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# Validity and reliability of catapult vector S7 GNSS units in distance measurement

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## Abstract

**Purpose** This study aimed to evaluate the validity and reliability of the Catapult Vector S7 GPS device in measuring total distance in a simulated team sport environment, with the specific goal of providing practical guidance for its application in sports science and practice.

**Methods** Thirty university-level football players performed a Team Sport Simulation Cycle (TSSC), covering a total distance of 1200 m. Actual field measurements were used to test the validity of all values. A high-frequency (10 Hz) Catapult Vector S7 GPS unit was used to collect movement data, which was compared against reference tape measurements. Statistical analyses included SEM, CV%, SWC, MDC, MAPE%, MAE, RMSE, and Bland-Altman plots.

**Results** The device demonstrated excellent reliability with a CV% of 0.17 and SEM of 2.00. The MDC (5.54) exceeded the SWC (2.19), suggesting high sensitivity in detecting meaningful performance changes. Validity analyses showed minimal error (MAPE% = 0.77; RMSE = 11.55; MAE = 9.40). Bland-Altman analysis indicated low systematic bias and high agreement with reference distances.

**Conclusions** The Catapult Vector S7 GPS unit provides highly reliable and valid measurements of total distance, supporting its application in monitoring athlete workload and performance in team sports. These findings underscore the importance of high-frequency GPS technology in sports science research and practice, significantly contributing to the field.

**Keywords** Athlete monitoring, Team sports, Sports science, Sports technology, Wearable technology

## Background

In recent years, Global Positioning System (GPS) technology has become increasingly prevalent in sports science, particularly in monitoring athlete workload, movement patterns, and performance outcomes [1]. GPS-based tracking systems allow coaches, practitioners, and researchers to obtain real-time and post-session data on variables such as total distance, sprint count, acceleration, deceleration, and positional tracking, which are critical for optimizing training prescriptions, reducing injury risk, and improving competitive performance [2]. Integrating GPS technology into team sports has provided practitioners with an objective, non-invasive method of quantifying external load. However, despite widespread adoption, the accuracy and reliability of GPS systems remain variable, influenced by device frequency, satellite reception quality, environmental interference, and athlete movement complexity [3, 4]. Lower-frequency GPS devices (e.g., 1–5 Hz) have been criticized for their poor accuracy during high-speed, multidirectional activities, often underestimating peak velocity and distance covered

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in short sprints [5]. As a result, researchers and manufacturers have increasingly moved toward higher-frequency devices (≥ 10 Hz), which have been shown to provide more precise tracking, especially during rapid directional changes and intermittent efforts common in sports like football, rugby, and basketball [6–8]. Data obtained by coaches and sports scientists using GPS units is crucial for planning. The quality and accuracy of the data are essential for guiding athletes' training sessions. Data quality issues and inaccurate measurements can lead to misdirection of athletes.

Among commercially available options, the Catapult Vector S7 GPS unit represents one of the most advanced technologies currently used in elite sports. Operating at 10 Hz and incorporating an inertial measurement unit (IMU) that includes an accelerometer, gyroscope, and magnetometer, the Vector S7 is designed to capture detailed biomechanical and spatiotemporal data with high fidelity. This allows for a more nuanced understanding of athlete workload, especially when GPS signals alone are insufficient—such as in indoor environments or congested areas with satellite signal obstruction. However, technological advancement alone is not sufficient to ensure practical application. Validation studies are essential to verify the accuracy, precision, and reproducibility of the data produced by such devices. Although some studies have investigated the general performance of high-frequency GPS units, more targeted research is still needed to evaluate specific models under controlled yet ecologically valid sport-like conditions. Moreover, discrepancies between reference measurements and GPS-reported values—even if minimal—can accumulate and lead to flawed interpretations of training load, player readiness, or injury risk [9, 10]. A key aspect of evaluating GPS systems is the use of comprehensive statistical approaches to determine the magnitude of measurement error and the system's sensitivity to detect meaningful changes in performance. Tools such as the Standard Error of Measurement (SEM), Coefficient of Variation (CV%), Minimal Detectable Change (MDC), and Smallest Worthwhile Change (SWC) are used to assess the precision of repeated measures and the practical relevance of observed variations [11]. Furthermore, Bland-Altman analysis offers a robust method for determining agreement between GPS-derived and reference values. At the same time, metrics like Mean Absolute Percentage Error (MAPE) and Root Mean Square Error (RMSE) provide insight into overall device accuracy [12].

Although research has been conducted on various models within the Catapult brand [13], there is currently no study that explicitly validates the performance of the Catapult Vector S7 GPS device in measuring total distance under standardized, repeatable sports simulation protocols. Addressing this gap is critical for practitioners who depend on such technologies to inform personalized training plans, assess fatigue and recovery, and make evidence-based return-to-play decisions [14]. Validating the accuracy and reliability of this device in measuring total distance in controlled conditions would contribute significantly to improving its application in sports science and practice. Therefore, this study aims to assess the validity and reliability of the Catapult Vector S7 GPS unit in measuring total distance during a structured team sport simulation cycle (TSSC). By comparing GPS-derived data against tape-measured reference values and evaluating both error margins and agreement statistics, this research aims to provide applied evidence for the device's effectiveness in sport performance monitoring. The findings are expected to contribute to the growing knowledge surrounding wearable technologies in elite and amateur sports and support more informed decision-making in training and competition contexts.

## Methods

### Participants

Thirty elite football players (Age: 22.16± 3.45 years; Height: 176.8 ± 34 cm; Body Weight: 75.21± 5.19 kg) who voluntarily played football on a university team participated in this study. The inclusion criterion was not having any injuries at least 1 month before the tests. Athletes who had injuries during training or competitions were excluded from the tests without being included in the study. All participants were informed about the possible risks and benefits of the study. All participants were encouraged to have adequate nutrition and sufficient hydration 24 h before the tests were conducted for the study. On the day of the test, the athletes were provided with shoes and clothing suitable for field tests. The Declaration of Helsinki carried out this protocol's data collection and measurement methods. When the study was planned, an application was made to the Gelişim University Ethics Committee with all the study details before the measurements were made. The measurements were started after Gelişim University approved the research's ethical suitability.

### Experimental procedure

Participants first completed a familiarization phase without any data recording. They participated in the first measurement session 48 h after this phase. All tests were administered using the team sport simulation cycle (TSSC) protocol [13, 15–17]. Before the TSSC protocol, a 15-minute warm-up program was implemented, which included various mobilization movements to increase the athletes' body temperature. The TSSC was designed to include acceleration, deceleration, stopping, walking, running, and sprint components to simulate team sports athletes' movements and was administered to the participants. The reference distance of the TSSC, 150 m, was measured using a tape measure during setup, and this value was determined as the reference measure for the total distance covered by the GPS units. The protocol covered a total distance of 1200 m, and the participants were asked to complete eight 150-meter laps. Details regarding the TSSC protocol are shown in Fig. 1. The field where the data were taken was a standard football field. Before the tests, the athletes were subjected to a standard warm-up procedure. A Catapult GPS unit (Vector S7 10-Hz; Catapult Sports, Melbourne, Australia) was used during all tests. This unit included GPS capabilities and an accelerometer, gyroscope, and magnetometer. The GPS connection had an accelerometer rate of 10 Hz and a data change rate of 100 Hz. All data were transferred from Catapult Openfield software (OpenField Console 3.12.0) to a Microsoft Excel spreadsheet file format.

During the tests, it was ensured that there were no metal or magnetic objects on or near the participants to prevent the data quality of the GPS units used from being negatively affected [13]. This precaution was taken to avoid the devices from being exposed to electromagnetic interference. In addition, the areas where the tests would be performed were carefully selected, and areas away from environmental factors that could block or disrupt the GPS signals, such as tall buildings, were preferred. The data recording process was started after both devices were connected to at least four GPS satellites. This is a critical requirement for obtaining the GPS signal with sufficient accuracy. Horizontal position dilution (HDOP) is a measure that defines the geometric arrangement of the satellites and is used to evaluate the accuracy and quality of the signals received during GPS measurements. HDOP values can vary between 1 and 50. While low HDOP values indicate high signal quality, high HDOP values indicate low data reliability. This study recorded the average HDOP value obtained during data collection as 0.89 ± 0.21. Principe and colleagues stated that GPS data is ideal when the HDOP value is below 1. In this context, the HDOP values of the data collected in our study are within the perfect range recommended in the literature. In addition, environmental conditions were also taken into account and recorded during the tests. The average air temperature on the measurement days was 25 °C, and the humidity was around 55%. These environmental data were reported based on official data provided by the national meteorological institution for the relevant period.

### Statistical procedure

Coefficients of Variation Percent (CV%) were calculated using the standard deviations/ mean x 100 formula, and the Smallest Worthwhile Change (SWC) was calculated by multiplying the between-subject standard deviation

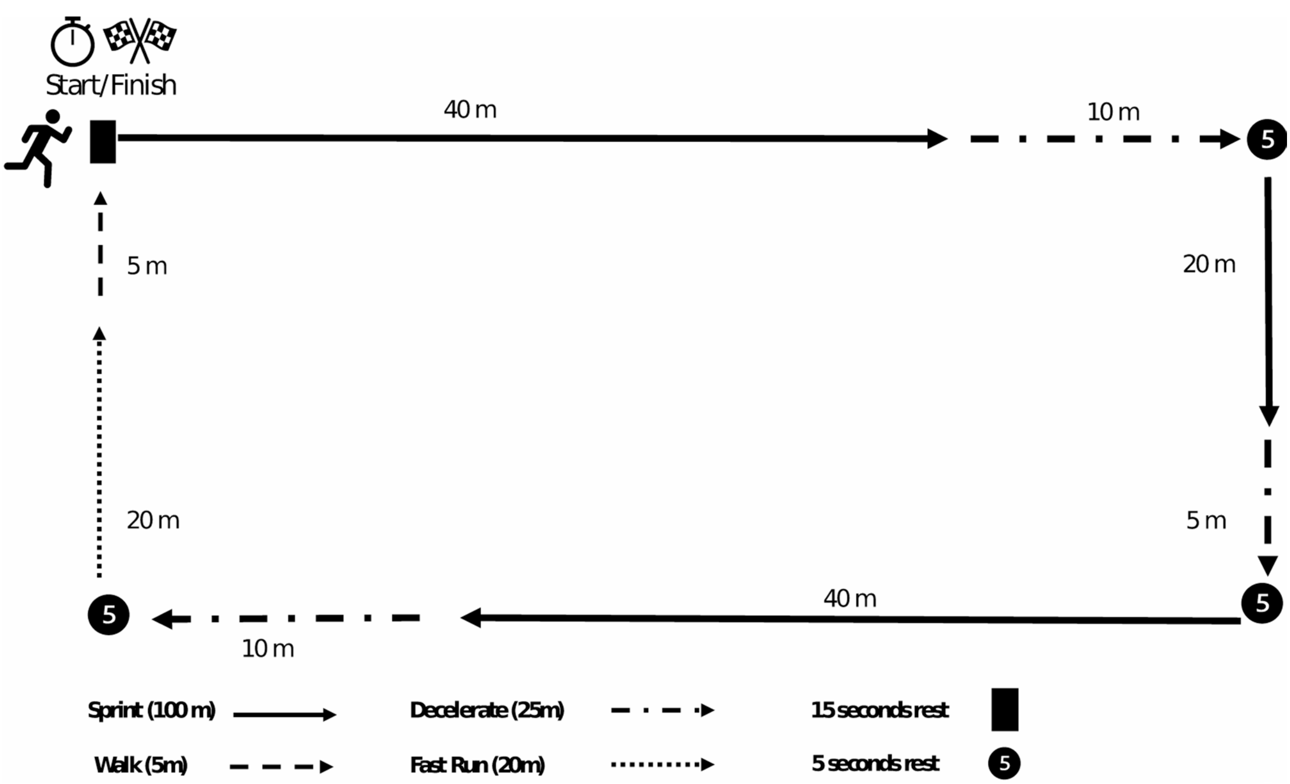


**Fig. 1** The team sport simulation cycle (TSSC)

**Table 1** Validity and reliability parameters of the GPS unit

| Total Distance Measurement with Catapult Vector S7 | |
|---|---|
| SEM (m) | 2.00 |
| CV% | 0.17 |
| MDC | 5.54 |
| SWC | 2.19 |
| SD | 10.95 |
| MAPE% | 0.77 |
| MSE | 133.60 |
| RMSE | 11.55 |
| MAE | 9.40 |

**SEM**: Standard error of measurement; **CV%**: Coefficient of Variation percent; **MDC**: Minimum detectable chance; **SWC**: Smallest worthwhile change; **SD**: Standard Deviation; **MAPE%**: Mean Absolute Percent Error; **MSE**: Mean Square Error; **RMSE**: Root Mean Square Error; **MAE**: Mean Absolute Error

(SD) of the performance by 0.2 (SWC, 0.2 x between-subject SD). The CV was classified as good (< 5%), as moderate (5–10%), and as poor (> 10%) [4, 18]. The validity of the different uses of the GPS device was analyzed for total distance parameters by Bland-Altman systematic bias±and random error in the JASP program. Moreover, Mean Squared Error (MSE), Mean Absolute Percent Error (MAPE), Mean Absolute Error (MAE), and Root Mean Squared Error (RMSE) values were used for the validity of GPS devices. The interpretation of the MAPE value was evaluated according to Lewis's citations [17]. According to this classification: <10 highly accurate, 10–20 good, 20–50 reasonable, and > 50 inaccurate forecasting. The significance level was evaluated as $p < 0.05$.

## Results

The analysis of total distance measurement using the Catapult Vector S7 GPS device revealed strong reliability and validity based on various statistical metrics. Table 1 shows the validity and reliability of the data provided by the GPS unit. The Standard Error of Measurement (SEM) was calculated as 2.00, indicating a low level of inherent variability in repeated measurements. Additionally, the Coefficient of Variation Percentage (CV%) was determined to be 0.17%, suggesting excellent consistency in the device's performance, as CV values below 5% are generally classified as highly reliable.

For sensitivity analysis, the Minimal Detectable Change (MDC) was found to be 5.54, meaning that changes in total distance measurements exceeding this threshold can be meaningful beyond measurement error. Moreover, the Smallest Worthwhile Change (SWC) was computed as 2.19, reflecting the minimum performance change considered practically significant. Comparing MDC and SWC values suggests the device can detect meaningful variations in athlete movement data with high precision. In terms of validity assessment, the Mean Absolute Percentage Error (MAPE%) was 0.77%, which, based on Lewis's classification, indicates highly accurate forecasting (MAPE < 10%). Similarly, the Mean Squared Error (MSE) was 133.60, and the Root Mean Square Error (RMSE) was 11.55, further supporting the device's high accuracy in measuring total distance. The Mean Absolute Error (MAE), which directly interprets the average deviation from actual values, was recorded at 9.40, demonstrating a minimal margin of error in GPS-based measurements. The Bland-Altman analysis determined low average error values between the reference distances and GPS units. The statistics of the Bland-Altman analyses are shown in Table 2. The Bland-Altman analysis differences of the Catapult Vector S7 units compared to the reference measurement are shown in Fig. 2. These findings indicate that the Catapult Vector S7 provides reliable, valid total distance measurements. The exceptionally low CV% and MAPE% values confirm the device's precision and accuracy, while the relationship between MDC and SWC suggests its capability to detect meaningful changes in performance. These results support the suitability of the Catapult Vector S7 for use in sports performance analysis, particularly for monitoring athlete workload and movement patterns with high precision.

## Discussion

The findings of this study demonstrate that the Catapult Vector S7 GPS unit provides highly reliable and valid measurements of total distance in a controlled team sport simulation setting. The exceptionally low coefficient of variation (CV%) of 0.17% and a minimal mean absolute percentage error (MAPE%) of 0.77% indicate that the device is exact and accurate. These results align with previous research evaluating the validity of GPS technology in sports science, reinforcing the suitability of high-frequency (10 Hz) GPS units for tracking athlete movement and workload [13].

One of the most critical aspects of GPS-based athlete monitoring is the ability to provide consistent measurements across repeated trials. The present study's findings reveal a standard error of measurement (SEM) of 2.00 and a minimum detectable change (MDC) of 5.54, suggesting that slight variations in movement patterns can

**Table 2** Bland-Altman- total distance (m)_GPS _Data - TSSC_Real_Distance

| Bias & Limits | Point Value | Lower 95% CI | Upper 95% CI |
|---|---|---|---|
| Mean difference + 1.96 SD | 25.667 | 18.583 | 32.751 |
| Mean difference | 4.200 | 0.110 | 8.290 |
| Mean difference – 1.96 SD | -17.267 | -24.351 | -10.183 |

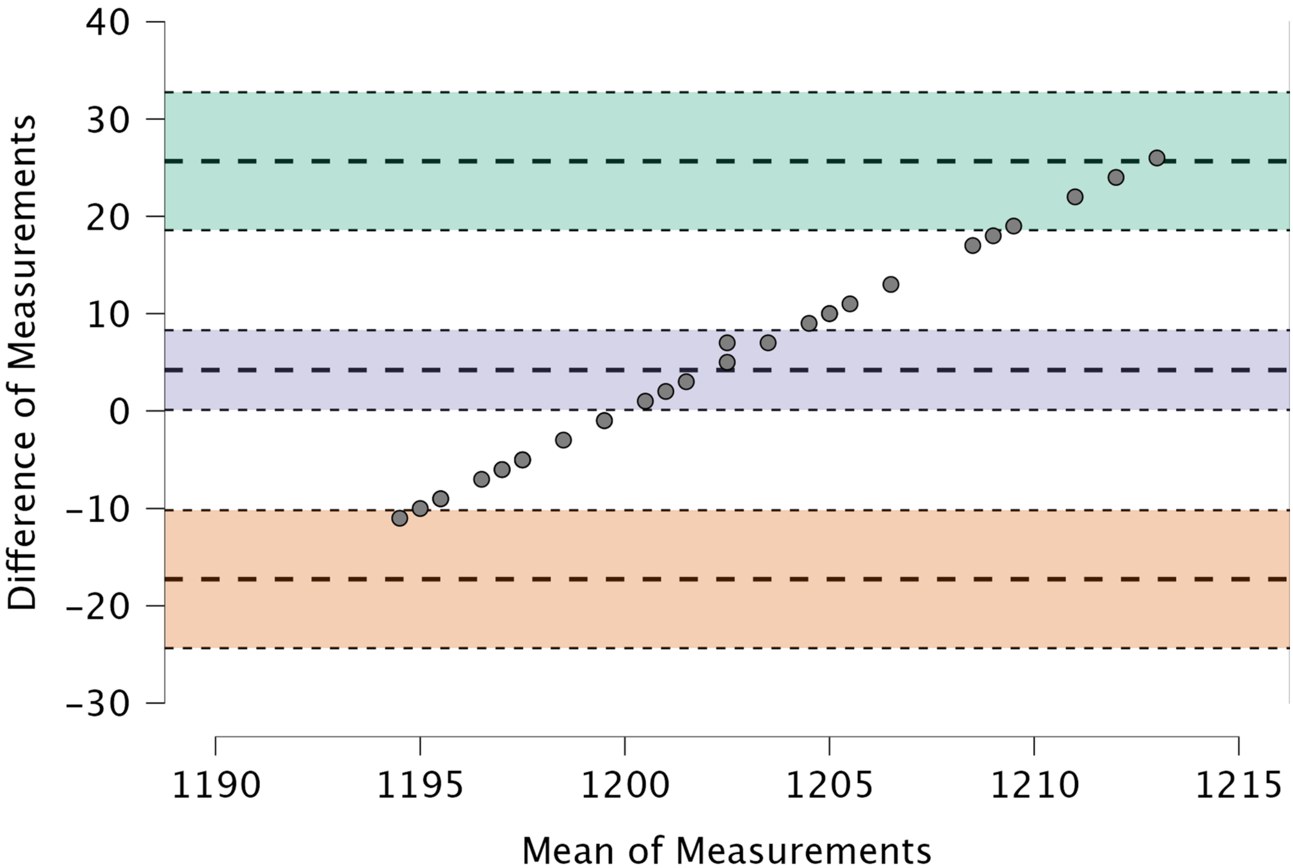


**Fig. 2** Bland-altman plot showing differences between reference distances and GPS units

be reliably detected. These values are essential for practitioners who rely on GPS data to make informed decisions about training loads and injury prevention. Furthermore, the smallest worthwhile change (SWC) was calculated as 2.19, indicating that the device can detect meaningful performance variations with high sensitivity. The ability to detect such subtle changes is critical in elite sports, where minor variations in workload can significantly influence player readiness, fatigue management, and long-term injury risk.

Compared to previous literature, our results support the consensus that GPS devices with higher sampling rates (10 Hz and above) offer superior accuracy and reliability over older models with lower sampling frequencies (e.g., 1–5 Hz). Studies by Coutts and Duffield (2010) [5] and Beato et al. (2018) [6] have highlighted the limitations of low-frequency GPS devices, particularly in tracking high-intensity movements and rapid changes in direction. The findings in this study suggest that the Catapult Vector S7 overcomes many of these limitations, providing robust data that can be confidently used in training load monitoring and performance assessments. Given that team sports involve frequent accelerations, decelerations, and multidirectional movements, the precision of GPS tracking in such scenarios is crucial for coaches and sports scientists aiming to optimize training regimens.

The validity assessment using the Bland-Altman analysis further confirms the device's high level of agreement with reference measures. The mean difference of 4.2 m, within the acceptable range of variation, suggests that the GPS unit's systematic bias is minimal. The root mean square error (RMSE) of 11.55 and the mean absolute error (MAE) of 9.40 further support the device's precision. Such low error margins indicate that the Catapult Vector S7 GPS unit can reliably capture the total distance athletes cover during training and competitive matches. This level of accuracy is crucial when designing individualized training programs, as even minor discrepancies in workload calculations can lead to undertraining or overtraining, both of which can impact performance and injury risk.

Despite the strong validity and reliability metrics, some limitations should be acknowledged [19]. Environmental factors, such as potential interference from atmospheric conditions or nearby structures, were minimized in this study but may influence GPS accuracy in real-world applications. While HDOP values were consistently below 1.0, ensuring optimal signal reception, variations in satellite connectivity may still affect measurement consistency in different settings. Future studies should explore the device's performance across various playing environments and under match conditions to provide further external validity. Furthermore, additional research comparing the Catapult Vector S7 with other GPS models under different competitive conditions could help establish benchmarks for performance analysis across various sports and levels of play.

Another important consideration is the practical application of these findings in real-world sports settings [20]. In elite sports, the ability to track movement with high precision has implications beyond just performance monitoring. It can influence tactical decision-making, recovery protocols, and player workload distribution [21]. Coaches and sports scientists increasingly rely on objective data to manage athlete load, prevent injuries, and ensure optimal performance [22]. The strong reliability and validity of the Catapult Vector S7 GPS unit make it a valuable tool in these processes, providing confidence in the accuracy of distance measurements and workload estimations [23].

The results of this study indicate that the Catapult Vector S7 GPS unit is a highly reliable and valid tool for measuring total distance in team sports settings. Its precision in detecting small but meaningful changes in athlete workload supports its application in sports performance monitoring. These findings contribute to the growing body of evidence advocating for the use of high-frequency GPS technology in elite and amateur sports contexts.

## Conclusion

The Catapult Vector S7 GPS device has proven to be a reliable and valid tool for measuring total distance in sports performance analysis. The device demonstrated exceptional consistency, with low Standard Error of Measurement (SEM) and Coefficient of Variation (CV%) values, indicating high precision across repeated measurements. Sensitivity and validity analyses further confirmed its ability to detect meaningful changes in athlete movement, with values for Minimal Detectable Change (MDC) and Smallest Worthwhile Change (SWC) highlighting its capability to identify performance variations that are both statistically and practically significant.

The extremely low Mean Absolute Percentage Error (MAPE%) and minimal error values from the Bland-Altman analysis further affirm the device's high accuracy. Given these results, the Catapult Vector S7 is well-suited for use in sports science applications, particularly in monitoring athlete workload, movement patterns, and overall performance with high reliability. This makes it a valuable tool for coaches, sports scientists, and performance analysts seeking precise and actionable data to optimize athlete training and performance outcomes.

Future research should continue to validate GPS devices in dynamic game environments to ensure their applicability in real-world performance analysis. Additionally, expanding research to include sport-specific movement patterns, such as changes in direction, acceleration profiles, and sprint distances, could further enhance our understanding of how GPS technology can be optimally utilized in performance monitoring and training adaptation.

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**Author contributions**

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**Data availability**

Data is available to the corresponding author upon reasonable request.

## Declarations

**Ethics approval and consent to participate**

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Gelişim University Ethics Committee. Gelişim University Ethics Committee approved all experimental protocols (Approval Number:2023-09). Written informed consent was obtained from the participants to publish this paper.

**Consent for publication**

No individual or identifiable data is being published as part of this manuscript.

**Competing interests**

The authors declare no competing interests.

**Clinical trial number**

Not applicable.

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## Publisher's note