AEROBIC ENDURANCE IMPROVES WITH AGE IN COMPETITIVE MALE TENNIS PLAYERS: EVIDENCE FROM A CROSS-SECTIONAL STUDY IN SOUTHERN INDIA

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Abstract

The present cross-sectional study explored differences across age groups in aerobic endurance among 500 district-level male tennis players (aged 16–35 years) from Tamil Nadu, India. Participants were stratified into four age groups: 16–20, 21–25, 26–30, and 31–35 years (n = 125 each). Aerobic endurance was evaluated using the Cooper 12-minute run/walk test a validated field measure of cardiorespiratory fitness. The analysis produced a highly significant F-value ($F = 255.38$, $p < 0.05$). Subsequent application of Scheffé's multiple comparison procedure revealed a steady rise in the average distance covered as age increased. Group I (1926.60 ± 266.12 m), Group II (2146.32 ± 70.24 m), Group III (2372.24 ± 125.52 m), and Group IV (2450.72 ± 129.91 m). These findings contrast with typical population trends of declining VO_2max after the early 20s, suggesting that sustained tennis participation enhances or preserves aerobic capacity into the mid-30s. The results highlight the role of accumulated training experience, physiological adaptations, and the sport's intermittent aerobic demands in mitigating age-related fitness decline. In the Indian regional context, this underscores tennis as a "lifetime" activity that promotes long-term cardiorespiratory health and performance. Practical implications include tailoring aerobic training strategies to age-specific developmental stages—accelerating endurance development in younger players and maintaining fitness in older athletes. Limitations include the cross-sectional design and focus on male district-level players; future longitudinal studies should incorporate diverse populations and sport-specific protocols.

Keywords: aerobic endurance, tennis, age-related fitness, Cooper's 12-minute test, VO_2max, district-level athletes, India, cardiorespiratory fitness.

INTRODUCTION

Tennis, as a globally prominent sport, demands a unique combination of technical skill, strategic thinking, and physical prowess, making it an ideal activity for promoting lifelong health and fitness. Originating from 19th-century innovations in England, the game has evolved into a professional circuit governed by organisations like the ATP and WTA, emphasising competitive performance across diverse age groups and regions (FernandezFernandez et al., 2021). In modern contexts, tennis not only fosters individual achievement but also contributes to societal well-being by encouraging physical activity that combats sedentary lifestyles, particularly in emerging markets like India, where participation is rapidly growing.

A key component of tennis performance is aerobic endurance, which enables players to sustain prolonged rallies, recover quickly between points, and maintain intensity during matches that can last several hours. Aerobic capacity, often measured through metrics like VO2max, supports the sport's intermittent nature, where bursts of high effort are interspersed with brief recoveries (Kovacs, 2007). Recent research highlights how targeted training, such

as high-intensity interval training (HIIT) integrated into on-court drills, can significantly enhance aerobic adaptations in young players, with improvements in VO2max ranging from 2.1 to 2.13 $mL \cdot kg^{-1} \cdot min^{-1}$ over short interventions. This underscores the importance of endurance for optimising match outcomes and reducing fatigue related errors.

Age plays a critical role in modulating aerobic endurance, with physiological changes influencing capacity over time. In youth athletes, endurance tends to improve markedly with maturation and training, while in adults, it may stabilise or decline without intervention, potentially dropping by up to 10% per decade in older populations. Systematic reviews indicate that training effects on physical fitness vary by age: youth tennis players (<18 years) show large gains in endurance, whereas adults (≥18 years) exhibit more pronounced improvements in power related attributes, highlighting the need for age tailored programs. Longitudinal studies further demonstrate that elite junior players experience progressive enhancements in aerobic fitness as they mature, linked to both biological development and performance level. However, veteran players who maintain regular tennis involvement preserve higher aerobic capacities compared to sedentary peers, suggesting the sport's potential as an anti-ageing activity that extends health span by nearly a decade. Despite these insights, research on age-related aerobic endurance in tennis remains limited in nonWestern contexts, particularly in India, where environmental factors, training access, and cultural influences may alter physiological profiles. Prior studies in Indian cohorts have explored general fitness in racket sports, but they lack depth in age specific endurance variations among competitive players. This gap is significant given India's burgeoning tennis scene, with district-level athletes representing a key talent pool. To address this, the present study investigates differences in aerobic endurance across age groups (16–20, 21–25, 26–30, and 31–35 years) among 500 district-level male tennis players from Tamil Nadu, India, through the administration of Cooper's 12-minute run/walk assessment. By focusing on this regional population, the research aims to inform customised training strategies that enhance performance and promote sustained participation in the sport.

METHODOLOGY

This study employed a cross-sectional design to examine age-related differences in aerobic endurance among district-level male tennis players in Tamil Nadu, India. The research focused exclusively on aerobic endurance as the primary variable, measured through a field-based test suitable for large-scale assessment in athletic populations. The methodology was adapted from established protocols, ensuring reliability and validity while addressing practical constraints in a regional sports setting.

Participants

A total of 500 male tennis players (N = 500) who had competed in district-level tennis matches in Tamil Nadu, India, were randomly selected as subjects. Participants were divided into four equal age groups (n = 125 each) based on chronological age:

- Group I: 16–20 years (mean height: 162 cm, weight: 60 kg, years of practice: 2 years)
- Group II: 21–25 years (mean height: 165 cm, weight: 65 kg, years of practice: 3 years)
- Group III: 26–30 years (mean height: 170 cm, weight: 70 kg, years of practice: 4 years)
- Group IV: 31–35 years (mean height: 172 cm, weight: 75 kg, years of practice: 5 years)

Inclusion criteria required active participation in

23 district-level competitions and male gender. The selection process was random to minimise selection bias, and groups were balanced for comparability. Height, weight, and training

experience were recorded as descriptive variables to contextualise potential physiological influences on performance.

Ethical considerations included voluntary participation and informed consent, with testing conducted under the supervision of qualified personnel.

Study Design

A true random group comparative design was utilised, with participants assigned to age-based groups and tested on a single aerobic endurance variable. This approach allowed for direct comparison of performance across age categories while controlling for extraneous factors through randomisation and standardisation.

Facilities and Equipment

- A standard 400-meter athletic track marked at every 10 meters
- Stopwatch (calibrated to 1/10 second)
- Whistle for signalling start/stop
- Score sheets and pencils

The test required participants to move continuously for 12 minutes, aiming to achieve the maximum distance through running and/or walking. Testing occurred on a marked track, with qualified testers (the researcher and assisted tennis coaches) serving as lap counters. Instructions emphasised maximal effort while allowing walking to prevent overexertion. The test began with a whistle, and time announcements were provided every minute. At the 12-minute mark, a final whistle signalled all participants to stop immediately, 24 standing in place. The covered distance was carefully 22 measured and expressed to the nearest whole meter.

The test was administered in standardised morning and evening sessions over two days to accommodate participants and minimise fatigue effects. A thorough warm-up was provided, and participants were oriented to the procedure beforehand to eliminate ambiguities.

Reliability of Data

Reliability was ensured through tester competency, instrument calibration, and subject consistency. Instruments were sourced from standard companies and verified against originals for accuracy. The researcher underwent extensive practice sessions under expert guidance, with assistance from experienced tennis coaches familiar with the protocol. Tester reliability was established via repeated trials on 15 subjects, yielding intra-class correlation coefficients indicative of high consistency. The Cooper test itself exhibits strong reliability in field settings (Penry et al., 2011), making it appropriate for this population.

Statistical Analysis

The gathered data were analyzed using a one-way analysis of variance (ANOVA) to determine whether significant variations in aerobic endurance existed across the four age categories. The criterion for statistical significance was set at $p < 0.05$. Whenever the computed F-ratio reached significance, Scheffé's post hoc test was applied to identify the specific differences among the group means. All statistical procedures were carried out using a 0.05 level of significance.

This methodology provides a robust, field-applicable framework for assessing aerobic endurance in tennis players, aligning with contemporary recommendations for practical fitness evaluation in racket sports (Fernandez-Fernandez et al., 2025; Pluim & Staal, 2025). The focus

on Cooper's test ensures ecological validity for district-level athletes in resource-limited settings like India.

RESULTS

The results of this cross-sectional study demonstrated clear age-related differences in aerobic endurance among 500 district-level male tennis players from Tamil Nadu, India, assessed during 2012–2013. Aerobic capacity was measured using the Cooper 12-minute run/walk test, with performance expressed as the total distance covered in meters. The data were analyzed statistically through a one-way analysis of variance (ANOVA) to examine variations across the age groups. Whenever the calculated F-ratio reached statistical significance, Scheffé's post hoc analysis was performed to determine the specific differences between groups. An alpha level of 0.05 was established as the standard for statistical significance throughout the study.

Descriptive Statistics and ANOVA Results Table 1 presents the mean distances (± standard deviation) covered by each age group in the Cooper's test, along with the ANOVA summary.

Table 1. Aerobic Endurance Performance (Cooper's 12-Minute Run/Walk Test) Across Age Groups

Group	Age (years)	Range	n	Mean Distance (m) ± SD
Group I	16–20		125	1926.60 ± 266.12
Group II	21–25		125	2146.32 ± 70.24
Group III	26–30		125	2372.24 ± 125.52
Group IV	31–35		125	2450.72 ± 129.91

ANOVA Summary

- Between-groups sum of squares: 20,760,065.6
- Degrees of freedom (between): 3
- Mean square (between): 6,920,021.87
- Within-groups sum of squares: 13,439,995.2
- Degrees of freedom (within): 496
- Mean square (within): 27,096.75
- Obtained F-ratio: 255.38* • Table F-value (df 3,496; $p < 0.05$): 8.53 *Significant at $p < 0.05$.

The obtained F-ratio (255.38) far exceeded the critical value (8.53), indicating highly significant differences in aerobic endurance across the four age groups ($p < 0.05$). This suggests that age is a strong determinant of aerobic performance in this population of competitive tennis players.

Post-Hoc Comparisons (Scheffé's Test) Scheffé's post-hoc analysis revealed significant pairwise differences between all group combinations ($p < 0.05$). The pattern showed a progressive increase in aerobic endurance with advancing age:

- Group IV (31–35 years) significantly outperformed Group III (26–30 years), which outperformed Group II (21–25 years), which in turn outperformed Group I (16–20 years).

- The largest mean difference was between Group I and Group IV (≈524 m), highlighting a substantial enhancement in distance covered among older players.

These findings indicate that aerobic endurance, as measured by maximal distance in the 12-minute run/walk, improves with age up to the mid-30s in this sample. The mean performance in the oldest group (2450.72 m) corresponds to an estimated VO2max in the "good" to "excellent" range for adult males, based on established Cooper test norms (adjusted for age and population), while the youngest group's mean (1926.60 m) aligns with "average" to "good" levels for adolescents transitioning to adulthood.

This age-related improvement contrasts with some general trends in non-athletic populations, where aerobic capacity often peaks in the early 20s and declines thereafter. However, it aligns with evidence from racket sports and tennis-specific research, where sustained training preserves or enhances aerobic fitness into later years. For instance, regular tennis participation in recreational and competitive contexts has been associated with maintained or superior aerobic capacity in middle-aged and older adults compared to sedentary peers, attributed to the sport's intermittent high-intensity demands combined with aerobic recovery periods.

In competitive tennis players, older groups often exhibit higher aerobic endurance due to accumulated training volume, experience, and physiological adaptations (e.g., improved cardiac output and mitochondrial efficiency). Studies on veteran tennis players have shown that long-term participation helps mitigate age-related declines in VO2max, with values remaining elevated even into the 40s–60s. Similarly, in youth and young adult players, aerobic fitness improves with maturation and training, but the present data suggest continued gains into the 30s among district-level athletes, possibly reflecting ongoing skill development and endurance-focused training in this Indian context.

28 These results support the hypothesis that aerobic endurance differs significantly across age groups in district-level male tennis players, with older players demonstrating superior performance. This pattern underscores the value of long-term tennis involvement for cardiorespiratory fitness, particularly in regional competitive settings where training may emphasise endurance over explosive power in later career stages.

Discussion

The present study revealed significant age-related differences in aerobic endurance among 500 districtlevel male tennis players from Tamil Nadu, India, Measured by means of the Cooper 12-minute run/walk test. The results indicated a progressive improvement in performance (distance covered) with advancing age, with the oldest group (31–35 years) achieving the highest mean distance (2450.72 m ± 129.91), followed by the 26–30 years group (2372.24 m ± 125.52), 21–25 years (2146.32 m ± 70.24), and 16– 20 years (1926.60 m ± 266.12). The large F-ratio (255.38, $p < 0.05$) and significant pairwise differences via Scheffé's post-hoc test confirmed that aerobic endurance peaked in the mid-30s within this sample.

This pattern of increasing aerobic capacity with age contrasts with general population trends, where VO2max typically peaks in the early 20s and declines by approximately 10% per decade thereafter due to reduced cardiac output, mitochondrial efficiency, and muscle mass. However, the findings align with evidence from racket sports and tennis-specific research, where sustained participation in the sport preserves or enhances aerobic fitness into later years.

Tennis's intermittent high-intensity nature— combining short bursts with aerobic recovery— promotes adaptations that mitigate typical age-related declines in cardiorespiratory function. For instance, long-term tennis involvement has been associated with maintained superior aerobic capacity in middle-aged and older adults compared to sedentary controls, often attributed to cumulative training volume, improved cardiac efficiency, and the sport's demands for prolonged endurance during matches. Veteran tennis players exhibit higher VO2max values (e.g., 50–55 ml/kg/min in elite contexts) and lower resting heart rates indicative of an endurance-trained state, even into the 40s–60s. In recreational and competitive settings, regular tennis participation serves as a protective factor against aerobic decline, with positive effects contributing to improved body composition and a lower risk of cardiovascular complications. In addition context of Indian athletes, these results may reflect regional training emphases, where district level players often accumulate more years of practice with age (as seen in the descriptive data: 2 years in the 16–20 group vs. 5 years in the 31–35 group), leading to greater physiological adaptations. The Cooper test's field-based nature provides ecological validity for such populations, and population-specific validations in India (e.g., for sedentary youth or other sports like cricket/swimming) support its use, though adjustments for athletic cohorts may enhance precision.

The superior performance in older groups suggests that aerobic endurance benefits from accumulated experience and training consistency, consistent with observations that better aerobic fitness enables players to sustain lower relative intensities during play, reducing fatigue and improving recovery between rallies. This is particularly relevant in tennis, where aerobic capacity supports repeated highintensity efforts and delays fatigue-related performance decrements.

These findings have practical implications for training in Indian tennis development pathways. Younger players (16–20 years) may benefit from targeted aerobic interventions to accelerate gains, while programs for older athletes (26–35 years) should emphasise maintenance through tennis specific drills to capitalise on accumulated adaptations. Contemporary studies could incorporate modern factors like advanced equipment or nutrition, but the core trend underscores tennis as a "lifetime" activity promoting sustained cardiorespiratory health. Limitations include the cross-sectional design (preventing causal inferences on age effects), focus on male district-level players (limiting generalizability to females, elite, or non-Indian cohorts), and potential uncontrolled variables (e.g., training history, nutrition). Future research should employ longitudinal designs, include diverse populations, and integrate sport-specific tests for a fuller picture.

In conclusion, aerobic endurance in district-level male tennis players from Tamil Nadu improves with age up to the mid-30s, highlighting the sport's role in fostering long-term cardiorespiratory fitness. This supports tailored, age-specific training to maximise performance and health benefits in regional competitive tennis.

CONCLUSION

This cross-sectional study of 500 district-level male tennis players from Tamil Nadu, India (2012–2013) demonstrates that aerobic endurance, assessed via Cooper's 12-minute run/walk test, improves progressively with age, peaking in the 31–35 years group (mean: 2450.72 m ± 129.91) compared to younger groups (e.g., 1926.60 m ± 266.12 in 16–20 years), with highly significant differences ($F = 255.38$, $p < 0.05$). These findings highlight tennis as a powerful "lifetime" sport that fosters sustained cardiorespiratory fitness, mitigating typical

agerelated VO2max declines through accumulated training, physiological adaptations, and the game's intermittent aerobic demands—benefits supported by evidence linking long-term tennis participation to enhanced aerobic capacity, healthier body composition, and increased longevity (up to 9.7 years in some cohorts). In the Indian regional context, this underscores the value of consistent practice for optimising performance and health. Future longitudinal research should incorporate modern training advancements, diverse populations (including females), and tennis-specific protocols to refine age-tailored strategies for enhanced endurance, injury prevention, and lifelong participation in the sport.

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