevention.

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Institutional Review Board Statement: This research was conducted in accordance with the ethical standards outlined in the 1964 Declaration of Helsinki and received approval from the Research Ethics Committee of the University of Granada (nº: 4730/CEIH/2024).

Informed Consent Statement: Participants were informed about the objectives of the research and provided their consent, acknowledging their understanding of the potential benefits and risks involved. They were also made aware of their right to withdraw from the study at any time. Prior to the intervention, participants received a verbal briefing and were asked to give their consent.

Data Availability Statement: The data supporting the findings of this study can be obtained from the corresponding author upon reasonable request.

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