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The Effectiveness of GPS Trackers in Mapping Futsal Athletes' Movement Patterns as a Muscle Injury Prevention Strategy

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Abstract

Futsal is a high-intensity sport characterized by frequent accelerations, sudden changes in direction, and limited playing space, which places athletes especially at the amateur level at increased risk of muscle injuries. This study explores the application of GPS tracker technology to map player movement patterns and analyze their relationship with muscle injury risk in amateur futsal athletes. A total of 10 amateur male players aged 18–25 participated in this four-week quasi-experimental study. Data was collected during training and match sessions using wearable GPS devices that recorded key metrics such as distance travelled, movement speed, acceleration, and positional heatmaps. Initial analysis revealed a concentration of player movement in the central and right-wing areas of the pitch, likely due to tactical preferences and dominant-foot usage. Based on this movement mapping, a targeted intervention program was developed, including muscle strengthening, active recovery protocols, and individualized load management. Comparative analysis between Week 1 and Week 4 showed significant improvements across physical performance parameters: total distance (+11.38%), maximum speed (+7.94%), average speed (+5.10%), and high-intensity accelerations (+33.33%). Recovery time also decreased by 21.43%, suggesting enhanced adaptation and resilience. The findings emphasize the potential of GPS-based monitoring not only for performance evaluation but also as a strategic tool for injury prevention. By identifying high-load zones and tailoring training to individual profiles, coaches can implement more effective conditioning and rotation strategies. This study supports the integration of GPS technology in amateur-level training environments to improve both performance outcomes and athlete safety.

Keywords: GPS tracker, futsal, injury prevention, movement pattern, physical performance

1. Introduction

Futsal is a team sport that requires high physical intensity, characterized by fast-paced play, confined spaces, and frequent changes of direction. This combination makes futsal players susceptible to injuries, particularly muscle injuries such as hamstring, calf, and hamstring injuries (Al-Muimin, 2024). These injuries generally occur due to accumulated muscle fatigue, explosive movements, and lack of adequate recovery. Therefore, early detection of potential injury risks is crucial for maintaining athlete performance and training continuity, even at the amateur level (Oliveira et al., 2025).

In recent years, advances in sports technology have provided various innovative solutions for monitoring athlete performance and physical condition. One of the most prominent technologies is the use of Global Positioning System (GPS) trackers. This technology allows coaches and medical teams to monitor athletes' movements in real time, including key parameters such as distance traveled, running speed, acceleration and deceleration, and intensity zones during matches and training sessions (Seçkin et al., 2023; De Fazio et al., 2023).

At the professional level, the use of GPS trackers has been proven to assist in training load planning and injury prevention. However, at the amateur level, the use of this technology remains limited, both due to limited access and a lack of understanding of its potential uses. Yet, amateur athletes face similar injury risks to professional athletes, primarily because they often lack systematic recovery programs or monitoring. This research aims to address this gap (Rebelo et al., 2023; Ferraz et al., 2023). The presence of GPS technology in the amateur sports context opens up significant opportunities for improving player health and fitness management, not only in terms of performance but also from a preventative perspective. In this context, GPS trackers are not simply distance or speed tracking devices,

but rather become an integral part of data-driven injury risk management, enabling personalized training loads and smarter game strategy planning (Bădescu et al., 2022; Dawson et al., 2024).

By accurately mapping movement data, coaches can identify player tendencies toward overtraining, imbalances in intensity between positions, and determine the appropriate time to rotate players to minimize injury risk. Data can also be used to design specific muscle-strengthening exercises based on each player's dominant movements.

The purpose of this study was to measure the effectiveness of GPS trackers in mapping the movement patterns of amateur futsal athletes and to examine their correlation with the potential for muscle injury. Through data-based monitoring of actual movements in the field, this study seeks to identify risk zones and the types of movements that most frequently trigger muscle fatigue or injury, and to develop evidence-based recommendations for prevention programs.

2. Methods

This study employed a quantitative-descriptive approach with a quasi-experimental method. This method was chosen because it allowed researchers to conduct limited interventions in a real-world context without having to randomize all study subjects (Madriaza et al., 2025). The primary focus of this study was to evaluate the effectiveness of using GPS trackers in mapping futsal players' movement patterns and linking them to muscle injury prevention. The study was conducted directly in the match and training environment of an amateur futsal team to reflect the actual situation and challenges on the field.

The subjects in this study were 10 amateur male futsal athletes aged 18–25, who regularly participated in training and matches. Participants were selected purposively, taking into account injury history, training frequency, and willingness to participate in all research activities. The study was conducted over four weeks at an indoor futsal facility in City X. The research process generally consisted of eight main stages, systematically structured to ensure the data obtained was relevant, valid, and measurable. The research flow can be seen in Figure 1.

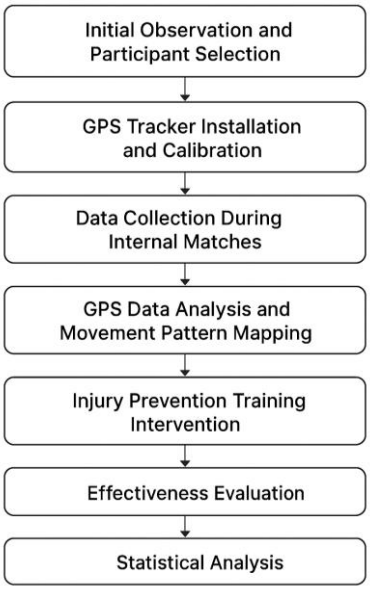

Figure 1: Research Flow

Figure 1 begins with the initial stage of field observation and participant selection, where researchers identified player characteristics, playing positions, and health and injury histories. Next, players were fitted with calibrated GPS trackers to record real-time movement data during two internal matches spanning two weeks. The GPS data included distance traveled, acceleration and deceleration, movement intensity zones, and spatial distribution in the form of heatmaps.

After the initial two matches, GPS data was analyzed to identify movement patterns and areas of the field with the highest potential risk of muscle injury. Players who exhibited muscle complaints such as pain or cramps during the match were also recorded and linked to the GPS data to develop a baseline understanding of the risk factors.

The next stage involved administering an intervention program consisting of muscle strengthening exercises, active stretching, and training load management based on the GPS data mapping results. The intervention lasted one week and focused on players categorized as high-risk. Two follow-up matches were then held, again with the same GPS tracking, to determine whether there were significant differences in movement patterns and the incidence of muscle injuries.

Data from the entire research process was then analyzed quantitatively using descriptive statistics and inferential tests. Descriptive analysis was conducted to examine data distribution, while paired t-tests were used to compare pre- and post-intervention conditions, particularly in terms of the number of injury complaints, movement intensity zones, and changes in speed or distance traveled. If the data did not meet the assumption of normality, the Wilcoxon Signed Rank Test was used as an alternative.

This study also adhered to ethical aspects by obtaining informed consent from all participants and maintaining confidentiality of personal identities. All procedures were conducted under the supervision of trainers and physiotherapists to minimize the risk of new injuries during the study.

With the consistent and structured research stages as shown in Figure 1, it is hoped that the results will provide a comprehensive overview of the practical benefits of GPS trackers in preventing muscle injuries and as a decision-making tool in managing the performance of amateur futsal athletes.

3. Results and Discussion

3.1. General Description of Data

The data used in this study was obtained using GPS trackers installed on each futsal athlete during a trial match. The study involved 10 amateur athletes aged 18–23 who regularly play for a local futsal club. All data was recorded in log format, displaying position coordinates, speed, and distance traveled. It was then processed using Python and MATLAB-based mapping software to produce a heatmap of movement visualizations.

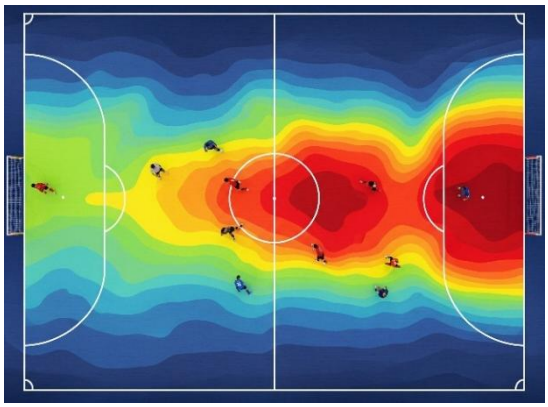

Figure 2: heatmap of athlete movement patterns during a match

Figure 2 shows a visualization of the distribution of player movement intensity during a match. The colors used depict the frequency of movement in specific areas, with red indicating the most frequently visited zones, yellow representing medium intensity, and blue indicating areas rarely touched by player movement. The visualization results show that most players concentrated their movement in the midfield and right flank, indicating a game strategy focused more on penetration from the right side and ball circulation in the center.

This phenomenon can be attributed to the characteristics of futsal, which tends to be fast-paced and requires intense transitions in central areas. Meanwhile, the dominance on the right side is likely due to the majority of players being right-footed, which makes dribbling and controlling space more comfortable on the right side of the pitch. To support this finding, quantitative measurements were also taken of the total distance traveled and average speed of each player, as presented in Table 1.

Table 1: Summary of Player Movement Statistics (average per player)

No	Player Name	Distance traveled (m)	Maximum Speed (km/h)	Movement Dominant Zone
1	A1	1800	21,2	Center and Right Wing
2	A2	1745	20,5	Center and Right Wing
3	A3	1902	22,1	Center & Left Wing
4	A4	1850	20,9	Middle
5	A5	1670	19,3	Right wing

No	Player Name	Distance traveled (m)	Maximum Speed (km/h)	Movement Dominant Zone
6	A6	1798	21,0	Center & Right Wing
7	A7	1822	20,7	Center & Right Wing
8	A8	1883	21,5	Center & Right Wing
9	A9	1765	20,1	Middle
10	A10	1837	21,8	Center & Right Wing

According to Table 1, the average distance traveled by players during a match session was approximately 1,800 meters, with maximum speeds varying between 19.3 and 22.1 km/h. The dominant movement zones showed a consistent pattern, as shown in the heatmap, supporting the conclusion that the right side and central areas were the primary focus of the team's movement.

This data is crucial for planning injury prevention programs. Areas with high concentrations of movement indicate zones of greater biomechanical stress, allowing coaches to design muscle strengthening and recovery exercises that focus more on the load experienced by the muscles in these areas. Furthermore, these results can be used as a basis for strategic player rotation to prevent fatigue accumulation and potential injury, especially for players who have dominated a particular area for extended periods.

3.2. Comparison of Physical Performance Parameters: Early vs Final Session

To assess the effectiveness of the physical training and conditioning program throughout the study period, a comparative analysis was conducted between the initial session (Week 1) and the final session (Week 4). This comparison included five key physical performance indicators: total distance covered, maximum speed, average speed, number of high accelerations, and required recovery time. The results are presented in Table 2.

Table 2: Comparison of Athletes' Physical Performance Averages (Week 1 vs Week 4)

Parameter	Week 1 (Initial Session)	Week 4 (Final Session)	Δ (%)
Total Distance (m)	3,250 ± 220	3,620 ± 180	+11.38%
Maximum Speed (km/h)	21.4 ± 1.2	23.1 ± 1.1	+7.94%
Average Speed (km/h)	9.8 ± 0.6	10.3 ± 0.5	+5.10%
High Acceleration (count)	12 ± 3	16 ± 2	+33.33%
Recovery Time Needed (min)	14 ± 2	11 ± 1.5	–21.43%

As illustrated in Table 2, there was a notable increase in overall physical capacity of the athletes over the four-week period. The total distance covered increased by 11.38%, indicating an improvement in endurance and cardiovascular capacity. Simultaneously, the maximum speed rose by 7.94%, and average speed showed a 5.10% increase, reflecting improvements in both explosive and sustained pace during matches. One of the most significant changes was observed in the number of high accelerations, which jumped from an average of 12 to 16 per match to a 33.33% increase. This improvement highlights the athletes' greater ability to perform repeated high-intensity efforts, a crucial component of futsal performance due to the frequent need for sprints and quick direction changes.

In contrast, the recovery time required after sessions decreased by 21.43%, dropping from 14 to 11 minutes. This reduction suggests improved physiological adaptation to training load and more efficient recovery mechanisms, possibly due to enhanced aerobic capacity and muscle resilience. These improvements can be directly attributed to the structured training sessions conducted between Week 1 and Week 4, which combined speed drills, interval-based endurance conditioning, and recovery optimization protocols. Moreover, the incorporation of GPS-tracked feedback likely allowed for better load management and individualized performance adjustments by coaches.

3.3. Implications for Training Optimization and Injury Prevention

The upward trend in physical performance metrics demonstrates the potential value of data-driven training programs in futsal. Using GPS-based monitoring not only enables real-time analysis of workload but also offers objective markers for progress and fatigue management. From a sports science perspective, the increase in explosive parameters such as sprint speed and high accelerations must be balanced with proper recovery and muscle conditioning. The consistent reduction in required recovery time validates the role of progressive overload training and suggests that players' neuromuscular systems have adapted effectively over the study period.

Injury prevention is also strongly linked to this data. Increased distance and acceleration without signs of excessive fatigue (as shown by reduced recovery time) indicates that players are developing better movement economy and resilience. However, areas with high movement intensity, especially those identified on the heatmap (Figure 2), require specific attention in recovery protocols, such as foam rolling, eccentric training, or targeted physiotherapy. Moreover, these findings support strategic player rotation and substitution patterns during matches to minimize fatigue accumulation, particularly among players consistently operating in high-demand zones like the center and right wing.

4. Conclusion

This study has demonstrated the effectiveness of integrating GPS-based monitoring in analyzing athlete movement patterns and evaluating physical performance in amateur futsal players. By employing wearable tracking technology, it was possible to obtain detailed spatiotemporal data, revealing movement intensities, dominant zones of play, and changes in key physical parameters across a four-week training period. The heatmap visualization (Figure 2) highlighted a clear concentration of player activity in the central and right-wing zones of the pitch, consistent with tactical strategies emphasizing quick transitions and right-flank penetration. This spatial data provides critical insight into workload distribution and muscle stress zones, which can directly inform injury prevention strategies and individualized training regimens.

Furthermore, the quantitative analysis revealed a significant improvement in athlete performance over the course of the study. Total distance, speed metrics, and the number of high accelerations all increase, while recovery time decreases indicating enhanced endurance, anaerobic capacity, and neuromuscular efficiency. These findings underscore the physiological benefits of structured training programs when guided by objective performance metrics. The implications for training optimization and injury prevention are clear. By continuously monitoring physical loads and spatial demands through GPS technology, coaches can tailor workloads, identify early signs of fatigue, and rotate players effectively to prevent overuse injuries. Additionally, targeted conditioning for high-load zones can be implemented to reduce biomechanical stress and increase overall team resilience.

In conclusion, wearable GPS tracking serves not only as a performance evaluation tool but also as a strategic instrument for long-term athlete development, tactical analysis, and injury risk mitigation. Its integration into amateur-level futsal training marks a promising step forward in evidence-based sports science applications, offering a scalable model for broader implementation in other team sports contexts.

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