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Estimated Cardiorespiratory Fitness in Multi-Discipline Martial Arts Athletes at the Beginning of Centralized Training: A Cross-Sectional Study

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ABSTRACT

Background & objective: Cardiorespiratory fitness (CRF) is an important component of combat-sport physiology because repeated high-intensity actions require adequate aerobic support and recovery between efforts. However, evidence describing CRF across multiple martial arts disciplines within a single high-performance training cohort remains limited. This study characterized estimated CRF among West Kalimantan PELATDA martial arts athletes at the beginning of centralized training and examined sex-related differences and performance relative to an external historical comparator.

Materials & Methods: A cross-sectional observational study included 41 athletes (26 males and 15 females) representing 11 martial arts disciplines. CRF was assessed using the 20-m Multistage Fitness Test (MFT), and estimated VO_2max was calculated using the Léger regression equation. Age- and sex-specific normative reference values were used to classify CRF into Very Poor, Poor, Fair, Good, Excellent, and Superior categories. Between-sex differences in estimated VO_2max were examined using Welch's independent-samples *t*-test. Fisher's exact test assessed the association between sex and dichotomized CRF status. Exploratory one-sample *t*-tests compared observed mean estimated VO_2max with an external historical comparator of $44.0 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$.

Results: Mean estimated VO_2max was $36.72 \pm 5.87 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ (range, 28.40–56.00; 95% CI 34.87–38.58). Based on age- and sex-specific norms, 4 athletes (9.76%) were classified as Very Poor, 9 (21.95%) Poor, 14 (34.15%) Fair, 7 (17.07%) Good, 4 (9.76%) Excellent, and 3 (7.32%) Superior. Overall, 13 athletes (31.71%) were classified as Low CRF. Males had higher estimated VO_2max than females (38.00 ± 5.85 vs. $34.50 \pm 5.40 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$), but the difference was not statistically significant, $t(31.33) = 1.94$, $p = .062$, Cohen's $d = 0.61$. The sex-by-CRF association was also not statistically significant (Fisher's exact $p = .084$; odds ratio = 4.77, 95% CI 0.89–25.57; Cramér's $V = 0.30$). Compared with the $44.0 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ historical comparator, estimated VO_2max was lower in the total cohort, $t(40) = -7.93$, $p < .001$, $d = -1.24$.

Conclusions: The study provides a multi-discipline baseline profile of estimated CRF in a real-world provincial high-performance cohort. The findings demonstrate substantial heterogeneity in aerobic fitness status and provide a practical reference for longitudinal athlete monitoring. Because the external comparator was derived from a small historical male Tae Kwon Do sample, it should be interpreted contextually rather than as a universal competitive standard.

Keywords

cardiorespiratory fitness; oxygen consumption; martial arts; athletes; multistage fitness test.

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INTRODUCTION

Global and Theoretical Context

Combat sports constitute a major component of international high-performance sport and encompass striking, grappling, and weapon-based disciplines with markedly different technical and physiological demands (Barley et al., 2019, p. 205; Emerson, 2025). Across these sports, athletes must repeatedly execute high-intensity actions while maintaining technical precision, tactical decision-making, and effective recovery between efforts. Although decisive actions may be brief and highly anaerobic, the physiological demands of combat competition are not exclusively anaerobic (Barley et al., 2019, p. 206; Bouzoualegh et al., 2023, p. 119). Evidence from Olympic combat sports indicates substantial oxidative-system involvement during match performance, with estimated oxidative contributions ranging from approximately 62% to 86% in striking sports, around 79% in judo,

and more than 80% in elite fencing (Franchini, 2023). Thus, aerobic capacity represents an important physiological foundation for sustaining repeated high-intensity actions rather than merely supporting prolonged continuous exercise.

Cardiorespiratory fitness (CRF), commonly operationalized through maximal oxygen uptake (VO_2max), reflects the integrated capacity of the cardiovascular, pulmonary, and muscular systems to transport and utilize oxygen during exercise (Rueggsegger & Booth, 2017, p. 2; Wang et al., 2022, p. 8). In combat sports, a well-developed aerobic system may contribute to the restoration of phosphocreatine, removal and metabolism of exercise-related metabolites, and maintenance of work capacity across repeated high-intensity sequences. Accordingly, contemporary combat-sport models conceptualize endurance as a multidimensional construct that extends beyond VO_2max and

includes metabolic thresholds, anaerobic capacity, movement economy, and the capacity to tolerate and recover from repeated high-intensity actions (Barley et al., 2019; Coates et al., 2023, p. 88; Huang et al., 2025, p. 4146).

This physiological framework provides a theoretical rationale for examining VO_2max in martial arts athletes. The energy-system model predicts that greater aerobic capacity should enhance the capacity to sustain intermittent exercise and recover between repeated efforts, while the relative contribution of aerobic and anaerobic metabolism varies according to discipline, bout structure, and technical demands (Archacki et al., 2023, p. 3; Franchini, 2023; Jones & Vanhatalo, 2017, p. 72). Consequently, CRF should not be interpreted as a standalone determinant of combat performance, but as one component of the physiological profile supporting repeated high-intensity performance and recovery.

Critical Review of Existing Evidence

Existing literature consistently demonstrates that elite combat athletes possess sport-specific physiological profiles, but the magnitude and interpretation of aerobic-capacity findings vary across disciplines and study populations. In judo, a systematic review of elite athletes reported high levels of physiological fitness and emphasized the importance of aerobic and anaerobic capacities in international competition (Franchini et al., 2011; Sterkowicz-Przybycień & Fukuda, 2016). Similarly, the review of elite karate athletes by Chaabène et al. (2012) demonstrated that physiological characteristics differ according to competitive level, sex, and event specialization. A meta-analytic investigation of competitive judo athletes including 188 males and 159 females reported mean VO_2max values of 54.8 ± 1.9 and 48.7 ± 2.2 $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, respectively, with a large sex effect ($d = 1.30$), illustrating that sex-specific physiological differences may be substantial in highly trained populations (Sterkowicz-Przybycień & Fukuda, 2016).

However, direct comparison across studies remains problematic because prior investigations differ substantially in population, discipline, testing method, training phase, and analytical design. Some studies have focused on single sports such as judo, karate, taekwondo, or fencing, whereas broader reviews have emphasized the heterogeneity of physiological demands across combat disciplines. For example, elite fencing involves repeated short-duration actions within competition formats that generate substantial cardiovascular and physiological demands, but its movement pattern differs from those of striking and grappling sports (Bottoms et al., 2023; Huang et al., 2025, p. 4146). This heterogeneity limits the validity of treating a single VO_2max value as a universal benchmark across martial arts.

Intervention studies provide additional evidence that aerobic capacity is modifiable, but they also illustrate methodological variability. A systematic review of high-intensity interval training (HIIT) in Olympic combat sports identified only nine eligible studies from 117 initially retrieved records, indicating a relatively limited evidence base at the time (Franchini et al., 2018; Vasconcelos et al., 2020). A subsequent meta-analysis incorporating 12 studies and 255 combat-sport athletes found increases in VO_2max of approximately 2.83 $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ in striking athletes and 2.36 $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ in grappling athletes following high-intensity interval-based interventions (Ma et al., 2023; Vasconcelos et al., 2020). More recent controlled studies continue to support the trainability of aerobic capacity, although sample sizes remain modest. Rezaei et al. (2024) studied only 16 elite karate athletes and found a significant between-group

difference in VO_2max after six weeks of additional HIIT performed three times weekly. In taekwondo, a 2024 controlled study compared technique-specific high-intensity intervals with short sprint interval training over six weeks and reported significant improvements in VO_2max and other physiological outcomes in both intervention conditions, with greater changes in several cardiorespiratory variables in the repeated-sprint condition (Ojeda-Aravena et al., 2021, p. 766159; Song & Sheykhlovand, 2024). These studies provide valuable experimental evidence, but their small samples, single-discipline designs, controlled intervention settings, and relatively short follow-up periods limit direct generalization to heterogeneous provincial high-performance cohorts.

The most recent evidence strengthens, but also complicates, the interpretation. A 2025 systematic review and meta-analysis of 20 studies in Olympic combat-sport athletes found a significant moderate effect of HIIT on maximal oxygen uptake ($ES = 1.007$, 95% CI 0.701–1.312), suggesting that structured interval training can produce meaningful aerobic adaptations in trained combat athletes (Vasconcelos et al., 2020; Yue et al., 2025). At the same time, evidence from non-athlete populations does not necessarily translate directly to elite or competitive athletes, highlighting the importance of training status, exercise dose, and population characteristics when interpreting CRF outcomes (Hernández-Martínez et al., 2025; Mandsager et al., 2018, p. 9).

Measurement strategy represents another important source of heterogeneity. Laboratory cardiopulmonary exercise testing provides the most direct assessment of CRF, whereas the 20-m shuttle run offers a more feasible field-based alternative for large athlete cohorts. Meta-analytic evidence indicates that the 20-m shuttle run demonstrates moderate-to-high criterion-related validity for estimating VO_2max , particularly when age, sex, and body mass are incorporated; nevertheless, the resulting value remains an estimate rather than a direct physiological measurement (Mayorga-Vega et al., 2015; Ruiz et al., 2009). This distinction is important when comparing field-based estimates with laboratory-derived values reported in elite-athlete studies.

Research Gap, Novelty, and International Contribution

Although previous studies demonstrate that CRF is an important component of combat-sport physiology and that aerobic capacity can respond to structured conditioning, it remains unclear how estimated CRF is distributed across multiple martial arts disciplines within a single provincial high-performance cohort entering a centralized national-competition preparation programme. Existing evidence is predominantly discipline-specific, intervention-oriented, or derived from elite athletes assessed under relatively controlled conditions. There is comparatively limited evidence describing the baseline aerobic-fitness profile of a heterogeneous multi-discipline cohort within a real-world regional training system.

The present study addresses this gap by examining the entire eligible cohort of West Kalimantan PELATDA martial arts athletes across 11 disciplines at the beginning of centralized preparation for PON XXI. The novelty therefore lies not in introducing a new physiological test or training intervention, but in applying a standardized field-based assessment to a multi-discipline, real-world high-performance cohort and examining the distribution of estimated VO_2max at the start of centralized preparation. In addition, the study provides sex-stratified comparisons and descriptive discipline-level estimates while explicitly accounting for the very small sample sizes of several sports.

Internationally, this approach extends the existing combat-sport evidence base by testing whether physiological patterns

identified mainly within individual sports are also observable within a heterogeneous provincial training environment. Rather than assuming that findings from elite judo, karate, taekwondo, or fencing can be directly generalized across martial arts, the study provides a pragmatic baseline framework for evaluating CRF within a multi-discipline athlete-management system. The findings can therefore refine current evidence by demonstrating the extent of within-cohort heterogeneity and by identifying the value of routine CRF surveillance during centralized preparation.

Objectives and Hypothesis

The primary objective of this study was to characterize the distribution of estimated cardiorespiratory fitness among martial arts athletes participating in the West Kalimantan PELATDA programme at the beginning of centralized training.

The secondary objectives were to: (1) compare estimated

VO₂max between male and female athletes; (2) describe variation in estimated VO₂max across the represented martial arts disciplines; and (3) compare the overall and sex-stratified mean estimated VO₂max values with a prespecified reference value of 44.0 mL·kg⁻¹·min⁻¹.

Based on established evidence concerning sex-related differences in maximal aerobic capacity, it was hypothesized that male athletes would demonstrate higher estimated VO₂max than female athletes. In addition, it was hypothesized that the overall and sex-stratified mean estimated VO₂max values would be lower than the prespecified reference value of 44.0 mL·kg⁻¹·min⁻¹. Because several disciplines were represented by very small numbers of athletes, no directional inferential hypothesis was specified for between-discipline differences; discipline-specific findings were therefore treated descriptively.

MATERIALS AND METHODS

Study Design and Setting

This study employed a cross-sectional observational design to characterize estimated cardiorespiratory fitness (CRF) among martial arts athletes participating in the West Kalimantan Regional Training Centre (Pusat Pelatihan Daerah [PELATDA]) programme in preparation for the 21st National Sports Week (Pekan Olahraga Nasional [PON] XXI Aceh–North Sumatra 2024). The assessment was conducted at Sultan Syarif Abdurrahman Stadium, Pontianak, West Kalimantan, Indonesia, during the initial phase of the PELATDA programme, before the athletes commenced systematic conditioning sessions within the centralized training programme. Data were collected from 8 to 12 January 2024 during morning testing sessions. The timing was selected to provide a baseline description of estimated CRF at the beginning of centralized preparation.

Participants and Sampling

The target population comprised all athletes registered in the West Kalimantan PELATDA programme for PON XXI. A total-population sampling approach was used, whereby all eligible athletes in the target cohort were invited to participate. A total of 41 athletes completed the assessment and were included in the final analysis, comprising 26 males (63.4%) and 15 females (36.6%) representing 11 martial arts disciplines: pencak silat, boxing, tarung derajat, taekwondo, sambo, muaythai, kickboxing, karate, judo, hapkido, and fencing. All 41 eligible athletes completed the Multistage Fitness Test (MFT), and no participant was excluded because of missing primary outcome data. Participants were eligible if they were officially registered in the West Kalimantan PELATDA programme, had medical clearance indicating no known cardiovascular or musculoskeletal contraindication to maximal field-based exercise, and completed the MFT protocol. Athletes with an acute musculoskeletal injury, a documented contraindication to maximal exercise, or incomplete MFT data were to be excluded. No a priori sample-size calculation was performed because the study aimed to assess the entire eligible PELATDA cohort.

Cardiorespiratory Fitness Assessment

CRF was assessed using the Multistage Fitness Test (MFT), also known as the 20-m Shuttle Run Test or Beep Test. The test was performed on a marked 20-m course on the outdoor rubberized athletics track. Participants ran continuously between two markers positioned 20 m apart in synchronization with

standardized audio signals. The initial running speed was 8.5 km·h⁻¹, with the speed increased by 0.5 km·h⁻¹ at each one-minute stage. Participants were instructed to reach the opposite line in accordance with the audio signal. The test was terminated when a participant failed to reach the required line on two consecutive occasions or voluntarily stopped because of exhaustion.

Before testing, participants were instructed to avoid vigorous exercise and alcohol for 24 h, maintain adequate hydration, and consume approximately 500 mL of water 2 h before testing. A standardized 5-min warm-up consisting of light jogging and dynamic stretching was conducted before the test. Two trained assessors supervised each assessment session. One assessor administered the test and the second independently recorded the final MFT level and shuttle achievement. Environmental conditions were documented during testing and were approximately 28–32°C, 70–80% relative humidity, and wind speed below 5 km·h⁻¹.

Estimation of VO₂max

The primary physiological outcome was estimated maximal oxygen uptake (VO₂max) expressed in mL·kg⁻¹·min⁻¹. Estimated VO₂max was calculated from the final running speed achieved during the MFT using the Léger regression equation: $VO_{2max} = 31.025 + (3.238 \times S) - (3.248 \times A) + (0.1536 \times S \times A)$, where S represents the final running speed in km·h⁻¹ and A represents age in years. The final running speed was determined from the highest successfully completed MFT stage and shuttle. Thus, VO₂max represented an estimated field-based outcome, not a direct measurement obtained from respiratory gas analysis.

Age- and Sex-Specific CRF Classification

Estimated VO₂max was classified according to established age- and sex-specific normative reference values into six categories: Very Poor, Poor, Fair, Good, Excellent, and Superior. The normative framework is attributed to Heyward (1998) and is based on established Cooper Institute reference tables. Because all participants were aged 18–27 years, athletes aged 18–19 years were classified using the 13–19-year reference group, whereas athletes aged 20–27 years were classified using the 20–29-year reference group.

Table 1. Age- and Sex-Specific Normative CRF Classification Thresholds

Age group	Sex	Very Poor	Poor	Fair	Good	Excellent	Superior
13–19 years	Male	<35	35–37	38–44	45–50	51–55	>55

13–19 years	Female	<25	25–30	31–34	35–38	39–41	>41
20–29 years	Male	<33	33–35	36–41	42–45	46–52	>52
20–29 years	Female	<24	24–28	29–32	33–36	37–41	>41

Note. Values are expressed in mL·kg⁻¹·min⁻¹. Classification thresholds are based on the normative framework attributed to Heyward (1998) and the Cooper Institute reference tables.

Importantly, these categories were used as a general normative reference framework, not as sport-specific performance standards for elite martial arts athletes. For an exploratory categorical analysis, Very Poor and Poor were combined as Low CRF, whereas Fair, Good, Excellent, and Superior were combined as Fair-or-Above CRF.

External Historical Comparator

A secondary exploratory analysis compared the observed mean estimated VO₂max values with an external historical comparator of 44.0 mL·kg⁻¹·min⁻¹. The comparator corresponds to the reported mean VO₂max of 44.0 ± 6.8 mL·kg⁻¹·min⁻¹ among 14 male Tae Kwon Do practitioners/black belts assessed using a progressive treadmill protocol in the study by (Thompson & Vinueza, 1991).

The value was treated strictly as a historical sport-specific comparator, not as a universal minimum physiological requirement, ACSM cutoff, or formal competitive standard. Because the original comparator consisted of males only and was obtained from a different historical population and testing context, comparisons involving the female subgroup were interpreted as exploratory and not sex-matched normative comparisons.

Data Management and Statistical Analysis

Participant data were coded using unique study identification

numbers. Variables included sex, martial arts discipline, age, body mass, final MFT level, final shuttle, final running speed, estimated VO₂max, and CRF classification. Continuous variables were summarized using the mean, SD, median, minimum, maximum, and 95% CI where appropriate. Categorical variables were summarized using frequencies and percentages. A Welch independent-samples *t*-test was used to compare estimated VO₂max between male and female athletes. The mean difference, 95% CI, and Cohen's *d* were reported.

A Fisher's exact test was used to evaluate the association between sex and the dichotomized CRF classification because of the small cell frequencies. Cramér's *V* and, where appropriate, the odds ratio with 95% CI were used to describe the strength and precision of the association. One-sample *t*-tests were conducted as exploratory reference-value comparisons between the observed estimated VO₂max means and the external historical comparator of 44.0 mL·kg⁻¹·min⁻¹. For each comparison, the mean difference, 95% CI, *t*, *df*, two-sided *p*, and Cohen's *d* were reported. All statistical tests were two-tailed with α = .05. Statistical analyses were performed using IBM SPSS Statistics version 26 and Microsoft Excel.

RESULTS

Participant Characteristics

A total of 41 athletes were included in the final analysis, comprising 26 males (63.4%) and 15 females (36.6%) across 11 martial arts disciplines. The mean age was 22.32 ± 2.07 years (range, 18–27 years), and mean body mass was 64.77 ± 7.38 kg (range, 52.0–82.0 kg). The largest discipline-specific groups were fencing (*n* = 16) and tarung derajat (*n* = 9), while several disciplines were represented by only one or two athletes. Complete data were available for all participants.

Table 2. Participant Characteristics and Estimated VO₂max by Sex

Variable	Total (N = 41)	Male (n = 26)	Female (n = 15)
Age, years	22.32 ± 2.07	22.31 ± 1.87	22.33 ± 2.44
Age range, years	18–27	19–26	18–27
Body mass, kg	64.77 ± 7.38	66.36 ± 7.52	62.00 ± 6.45
Body mass range, kg	52.0–82.0	52.0–82.0	52.6–75.6
Estimated VO ₂ max, mL·kg ⁻¹ ·min ⁻¹	36.72 ± 5.87	38.00 ± 5.85	34.50 ± 5.40
VO ₂ max range, mL·kg ⁻¹ ·min ⁻¹	28.40–56.00	28.40–56.00	28.40–44.40
VO ₂ max median, mL·kg ⁻¹ ·min ⁻¹	35.87	36.89	33.45

Values are presented as mean ± SD unless otherwise indicated.

Overall Estimated Cardiorespiratory Fitness

The mean estimated VO₂max for the cohort was 36.72 ± 5.87 mL·kg⁻¹·min⁻¹, with values ranging from 28.40 to 56.00 mL·kg⁻¹·min⁻¹ and a median of 35.87 mL·kg⁻¹·min⁻¹. The 95% CI for the cohort mean was 34.87–38.58 mL·kg⁻¹·min⁻¹. Using the age- and sex-specific normative classification framework, 4 athletes (9.76%) were classified as Very Poor, 9 (21.95%) as Poor, 14 (34.15%) as Fair, 7 (17.07%) as Good, 4 (9.76%) as

Excellent, and 3 (7.32%) as Superior. Overall, 13 of 41 athletes (31.71%) were classified as Low CRF (Very Poor or Poor), whereas 28 athletes (68.29%) were classified as Fair or Above.

Table 3. Distribution of Estimated VO₂max by Normative CRF Category

CRF category	n	%
Very Poor	4	9.76
Poor	9	21.95
Fair	14	34.15
Good	7	17.07
Excellent	4	9.76
Superior	3	7.32
Total	41	100.00
Low CRF (Very Poor + Poor)	13	31.71
Fair-or-Above CRF	28	68.29

Note. Classification was based on age- and sex-specific normative thresholds shown in Table 1.

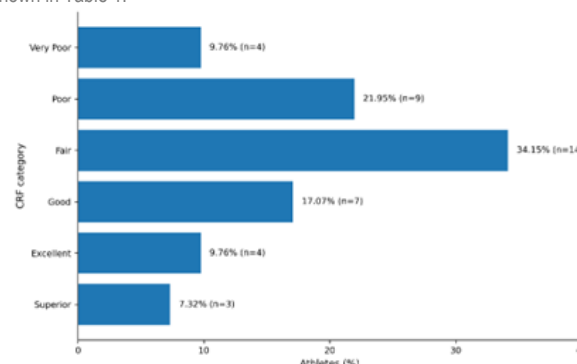


Figure 1. Distribution of estimated cardiorespiratory fitness according to age- and sex-specific normative categories among West Kalimantan PELATDA martial arts athletes (N = 41).

Sex-Stratified Distribution of CRF

The distribution of normative CRF categories differed descriptively by sex. Among male athletes, 4 (15.38%) were

classified as Very Poor, 7 (26.92%) as Poor, 9 (34.62%) as Fair, 4 (15.38%) as Good, 1 (3.85%) as Excellent, and 1 (3.85%) as Superior. Among female athletes, none were classified as Very Poor, 2 (13.33%) were classified as Poor, 5 (33.33%) as Fair, 3 (20.00%) as Good, 3 (20.00%) as Excellent, and 2 (13.33%) as Superior. When categories were dichotomized, 11 male athletes (42.31%) and 2 female athletes (13.33%) were classified as Low CRF. Conversely, 15 males (57.69%) and 13 females (86.67%) were classified as Fair-or-Above CRF.

Table 4. Normative CRF Classification by Sex

CRF category	Male, n (%)	Female, n (%)	Total, n (%)
Very Poor	4 (15.38)	0 (0.00)	4 (9.76)
Poor	7 (26.92)	2 (13.33)	9 (21.95)
Fair	9 (34.62)	5 (33.33)	14 (34.15)
Good	4 (15.38)	3 (20.00)	7 (17.07)

Excellent	1 (3.85)	3 (20.00)	4 (9.76)
Superior	1 (3.85)	2 (13.33)	3 (7.32)
Low CRF	11 (42.31)	2 (13.33)	13 (31.71)
Fair-or-Above CRF	15 (57.69)	13 (86.67)	28 (68.29)

Note. Low CRF = Very Poor + Poor; Fair-or-Above CRF = Fair + Good + Excellent + Superior.

Sex-Based Comparison of Estimated VO₂max

Male athletes had a higher mean estimated VO₂max than female athletes (38.00 ± 5.85 vs. 34.50 ± 5.40 mL·kg⁻¹·min⁻¹), corresponding to a mean difference of 3.50 mL·kg⁻¹·min⁻¹. The Welch independent-samples *t*-test indicated that this difference did not reach the prespecified $\alpha = .05$ significance threshold, $t(31.33) = 1.94$, $p = .062$. The 95% CI for the mean difference was -0.18 to 7.18 mL·kg⁻¹·min⁻¹, and Cohen's *d* was 0.61.

Table 5. Between-Sex Comparison of Estimated VO₂max

Variable	Male (n = 26)	Female (n = 15)	Mean Difference	Welch <i>t</i>	df	<i>p</i>	95% CI	Cohen's <i>d</i>
Estimated VO ₂ max, mL·kg ⁻¹ ·min ⁻¹	38.00 ± 5.85	34.50 ± 5.40	3.50	1.94	31.33	.062	-0.18 to 7.18	0.61

Values are mean ± SD. Welch's independent-samples *t*-test was used.

Comparison With the External Historical Comparator

The overall mean estimated VO₂max was 7.28 mL·kg⁻¹·min⁻¹ lower than the external historical comparator of 44.0 mL·kg⁻¹·min⁻¹. The exploratory one-sample comparison yielded $t(40) = -7.93$, $p < .001$, with a 95% CI for the mean difference of -9.13 to -5.42 mL·kg⁻¹·min⁻¹ and Cohen's *d* = -1.24. For males, the mean estimated VO₂max was 6.00

mL·kg⁻¹·min⁻¹ lower than the comparator, $t(25) = -5.23$, $p < .001$, 95% CI -8.36 to -3.63, Cohen's *d* = -1.02. For females, the mean estimated VO₂max was 9.50 mL·kg⁻¹·min⁻¹ lower, $t(14) = -6.81$, $p < .001$, 95% CI -12.49 to -6.50, Cohen's *d* = -1.76. Because the comparator was derived from a historical male Tae Kwon Do sample, these sex-specific comparisons are considered exploratory and are not interpreted as sex-matched normative comparisons.

Table 6. Exploratory One-Sample Comparison With the 44.0 mL·kg⁻¹·min⁻¹ Historical Comparator

Group	n	Mean ± SD	Comparator	Mean Difference	95% CI	<i>t</i>	df	<i>p</i>	Cohen's <i>d</i>
Total	41	36.72 ± 5.87	44.00	-7.28	-9.13 to -5.42	-7.93	40	< .001	-1.24
Male	26	38.00 ± 5.85	44.00	-6.00	-8.36 to -3.63	-5.23	25	< .001	-1.02
Female	15	34.50 ± 5.40	44.00	-9.50	-12.49 to -6.50	-6.81	14	< .001	-1.76

Note. Mean difference = observed mean - 44.0 mL·kg⁻¹·min⁻¹. The 44.0 value is an external historical comparator reported for 14 male Tae Kwon Do practitioners/black belts by Thompson and Vinuesa (1991), not a universal competitive standard.

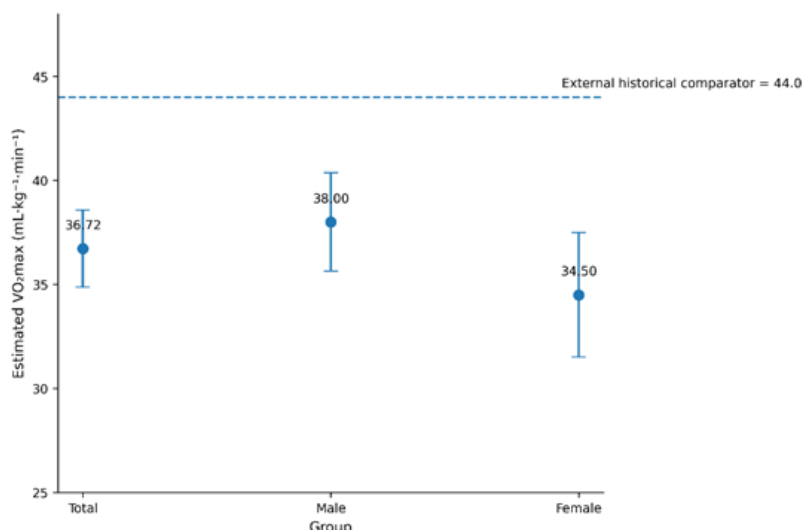


Figure 2. Estimated VO₂max in the total cohort and by sex, presented as mean values with 95% confidence intervals. The horizontal dashed line indicates the external historical comparator of 44.0 mL·kg⁻¹·min⁻¹.

Association Between Sex and Dichotomized CRF

Among male athletes, 11 of 26 (42.31%) were classified as Low CRF compared with 2 of 15 female athletes (13.33%). Fisher's exact test yielded a two-sided $p = .084$, indicating that the observed distribution did not meet the prespecified $\alpha = .05$ threshold. The corresponding odds ratio was 4.77, with a 95% CI of approximately 0.89–25.57, and Cramér's *V* = 0.30. These

estimates indicate considerable uncertainty associated with the sex-by-category comparison because of the modest sample size, particularly the small number of participants classified as Low CRF among females.

Table 7. Association Between Sex and Dichotomized CRF Classification

Sex	Low CRF, n (%)	Fair-or-Above CRF, n (%)	Total
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Male	11 (42.31)	15 (57.69)	26
Female	2 (13.33)	13 (86.67)	15
Total	13 (31.71)	28 (68.29)	41

Note. Low CRF = Very Poor + Poor; Fair-or-Above CRF = Fair + Good + Excellent + Superior. Fisher's exact test, two-sided $p = .084$; odds ratio = 4.77 (95% CI, 0.89–25.57); Cramér's $V = 0.30$.

Estimated VO₂max Across Martial Arts Disciplines

Estimated VO₂max varied descriptively across the 11 martial arts disciplines. Among disciplines represented by more than one athlete, mean estimated VO₂max ranged from 33.30 ± 6.92 mL·kg⁻¹·min⁻¹ in taekwondo ($n = 2$) to 41.15 ± 4.03 mL·kg⁻¹·min⁻¹ in muaythai ($n = 2$). Tarung derajat athletes ($n = 9$) had a mean of 37.73 ± 3.28 mL·kg⁻¹·min⁻¹, while fencing, the largest subgroup ($n = 16$), had a mean of 34.57 ± 4.98 mL·kg⁻¹·min⁻¹.

Karate had the highest observed discipline-specific mean (56.00 mL·kg⁻¹·min⁻¹; $n = 1$), whereas hapkido had the lowest

individual value (31.35 mL·kg⁻¹·min⁻¹; $n = 1$). Because several disciplines had only one or two athletes, these results are reported descriptively only and were not subjected to formal inferential comparison.

Table 8. Estimated VO₂max by Martial Arts Discipline

Discipline	n	Mean ± SD, mL·kg ⁻¹ ·min ⁻¹	Range
Pencak Silat	1	44.40	44.40
Boxing	3	39.02 ± 8.27	29.58–44.99
Tarung Derajat	9	37.73 ± 3.28	34.54–44.00
Taekwondo	2	33.30 ± 6.92	28.40–38.19
Sambo	3	33.34 ± 0.51	33.04–33.93
Muaythai	2	41.15 ± 4.03	38.30–44.00
Kickboxing	2	38.73 ± 7.46	33.45–44.00
Karate	1	56.00	56.00
Judo	1	37.86	37.86
Hapkido	1	31.35	31.35
Fencing	16	34.57 ± 4.98	28.40–46.14

Note. SD is not estimable for disciplines with $n = 1$. Discipline-specific findings are descriptive because of the small and unequal subgroup sizes.

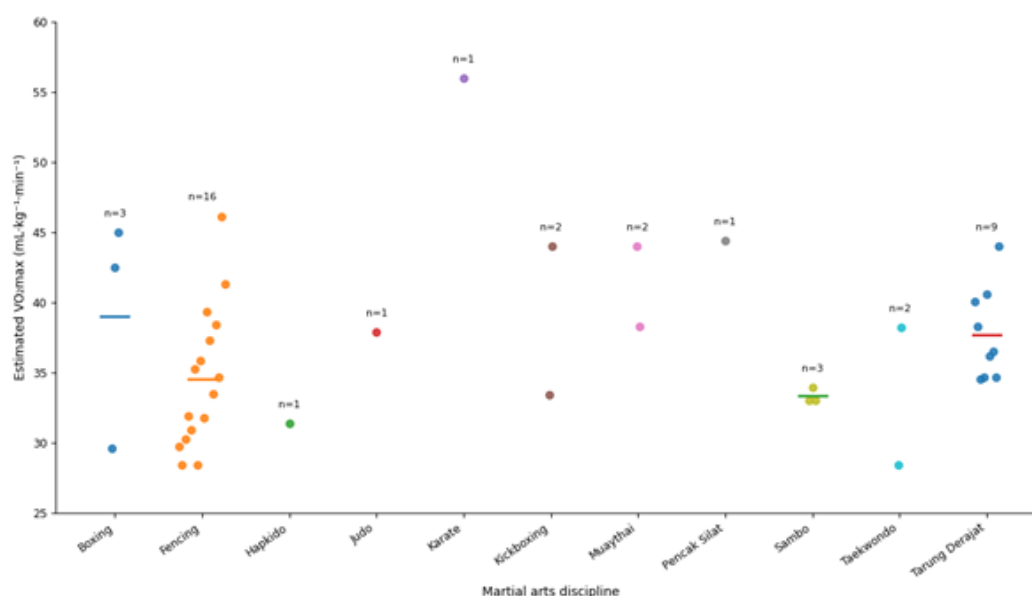


Figure 3. Individual estimated VO₂max values across the 11 represented martial arts disciplines. Each point represents an individual athlete; horizontal markers indicate the group mean for disciplines with at least three participants.

DISCUSSION

Principal Findings

The present study characterized estimated cardiorespiratory fitness (CRF) among 41 martial arts athletes participating in the West Kalimantan PELATDA programme at the beginning of centralized preparation for PON XXI. The overall estimated VO₂max was 36.72 ± 5.87 mL·kg⁻¹·min⁻¹, with values ranging from 28.40 to 56.00 mL·kg⁻¹·min⁻¹. When age- and sex-specific normative reference values were applied, 4 athletes (9.76%) were classified as Very Poor, 9 (21.95%) as Poor, 14 (34.15%) as Fair, 7 (17.07%) as Good, 4 (9.76%) as Excellent, and 3 (7.32%) as Superior. Thus, 13 athletes (31.71%) were classified as Low CRF, whereas 28 (68.29%) were classified as Fair or above. These findings indicate considerable heterogeneity in aerobic-fitness status within this multi-discipline provincial high-performance cohort rather than a uniformly low CRF profile.

The physiological relevance of CRF in combat sports is supported by the intermittent nature of martial arts competition. Combat athletes repeatedly perform high-intensity actions separated by brief recovery periods, requiring coordinated contributions from oxidative and anaerobic energy systems. Franchini (2023) reported substantial oxidative contributions

across Olympic striking, grappling, and weapon-based combat sports, although the relative contribution varies according to discipline and competition structure. Consequently, aerobic capacity may contribute to the restoration of energy substrates and recovery between repeated high-intensity actions even when the decisive actions themselves are predominantly anaerobic.

The mean estimated VO₂max observed in the present cohort was lower than values frequently reported in highly trained international combat-sport populations. For example, Sterkowicz-Przybycień and Fukuda (2016) reported pooled VO₂max values of approximately 54.8 mL·kg⁻¹·min⁻¹ in male and 48.7 mL·kg⁻¹·min⁻¹ in female competitive judo athletes. However, direct numerical comparisons should be interpreted cautiously because the present study used a field-based estimate, whereas many elite-athlete studies have used laboratory-based measurements. In addition, differences in training status, body mass, competitive level, discipline, and testing procedures can produce substantial variation in observed VO₂max (Kaur et al., 2026; Williams et al., 2019, p. 29).

Accordingly, the present findings should be interpreted primarily as a baseline physiological profile of a specific real-

world training cohort, rather than as evidence that the athletes possess inadequate competitive performance. Combat-sport endurance is multidimensional and extends beyond VO_2max to include metabolic thresholds, anaerobic capacity, movement economy, repeated-sprint ability, and recovery capacity (Barley et al., 2019; Gaziyeve et al., 2026, p. 429).

Interpretation of the Multi-Discipline Profile

The inclusion of 11 martial arts disciplines represents an important contribution of the study because much of the existing literature is discipline-specific. The physiological requirements of boxing, taekwondo, judo, karate, fencing, and other combat sports differ in bout structure, technical actions, movement patterns, work-to-rest ratios, and relative energy-system contributions (Franchini, 2023; Tortu et al., 2024, p. 3).

The discipline-specific values in the present study should nevertheless be interpreted descriptively. Several disciplines were represented by only one or two athletes, so individual observations can strongly affect group means. For example, a high value in a single athlete cannot reasonably be interpreted as evidence that the entire discipline has superior aerobic capacity. Conversely, a low individual value should not be interpreted as evidence of a discipline-wide deficiency.

This heterogeneity supports a discipline-aware approach to athlete monitoring. A common field-based CRF assessment can facilitate programme-level surveillance, but the interpretation of individual results should consider discipline-specific physiological demands and the athlete's broader training profile. The present study therefore extends the literature by demonstrating the feasibility of characterizing aerobic fitness across a heterogeneous provincial cohort without assuming that all martial arts disciplines share the same physiological profile.

Sex Differences in Estimated VO_2max

Male athletes demonstrated a higher mean estimated VO_2max than female athletes (38.00 ± 5.85 vs. 34.50 ± 5.40 $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$), corresponding to a mean difference of 3.50 $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$. However, the Welch independent-samples *t*-test did not reach the prespecified significance level, $t(31.33) = 1.94$, $p = .062$, with a 95% CI of -0.18 to 7.18 $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ and Cohen's $d = 0.61$. Thus, the point estimate favored males, but the confidence interval included zero and the study did not provide sufficient statistical evidence to establish a between-sex difference.

The direction of the observed difference is compatible with established physiological differences in maximal aerobic capacity between males and females. Sex-related variation in hemoglobin concentration, cardiac output, body composition, and oxygen transport can contribute to differences in VO_2max (Santisteban et al., 2022; Tocci et al., 2020). Comparable sex differences have also been reported in competitive judo populations (Nicholas et al., 2025, p. 242; Sterkowicz-Przybycień & Fukuda, 2016).

Nevertheless, the present study cannot determine the mechanisms underlying the observed difference. The female subgroup comprised only 15 athletes, and the study was not designed to disentangle the effects of sex from discipline, training history, body composition, or other physiological characteristics. The moderate effect size should therefore be interpreted as an estimate of the observed between-group difference rather than as confirmation of a population-level effect.

The categorical analysis yielded a complementary result. Low CRF was observed in 42.31% of males and 13.33% of females. Fisher's exact test produced $p = .084$, with an odds ratio of approximately 4.77 (95% CI, 0.89–25.57) and Cramér's $V = 0.30$. Although the point estimate suggests higher odds of Low CRF

classification among males in this sample, the wide confidence interval and non-significant Fisher's exact test indicate substantial uncertainty. The categorical findings therefore should not be interpreted as evidence of a definitive sex-related difference.

Comparison With the External Historical Comparator

An exploratory comparison was conducted against the 44.0 $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ external historical comparator. This value corresponds to a reported mean VO_2max of 44.0 ± 6.8 $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ among 14 male Tae Kwon Do black belts/practitioners in an earlier study by Thompson and Vinueza (1991). The original study examined the physiological profile of 14 male Tae Kwon Do black belts whose regular exercise consisted exclusively of Tae Kwon Do training two to three days per week.

The overall estimated VO_2max in the present cohort was 7.28 $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ below this historical comparator. The exploratory one-sample analysis yielded $t(40) = -7.93$, $p < .001$, Cohen's $d = -1.24$, with a 95% CI for the mean difference of -9.13 to -5.42 $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$. Similar differences were observed in males, $t(25) = -5.23$, $p < .001$, $d = -1.02$, and females, $t(14) = -6.81$, $p < .001$, $d = -1.76$.

These results indicate that the mean estimated VO_2max of the present cohort was lower than the historical comparator. However, the comparison must be interpreted cautiously because the comparator was derived from a small, exclusively male Tae Kwon Do sample from a different historical, training, and methodological context. It should therefore not be interpreted as a universal minimum physiological requirement or as a formal standard for national-level martial arts competition. Indeed, published data show that VO_2max values among competitive taekwondo athletes can vary substantially across competitive levels and testing methods.

The one-sample *t*-test should therefore be understood as a contextual external-comparator analysis rather than as a normative test against a known population parameter. This distinction is particularly important for the female subgroup because the external comparator itself was derived from males.

Interpretation of the Normative CRF Classification

The revised classification approach provides a more appropriate demographic interpretation than a single universal cutoff. Established normative tables differentiate VO_2max categories by age and sex, recognizing that expected aerobic capacity varies across these characteristics ("Advanced Fitness Assessment & Exercise Prescription," 1998). For the present sample, athletes aged 18–19 years were evaluated using the 13–19-year reference group and those aged 20–27 years using the 20–29-year reference group.

Under this framework, the largest proportion of athletes fell within the Fair category (34.15%), followed by Poor (21.95%) and Good (17.07%). This distribution differs substantially from the previous classification, which treated a much larger proportion of athletes as Very Poor or Poor. The revised classification consequently provides a more defensible description of the cohort because it accounts for demographic differences in expected CRF rather than applying a single threshold across all participants.

Importantly, normative classifications developed for general fitness populations should not be equated with sport-specific performance standards. High-performance combat athletes may have physiological demands that differ from those of general fitness populations, and discipline-specific benchmarks may be considerably higher. Therefore, the normative categories are useful for contextualizing individual CRF status, whereas direct

comparisons with elite sport populations are better reserved for the discussion of competitive physiology.

Measurement Considerations

The use of the 20-m Multistage Fitness Test provides a practical method for evaluating CRF across a relatively large cohort outside a laboratory environment. The test was specifically designed as a field-based assessment of aerobic fitness, and subsequent evidence supports its criterion-related validity for estimating VO_2max , particularly in adults. A meta-analysis of 57 studies and 78 correlation coefficients reported moderate-to-high validity coefficients, with stronger validity when variables such as sex, age, and body mass were incorporated (Mayorga-Vega et al., 2015).

However, the estimated VO_2max generated by the MFT remains an indirect outcome rather than a direct measurement of oxygen uptake. Field-test performance can also be influenced by pacing, motivation, turning ability, running economy, familiarity with the protocol, and environmental conditions. The MFT should therefore be interpreted as a practical estimate of CRF rather than a substitute for laboratory cardiopulmonary exercise testing when high physiological precision is required.

This limitation is particularly relevant to comparisons with published elite-athlete datasets obtained using treadmill or cycle-ergometer gas analysis. Apparent differences between studies may partially reflect measurement-method differences rather than true differences in physiological capacity.

Environmental and Training Context

Testing was performed outdoors under approximately 28–32°C and 70–80% relative humidity. Heat and humidity can increase thermoregulatory and cardiovascular strain during endurance exercise and may reduce exercise performance when compared with more temperate conditions (Alhadad et al., 2019, p. 89; Jenkins et al., 2022).

The environmental conditions should therefore be considered when interpreting the absolute MFT results and comparing them with studies conducted under laboratory or cooler conditions. At the same time, because all athletes were assessed within the same general training environment, the study retains practical value for monitoring this specific PELATDA cohort.

The assessment also occurred at the beginning of centralized training. A possible contextual explanation for lower individual values is a reduction in prior training stimulus during a transition or off-season period. Detraining research has demonstrated that reductions in training stimulus can produce decreases in VO_2max and other cardiorespiratory adaptations in trained individuals (Mujika & Padilla, 2000; Zheng et al., 2022). However, the present study did not measure preceding training volume, intensity, duration, or frequency. Therefore, detraining should be considered only a plausible contextual explanation, not a demonstrated cause of the present results.

Practical Implications

The findings support the use of systematic and repeated CRF monitoring within high-performance martial arts programmes. The value of baseline assessment is not simply to classify athletes but to identify individual trajectories over time and to determine whether conditioning programmes produce meaningful physiological adaptation.

HIIT is one potential conditioning strategy supported by combat-sport intervention literature. A systematic review by Franchini et al. (2018) identified evidence that HIIT can improve physiological and performance outcomes in Olympic combat-sport athletes, while a meta-analysis by Vasconcelos et al. (2020)

reported improvements in VO_2max among striking and grappling athletes. More recently, Yue et al. (2025) reported a significant effect of HIIT on aerobic capacity across Olympic combat sports.

These findings provide a rationale for considering interval-based aerobic conditioning within future PELATDA training programmes, but they should not be interpreted as evidence that HIIT itself was effective in the current study. The present research was observational and did not include a training intervention or control group. Any conditioning strategy should therefore be integrated with technical-tactical practice, strength and power development, recovery management, and the specific physiological demands of each martial art.

Strengths and Limitations

The study has several strengths. First, all eligible athletes within the West Kalimantan PELATDA cohort were assessed, avoiding the sampling of only a selected subgroup. Second, the cohort included 11 martial arts disciplines, expanding the descriptive evidence beyond the single-discipline populations that dominate much of the combat-sport literature. Third, the MFT procedure, pre-test instructions, testing location, environmental conditions, and assessor procedures were standardized and documented.

Several limitations should nevertheless be considered. The cross-sectional design prevents causal inference and does not allow assessment of changes in CRF across the training cycle. VO_2max was estimated from a field test rather than directly measured using respiratory gas analysis. The small and unequal discipline-specific samples also limit the precision of sport-specific estimates and preclude robust inferential comparisons across all disciplines. In addition, the study did not collect detailed information on previous training exposure, training load, body composition, nutrition, sleep, ventilatory thresholds, anaerobic capacity, or competition performance (Alessandro et al., 2025, p. 10; Blume & Wolfarth, 2019, p. 1406; Woods et al., 2018, p. 16).

A further limitation concerns the 44.0 $\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ historical comparator. Because it was derived from a small male Tae Kwon Do sample, it cannot be considered a universal benchmark for the heterogeneous population studied here. Its use is therefore restricted to exploratory contextual comparison. Finally, the revised normative classification is based on general age- and sex-specific reference values rather than martial-arts-specific performance standards. Future studies should combine normative classification with directly measured VO_2max and discipline-specific reference distributions.

Future Research

Future research should use longitudinal designs to examine changes in CRF across the PELATDA training cycle and determine whether baseline estimated VO_2max predicts subsequent physiological adaptation. Direct cardiopulmonary exercise testing would improve measurement precision, while simultaneous assessment of ventilatory thresholds, repeated-sprint ability, heart-rate responses, training load, body composition, and sport-specific performance would provide a more comprehensive understanding of combat-sport endurance.

Larger multicentre samples would also permit robust comparisons between martial arts disciplines and sex groups. Rather than applying a single reference value to heterogeneous combat sports, future investigations should establish discipline-, sex-, age-, and competitive-level-specific reference distributions. Such evidence would enable more precise interpretation of CRF in high-performance martial arts and strengthen the transferability of findings across different athlete populations.

CONCLUSION

This study provides a multi-discipline baseline profile of estimated cardiorespiratory fitness among 41 West Kalimantan PELATDA martial arts athletes representing 11 disciplines at the beginning of centralized preparation. The overall estimated VO_2max was $36.72 \pm 5.87 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. Using age- and sex-specific normative reference values, 13 athletes (31.71%) were classified as Very Poor or Poor, while 28 athletes (68.29%) were classified as Fair or above. Male athletes had a higher mean estimated VO_2max than female athletes, but the between-sex difference did not reach statistical significance.

The exploratory comparison with the $44.0 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ external historical comparator showed that the overall, male, and female subgroup means were lower than that comparator.

However, because the comparator originated from a small historical male Tae Kwon Do sample, it should not be interpreted as a universal competitive threshold. The principal contribution of this study is therefore the characterization of estimated CRF within a real-world, multi-discipline provincial high-performance cohort.

These findings support systematic longitudinal CRF monitoring and individualized conditioning assessment rather than reliance on a single universal aerobic-fitness standard. Future research should prioritize direct VO_2max measurement, longitudinal training-cycle assessment, larger multicentre samples, and discipline-specific physiological and performance indicators to determine how aerobic-fitness development relates to training adaptation and competitive performance.

DECLARATIONS

Ethical Approval

This study was conducted in accordance with the ethical principles of the Declaration of Helsinki and applicable Indonesian research-ethics requirements. Ethical approval was obtained from the Research Ethics Committee of Universitas Tanjungpura before commencement of data collection (Approval Reference No. UT-PNLTN/LPPM-7211). The study protocol, participant information, consent procedures, and data-protection arrangements were approved by the relevant ethics committee.

Consent to Participate

Written informed consent was obtained from all participants before their participation in the study. For participants younger than 18 years, written informed consent from a parent or legal guardian was additionally obtained. Participation was voluntary, and participants were informed of their right to withdraw from the study at any time without consequences for their participation in the PELATDA programme. Participant information and individual-level data were anonymised for research reporting.

Consent for Publication

Not applicable. This manuscript does not contain personally identifiable participant information, identifiable clinical information, or identifiable images requiring individual consent for publication. Results are reported in aggregate form, and individual participant identities are not disclosed.

Author Contributions (CRediT)

Based on the contribution statement provided in the original manuscript, which identifies contributions to study design, data collection, statistical analysis, manuscript preparation, and funding acquisition, the contributions are reported using the CRediT taxonomy as follows:

Novi Yanti: Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft, Funding acquisition.

Victor G. Simanjuntak: Investigation, Formal analysis, Writing – review & editing, Funding acquisition.

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Conflict of Interest

The authors declare no conflict of interest. The authors confirm that there were no commercial, financial, or personal relationships that could have influenced the design, conduct, analysis, interpretation, or reporting of this study.

Data Availability

The data underlying this study are not publicly available in an open repository because they contain participant-level research information and are subject to ethical and confidentiality considerations. De-identified data may be made available by the corresponding author upon reasonable request, subject to approval by the responsible institutional ethics authority and applicable data-protection requirements.

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Generative AI Disclosure

Generative AI was used solely to assist the authors during manuscript preparation, including language refinement, structural editing, organization of sections, and improvement of clarity and readability. Generative AI was not used to generate, fabricate, alter, or selectively report research data, statistical results, participant characteristics, or study findings. All scientific content, methodological decisions, statistical interpretations, citations, and final statements were reviewed and verified by the authors, who retain full responsibility for the accuracy, originality, integrity, and final content of the manuscript.

No confidential participant-identifying information was intentionally entered into a generative-AI prompt for manuscript generation or editing. Participant confidentiality and institutional data-governance requirements remain the responsibility of the authors throughout the research and publication process.

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