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Test–retest reliability of grip force perception assessment in healthy adolescents

Sağlıklı adölesanlarda kavrama kuvveti duyusu test-tekrar test güvenilirliğinin incelenmesi

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Abstract

Aim: To investigate the test–retest reliability of grip force perception assessment at different target force levels in healthy adolescents.

Materials and Methods: Twenty-seven participants aged 12–18 years were included. Maximal grip strength (MGS) was determined, and target forces of 30% and 50% of MGS were used to assess force perception using a Martin Vigorimeter. Target forces were reproduced first with, and then without visual feedback. Absolute Error (AE) was calculated as the difference between reproduced and target values. Measurements were repeated after one week.

Results: ICC values indicated good reliability for MGS and moderate reliability for force perception at both target force levels. SEM was lower for the 30% target force. Bland–Altman plots showed no proportional bias.

Conclusion: Grip force perception assessment exhibited moderate reliability, supporting its clinical applicability.

Keywords: Grip; force perception; Proprioception; Test-retest reliability; Adolescence.

Öz

Amaç: Sağlıklı adolesanlarda farklı hedef kuvvet seviyelerinde kavrama kuvveti duyusu değerlendirmesinin test–tekrar test güvenilirliğini incelemektir.

Gereç ve Yöntem: Yaşları 12–18 arasında değişen 27 katılımcı çalışmaya dahil edildi. Maksimum kavrama kuvveti (MKK) belirlendi ve kuvvet duyusunu değerlendirmek için MKK'nin %30'u ve %50'si hedef kuvvet olarak kullanıldı. Martin Vigorimeter ile yapılan ölçümlerde hedef kuvvetler önce görsel geri bildirimle, ardından görsel geri bildirim olmadan yeniden üretildi. Yeniden üretilen ve hedef değerler arasındaki farktan Mutlak Hata (AE) hesaplandı. Ölçümler bir hafta arayla tekrarlandı.

Bulgular: ICC değerleri MKK için iyi, her iki hedef kuvvet seviyesi için orta düzeyde güvenilirlik gösterdi. SEM değeri %30 hedef kuvvet için daha düşüktü. Bland–Altman grafiklerinde oransal bir yanlılık gözlenmedi.

Sonuç: Kavrama kuvveti duyusu değerlendirmesi orta düzeyde güvenilirlik göstermiştir ve klinik uygulamalarda kullanılabilirliğini desteklemektedir.

Anahtar Kelimeler: Kavrama; kuvvet duyusu; Propriosepsiyon; Test-tekrar test güvenilirliği; Adolesan.

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Bu makale araştırma ve yayın etiğine uygun hazırlanmıştır.
intihal incelemesinden geçirilmiştir.

Introduction

Proprioception refers to the sense of movement and position of the limbs in space in the absence of visual input.[1] Proprioception has three submodalities, including kinesthesia, joint position sense, and force perception. In addition to kinesthesia and joint position sense, force perception is crucial for effective neuromuscular control. Force perception is defined as the ability to sense and interpret the magnitude of force applied to or generated within a joint.[2] While most studies on proprioception have focused on joint position sense or kinesthesia, research on force perception remains limited.[3]

Accurate perception and regulation of grip force are essential for performing daily activities, such as writing and holding a pen, as well as sports activities like tennis and climbing.[4] The ability to grip an object is a complex motor task that requires the application of sufficient force to prevent the object from slipping. Repetitive or unnecessarily high grip forces can lead to musculoskeletal disorders.[5] Understanding force perception is therefore important for better comprehension of musculoskeletal conditions associated with impaired force perception, reducing injury risk, and implementing preventive measures.[6]

Factors that influence force generation include age, sex, body weight, height, body composition, and handedness.[7] Force control has predominantly been studied in the context of maximal force production. However, maximal strength is seldom required in activities of daily living.[8] Consequently, evaluating grip force perception at submaximal force levels is particularly relevant, because most daily and functional tasks involve submaximal rather than maximal forces.

For a clinical variable to be interpreted accurately, the measurement tool must exhibit good test–retest reliability. A tool with high test–retest reliability allows valid comparisons across different time points, producing consistent results that are less influenced by external factors.[9] Numerous studies have examined grip force perception based on force reproduction tasks.[10] The test–retest reliability of force perception assessments has been investigated in joints such as the ankle, knee, hip, and shoulder, demonstrating variable reliability depending on the joint tested.[11-14] These studies primarily involved healthy adults or athletes.

Adolescence is characterized by ongoing maturation of sensorimotor and neuromuscular systems, including proprioception, postural control, and intersegmental coordination, which may influence the perception and control of force. Transient regressions and individual variability in these systems during adolescence suggest that assessments of grip force perception may not be as consistent as in adults. Therefore, studying this population allows for the evaluation of whether commonly used force perception tests provide reliable results during this critical developmental stage.[15] Human fingers contain numerous small muscles and are highly susceptible to fatigue, which limits the ability to maintain a high target force level over extended periods.[16] Moreover, there is no linear relationship between different force levels and force reproduction errors.[17,18] Consequently, interactions between target force levels and test–retest reliability may be expected.

Handgrip assessment is a widely used tool for evaluating neuromuscular performance in children and adolescents. It provides insights into the function of the finger flexor muscles, intrinsic hand muscles, and the thenar and hypothenar regions, making it relevant for understanding hand function and motor control during adolescence. Grip strength develops with age and is influenced by growth, sex, and physical activity, highlighting the importance of establishing normative patterns in this population. Assessing grip strength in adolescents allows researchers and clinicians to evaluate functional status, monitor neuromuscular development, and compare individuals with age- and sex-matched peers.[19] To our knowledge, no study has yet examined the test–retest reliability of grip force perception assessment in healthy adolescents. Accordingly, this study aimed to investigate the test–retest reliability of grip force

perception assessed at different target force levels in this population, providing data that may inform rehabilitation, hand therapy, and injury prevention strategies where reliable assessment of force perception is essential.

Materials and Methods

Participants

This observational study was conducted between September and October 2025 at the Private Eylül Physiotherapy and Healthy Living Center. Healthy adolescents attending the center were invited to participate. The sample size was determined according to the guidelines proposed by Fleiss, indicating that 15–20 participants are sufficient to estimate the reliability of a quantitative measure.[20] A total of 30 adolescents aged 12 to 18 years were initially recruited. Participants with a history of surgery of the hand or wrist, previous upper-extremity fractures, or any neuromuscular or orthopedic conditions affecting hand strength were excluded. Three adolescents were excluded due to a history of upper extremity fractures from falls, resulting in a final sample of 27 participants.

Apparatus

The Martin Vigorimeter (KLS Martin Group, Tuttlingen, Germany) (Figure 1) is a pneumatic dynamometer equipped with three rubber bulbs of different sizes to accommodate varying hand sizes and grips.[21] It consists of a pressure gauge and a manometer with a dial resembling a clock face, to which one of the bulbs can be attached via a rubber tube. The smallest bulb is used for children, while the larger bulbs are intended for adults. Before measurement, the needle on the gauge is set to zero, and the participant is instructed to squeeze the bulb firmly and then release it. The colored needle remains at the maximum point reached on the dial, which is then reset using a small button. Grip force is recorded in kilopascals per square centimeter. Due to its lightweight design, the Martin Vigorimeter is suitable for measuring grip and pinch strength in children.[21] The device has demonstrated excellent reliability (ICC > 0.90) and validity, showing a high correlation ($0.7 \leq r < 0.9$) with the Jamar dynamometer.[22] Measurements are typically obtained three times, and the average of the three trials is recorded.[23]



Figure 1. Martin vigorimeter.

Protocol

Demographic data, including age, height, body weight, body mass index (BMI), and hand length, were recorded. The test was performed in the standardized position recommended by the American Society of Hand Therapists: sitting in a straight-backed chair with feet supported on the floor, elbow flexed at 90°, shoulder in adduction and neutral rotation, forearm in neutral position, and wrist between 0° and 30° of extension and between 0◦ and 15° of ulnar deviation).[24] Before measuring maximal grip strength (MGS), participants performed three submaximal grip trials as a warm-up.[25] They were then instructed to apply and maintain their maximal grip force for 5 seconds, and then relax.[26] This procedure was repeated three times, with a 3-minute rest period between trials. The mean of the three trials was recorded as the MGS value.

For the evaluation of grip force perception, target values corresponding to 30% and 50% of MGS were calculated. Participants were shown these target levels on the Martin Vigorimeter dial (Figure 2) to ensure understanding. Subsequently, they were asked to reproduce the learned grip force without visual feedback. The difference between the reproduced and target values was used to calculate the Absolute Error (AE). All measurements were performed twice, one week apart, under identical physical conditions and by the same researcher to assess the

reliability of grip force perception. Participants refrained from engaging in any physical activity that could affect test performance during the one-week interval. Measurements were taken only from the dominant hand, determined based on the hand used for writing.

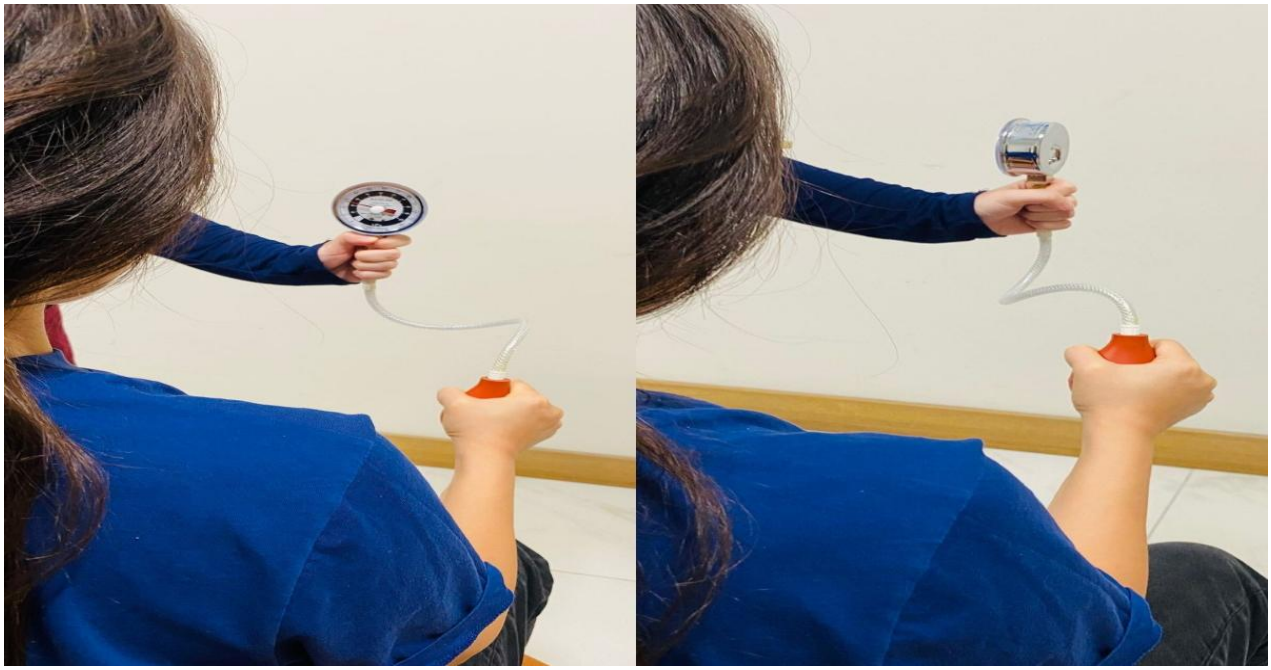


Figure 2. Force perception assessment.

Statistical analysis

Data were analyzed using SPSS version 26.0 (IBM Corp., Armonk, NY). A p-value < 0.05 was considered statistically significant. The Kolmogorov-Smirnov test was used to assess whether the data followed a normal distribution before conducting parametric tests. Paired t-tests were used to compare measurements between the first and second sessions to assess whether systematic differences existed between test and retest).[27] Intraclass correlation coefficients (ICCs**)** were calculated to determine test-retest reliability. ICC values were interpreted according to the following criteria: weak, 0.00–0.39; moderate, 0.40–0.74; and good, 0.75–1.00.[28] The **s**tandard error of measurement (SEM) was calculated to assess absolute reliability. A high SEM indicates a high level of variability in repeated measurements, reflecting low reproducibility.[29] The minimal detectable change (MDC) was calculated using the formula $MDC = 1.96 \times \sqrt{2} \times SEM$ to determine the smallest amount of change that exceeds measurement error with 95% confidence. Agreement between test and retest sessions was assessed using Bland–Altman plots. The plots depicted the differences between the first and second measurements (second session – first session) against the mean of the two measurements, with 95% limits of agreement (LOA = mean difference ± 1.96 SD).[30]

Results

A total of 27 adolescents (16 females and 11 males) with a mean age of 14 ± 2.2 years participated in the study. Twenty-four participants were right-hand dominant and three were left-hand dominant. Demographic characteristics of the participants were as follows: height, 162.88 ± 8.48 cm; body weight, 51.77 ± 12.32 kg; and BMI, 19.54 ± 3.59 kg/m².

The Absolute Error, ICC, SEM and MDC values for MGS and grip force perception at 30% and 50% target force levels are presented in Table 1. ICC values indicated good test–retest reliability for MGS and moderate reliability for AE at 30% and 50% target force levels. SEM values at the 30% target force level were lower than that at the 50% target force level.

Table 1. Test-retest reliability of grip force perception assessment.

n=27	Test	Re-test	Mean difference	ICC (p-value)	SEM	MDC	95% LOA (kPa)
MGS	50.52 ± 14.6	51.50 ± 12.52	0.98 ± 7.62	0.915 (0.000)	3.96	10.98	-13.95 to 15.91
30% AE	2.37 ± 1.27	2.55 ± 1.50	0.18 ± 1.59	0.514 (0.036)	0.96	2.68	-2.93 to 3.30
50% AE	2.77 ± 2.00	3.00 ± 1.51	0.22 ± 2.10	0.538 (0.027)	1.29	3.33	-3.84 to 4.07

MGS: Maximal Grip Strength, **AE:** Absolute Error, **ICC**: Intraclass Correlation Coefficient, **SEM:** Standard Error of Measurement, **MDC:** Minimal Detectable Change, **LOA:** Limits of Agreement, **x̄ ± SD**: Mean ± Standard Deviation.

Figure 3 shows the Bland–Altman plots for MGS, 30% AE, and 50% AE. Visual inspection of the plots (Figure 3A–C) indicated no statistically significant proportional bias between the test–retest differences and the mean AE values for MGS, 30%, and 50% target force levels.

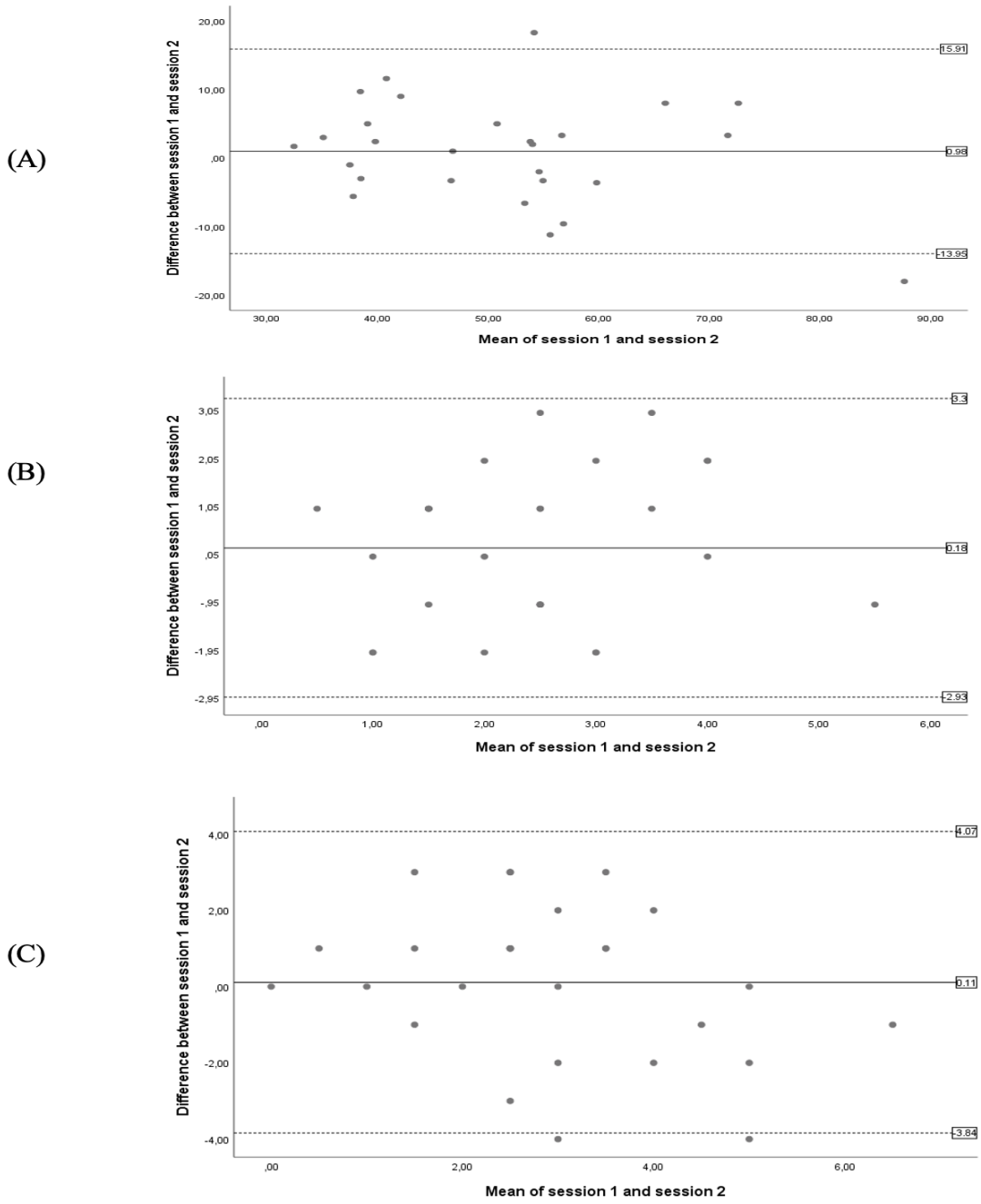


Figure 3 (A-C). Bland–Altman plots for MGS, 30% AE (B), and 50% AE (C) showing the relationship between the test–retest differences and the mean of the test and retest AE values. Note: The ordinate axis represents the differences between the two measurements (second session – first session), while the abscissa axis represents the mean of the two measurements. The solid line in the middle indicates the mean difference, and the upper and lower dashed lines represent the 95% limits of agreement (LOA).

Discussion

This study demonstrated the test–retest reliability of grip force perception assessment at different target force levels in healthy adolescents. Measurements conducted one week apart showed consistent results. Our findings indicate moderate test–retest reliability, with similar AE values observed at both target force levels (30% and 50% of MGS).

Dynamic control of fingertip forces, a key component of dexterous hand function, continues to develop well into late adolescence, largely independent of hand strength.[31] This prolonged maturation of neural control may contribute to the moderate test–retest reliability observed in adolescents, as variability in force reproduction may reflect ongoing refinement of finger dexterity rather than limitations of the assessment itself. Additionally, adolescent sensorimotor development is characterized by transient regressions and individual variability in proprioceptive and neuromuscular control, which may further explain some of the observed variability in test–retest performance.[15] Reliable measurement of grip force perception in this age group can therefore provide valuable insights into neuromuscular development and inform clinical interventions aimed at preventing or managing upper-extremity functional deficits. Accordingly, the moderate reliability associated with these error measures was considered acceptable for the assessment of grip force perception in adolescents.

Although only the dominant hand was assessed in this study, maximal handgrip strength is widely used as an index of overall health and is considered the single clinical measure most representative of total body strength. Previous work has shown that grip strength of the dominant hand is typically about 10% greater than the non-dominant hand across sexes and ages.[32]

In a study by Benjaminse et al.[13], hip joint force perception during flexion demonstrated good test–retest reliability (ICC = 0.764), whereas force perception measurements in other planes were found to be unreliable. In a study examining the test–retest reliability of grip force perception assessment in healthy adults, ICC values (0.42–0.63) indicated moderate reliability for force perception tests at target forces of 20 N and 50 N.[6] Similarly, another study investigating tip, key, and palmar pinch force perception at different force levels in healthy adults reported high test–retest reliability, with the most reliable measurements observed at 30% and 50% of maximal voluntary isometric contraction (MVIC).[33]

In our study, the 95% LOA for force perception at target levels of 30% and 50% of MGS revealed that the 30% AE had a narrower range. Consistently, Bland–Altman plots and SEM values indicated superior agreement and repeatability for the 30% MGS condition compared with the 50% condition. Similarly, in a study examining contralateral pinch force-matching across different force levels, reference forces set at 10% of MVIC exhibited lower SEM and narrower 95% LOA ranges for both absolute and constant error compared with 30% and 50% MVIC.[34] The MDC values further support these findings, indicating that changes exceeding approximately 11 kPa for MGS, 2.68 kPa for 30% AE, and 3.33 kPa for 50% AE would be required to represent true change beyond measurement error. The slightly lower MDC at the 30% target force level is consistent with its narrower LOA range and smaller SEM, indicating marginally better repeatability compared with the 50% condition.

Our sample size of 27 participants exceeds the recommended minimum of 15–20 for estimating reliability in clinical studies[20,35], providing confidence in the robustness of our ICC estimates. Additionally, the inclusion of multiple trials, standardized handle sizes, and careful familiarization in our protocol follows established best practices for reliable grip and pinch force measurements[6,33,36] minimizing learning effects and ensuring reproducible assessment.

The literature indicates that higher force levels are associated with greater difficulty in coordinating pinch grip, leading to increased errors.[37] In a study by Yiğit et al., a positive correlation was observed between MGS and

force perception.[38] Similarly, in our study, although force perception measurements at both 30% and 50% of MGS were reliable, the 30% MGS condition demonstrated greater test–retest reliability.

Accurate reproduction of muscle contractions is essential for effective motor control.[39] Force perception, an important component of proprioception, is known to be influenced by various factors, including age, sex, hand dominance, the tested extremity, and the number of recruited motor units.[40] Recently, an increase in upper-extremity complaints among adolescents has been reported, attributed to rising smartphone use.[41] Assessing the test–retest reliability of force perception in adolescents may help improve the effectiveness of rehabilitation interventions for musculoskeletal disorders.

Limitations

ICC values are influenced by sample size; as the sample size increases, ICC values generally tend to be lower. However, this does not imply that the ICC obtained from a smaller sample is necessarily less valid. In determining the sample size for our study, we followed the recommendations of Fleiss, who suggested that 15–20 participants are sufficient for estimating the reliability of a quantitative variable.[20] Although our sample size met this criterion, a larger number of participants could have provided more precise ICC estimates.

Force perception can be affected by multiple factors, including age, sex, and hand dominance. Our study included both male and female participants, and the unequal distribution of sexes may have influenced the results. Future studies with balanced sex representation or sex-stratified analyses could provide more detailed insight into potential differences in grip force perception reliability. Similarly, upper extremity anthropometric characteristics, such as hand size, forearm length, or grip span, can affect force perception and grip performance. These measurements were not collected in the present study, and their absence may limit the generalizability of the findings. Additionally, narrowing the age range of participants might have increased the consistency of the results. Taken together, these factors should be considered in interpreting our findings and in planning future studies on adolescent grip force perception.

Conclusion

Our study demonstrates that grip force perception measurements using a force reproduction test show moderate reliability in healthy adolescents. Target forces set at 30% and 50% of maximal grip strength are appropriate for use in this population. These findings underscore the importance of reliably assessing force perception to support effective treatment and rehabilitation interventions in adolescents.

Ethics Committee Approval

Ethical approval for the study was obtained from the Institutional Review Board of Gaziantep Islam Science and Technology Institute (No: 2025/683-17/09/2025).

Informed Consent

Prior to participation, all adolescents and their parents were provided with detailed information about the study, and written informed assent and consent were obtained. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Author Contributions

S.Y: Conception and design, writing manuscript, editing and final approval of manuscript; **K.C:** Data collection; **M.A.C:** Writing manuscript; **İ.A:** Writing manuscript, editing; **H.İ.E:** Writing manuscript, critical review of manuscript; **Ç.M:** Critical review of manuscript.

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Conflict of Interest

The authors have no conflicts of interest to declare.

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