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Association between peak height velocity (PHV), speed, and agility in pencak silat athletes

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ABSTRACT

Background: Peak height velocity (PHV) is a key indicator of biological maturity in youth athletes, strongly influencing neuromuscular development and physical performance. While PHV has been widely studied in sports science, its association with speed and agility in pencak silat—an Indonesian martial art that relies heavily on explosive movements and motor coordination—remains underexplored. **Research Objectives:** This study aimed to examine the association between PHV, speed, and agility in young pencak silat athletes and to discuss implications for maturity-based training programs. **Methods:** A cross-sectional study was conducted on 53 athletes (21 males, 32 females; aged 11–15 years) from the Al Ghozaliyah Pencak Silat Training Center. PHV was estimated using the Mirwald equation from anthropometric measurements. Speed was assessed via a 20 m sprint test, and agility using the Illinois Agility Test. Pearson correlation and independent t-tests were performed to analyze associations and sex-based differences. **Finding/Results:** PHV showed a significant negative correlation with agility ($r = -0.356$, $p = 0.009$) and sprint speed ($r = -0.341$, $p = 0.013$), indicating that athletes past PHV performed better. A strong positive correlation was also found between agility and speed ($r = 0.509$, $p < 0.001$). Male athletes demonstrated superior sprint performance ($p = 0.021$), while females recorded slower agility times ($p = 0.018$). **Conclusion:** Biological maturity, as reflected by PHV, plays a significant role in shaping speed and agility in young pencak silat athletes. Training programs should therefore be individualized based on maturation status rather than chronological age, with emphasis on neuromuscular development during and after PHV to maximize performance potential and reduce injury risk. Future research should employ longitudinal designs with larger, multi-center samples and explore PHV's influence on technical–tactical performance and the potential role of bio-banding in martial arts competitions.

Keywords: Peak height velocity; pencak silat athletes; speed and agility; youth sports training

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INTRODUCTION

Sport plays a vital role in enhancing physical and mental health, social interaction, and promoting overall well-being (Bull et al., 2020; Mandolesi et al., 2018; Eather et al., 2023). In competitive sports, optimal performance depends on systematic training grounded in sports science, including an understanding of athletes' biological development (Matagi, 2025).

One key indicator of biological maturation is Peak Height Velocity (PHV), the period of maximum growth in stature during adolescence. PHV is associated with significant changes in body composition, strength, and motor performance, making it a crucial factor in youth athletic development (Malina et al., 2021; Albaladejo-Saura et al., 2021). Because chronological age does not accurately reflect biological maturity, PHV provides a more precise benchmark for adaptation of training programs (Cumming et al., 2017; Murray et al., 2024).

Pencak silat, a traditional Indonesian martial art and cultural heritage, demands high levels of physical fitness, including speed, agility, coordination and explosive power (Ihsan et al., 2018). During the PHV phase, rapid skeletal growth and hormonal changes can temporarily disrupt motor control, increase injury risk and affect technical execution (Lloyd & Oliver, 2012; Towlson et al., 2021). Therefore, training programs that consider PHV may enhance performance and safety in young pencak silat athletes.

Previous study by Annas and Sumartiningsih (2022) has demonstrated that physical activity levels are significantly associated with the timing and progression of PHV in children aged 9-11 years, highlighting the role of structured training in supporting healthy growth. Their findings suggest that well-designed physical activity programs can positively influence growth trajectories, reinforcing the need for maturity-sensitive training in youth sports.

Further supporting this, Sumartiningsih et al. (2021) found that regular, moderate to vigorous physical activity is positively correlated with optimal PHV expression in school-aged children. This underlines the importance of consistent training promoting favorable developmental outcomes. Additionally, Fanita and Sumartiningsih (2023) showed that both the frequency and duration of training significantly influence PHV timing in young athletes, with longer and more frequent training sessions associated with earlier and more stable PHV onset in football players. These findings emphasize that training load must be carefully managed in relation to biological development.

Despite this growing body of evidence, a critical research gap remains in the application of PHV to martial arts, particularly pencak silat. While studies such as Hindawan et al. (2020) have analyzed the anthropometric and physical profiles of pencak silat athletes, they did not integrate biological maturity into their assessments. Similarly, Lubis and Wardoyo (2014) focused on technical and conditioning aspects without considering PHV, potentially limiting the effectiveness of their training recommendations.

Moreover, while PHV has been extensively studied in sports like soccer (Philippaerts et al., 2006), and handball (Hammami et al., 2018), its role in martials art, where agility, speed and precise motor control are paramount, remains underexplored. Most existing studies apply PHV to team sports or general fitness, but few have examined its relationship with sport-specific performance in pencak silat.

Recent research by Shapie et al. (2018) highlights that pre-PHV athletes show greater responsiveness to coordination and skill training, while post-PHV athletes benefit more from strength and tactical development. However, this finding has not yet been validated in pencak silat, where technical precision and rapid directional changes are central to performance.

The novelty of the study is to examine the relationship between PHV, speed, and agility in adolescent pencak silat athletes; use PHV as a biological maturity marker to inform sport-specific training design in a martial art context; provide gender comparative data on performance difference aligned with maturation status; build the foundational work to advance maturity-based training in Indonesian youth sports. By focusing on biological age rather than chronological age, this research offers a more individualized and scientifically grounded approach to athletes' development in pencak silat.

This study aims to analyze the association between Peak Height Velocity (PHV) and physical performance (speed and agility) in young pencak silat athletes, compare speed and agility performance between male and female athletes in relation to their PHV status, provide evidence base recommendations for designing maturity-sensitive training program that optimize performance and reduce injury risk. The findings are expected to support coaches in trasitioning from age-based to maturity-based programming, using PHV as a practical tool for individualizing training in pencak silat.

METHOD

Study Design

A cross-sectional design was conducted to assess the association between PHV, speed, and agility in adolescent pencak silat athletes (Wang & Cheng, 2020). The design focus in maturation and performance during a critical development.

Participants

Fifty-three athletes (21 males and 32 females, aged 11-15 years), were recruited via purposive sampling from the Al-Ghozaliyah Pencak Silat Training Center in Semarang, Central Java, Indonesia. Inclusion criteria (1) regular training (≥ 3 sessions/week), (2) no current injury or illness, (3) active in competition. Exclusion criteria included physical or cognitive conditions affecting participation. Mean age was 13.9 ± 0.8 years for males and 12.3 ± 0.8 years for females. All participants and their guardians provided written informed consent prior to data collection.

Measurements

Anthropometry and PHV Estimation

Height, sitting height, leg length, body weight and body mass index (BMI) were measured using standrdized protocols. Standing height was recorded to the nearest 0.1 cm using a stadiometer and body weight to the nearest 0.1 kg using a digital scale. Sitting height was measure with a sliding headboard and leg length calculated as the difference between standing and sitting height.

PHV age (years from peak height velocity) was estimated using the Mirwald et al. (2002) regression equation, implemented via Microsoft Excel, based on chronological age, sex, height, sitting height and weight. This non-invasive method is widely validated and used in youtth athletic populations to estimate biological maturiy status (Malina et al., 2021; Annas & Sumartiningsih, 2022).

Physical Performance Tests

Speed was assessed using a 20-meter sprint test. Athletes started from a standing position, and time was recorded using a digital stopwatch by two trained assessors. Two trial were conducted with a 3 minutes rest interval, and best time was used for analysis. This test has demonstrated high reliability (ICC = 0.91) in youth athletes (Lutorco et al., 2018).

Agility was evaluated using the Illinois agility test. Athletes navigated a zig-zag course (10 m x 5 m) marked with cones, and the best of two trials was recorded. The test requires rapid changes in direction and has excellent test-retest reliability (ICC = 0.96) (Hachana et al., 2013). All tests were conducted on a flat, non-slip surface under consistent environmental conditions.

Procedures

Data collection was conducted on September 12, 2024, at the Al-Ghozaliyah Pencak Silat Training Center. After a standardized 10-minute dynamic warm-up (jogging, joint mobility, and sports specific movements), anthropometric measurements were taken, followed by the 20-meter sprint and Illinois agility test. Trial was separated by 3-5 minutes of passive rest to minimize fatigue. All procedures were supervised by trained researchers to ensure consistency and validity.

Ethical Approval

The study was approved by the Research Ethics Committee of the Faculty of Medicine, Universitas Negeri Semarang (No:104/KEPK/FK/KLE/2025). Written informed consent was obtained from all participants and their legal guardians prior to participation. All procedures adhered to the ethical standards of the Declaration of Helsinki.

Statistical Analysis

Data was analyzed using IBM SPSS Statistics version 27. Descriptive statistics (mean ± standard deviation) were used to summarize participant characteristics. The Shapiro-Wilk test was used to assess normality of data distribution. For normally distributed data, Pearson's correlation coefficient was used to examine relationships between PHV, speed, agility, and age. Independent samples t-test were performed to compare speed agility performance between male and female athletes. Effect sizes were interpreted as small (r = 0.10), moderate (r = 0.30), and large (r = 0.50) (Cohen, 1988 as cited in Schober et al., 2018). Statistical significance was set at $p < 0.05$. The sample size (n = 53) provided 80% power to detect a moderate correlation ($r \geq 0.3$) at $\alpha = 0.05$, which is adequate for correlation studies in sports science (Faul et al., 2007).

RESULTS AND DISCUSSION

Results

Participant Characteristics

A total of 53 adolescent pencak silat athletes (21 males, 32 females), aged 11-15 years, participated in this cross-sectional study. Descriptive anthropometric and training data are presented in Table 1.

Table 1. Description of Research Data

Variable	Female (N = 32) Mean ± SD	Male (N = 21) Mean ± SD
Age (year)	12.25 ± 0.80	13.91 ± 0.77
Height (cm)	152.19 ± 6.54	162.24 ± 8.67
Body Weight (kg)	43.51 ± 6.73	49.44 ± 12.16
Sitting Height (cm)	68.32 ± 2.98	73.41 ± 3.55
Leg Length (cm)	83.87 ± 4.52	88.82 ± 6.44
Body Mass Index (kg/m2)	18.71 ± 2.08	19.50 ± 3.39
PHV (Year, Month)	11.85 ± 0.32	14.22 ± 0.57
Frequency (Week)	3.00 ± 0.00	3.00 ± 0.00
Duration (Minutes)/exercise	150.0 ± 0.00	150.0 ± 0.00

Male athletes were significantly older ($p < 0.001$), taller ($p < 0.001$), and heavier ($p = 0.018$) than female athletes. PHV age was significantly higher in males ($p < 0.001$), indicating that males were, on average, closer to or past their peak growth phase.

Speed and Agility Performance

Independent samples t-tests revealed significant differences in physical performance between male and female athletes (Table 2).

Table 2. Independent T-test of Agility and Speed

Variable	Female (N = 32)	Male (N = 21)	p-value
Agility (s)	20.43 ± 1.45	19.23 ± 2.05	0.018
Speed (s)	3.53 ± 0.46	3.85 ± 0.47	0.021

Correlation Analysis

Pearson correlation analysis revealed significant associations between key variables (Table 3); A significant negative correlation was found between PHV and agility ($r = -0.356$, $p = 0.009$), indicating that athletes with higher PHV (i.e., past or near peak growth) exhibited better agility; Similarly, a significant negative correlation was observed between PHV and sprint speed ($r = -0.341$, $p = 0.013$), suggesting superior speed performance in more mature athletes; A strong positive correlation existed between agility and speed ($r = 0.509$, $p < 0.001$), indicating that these physical components are closely related; PHV showed a very strong positive correlation with age ($r = 0.816$, $p < 0.001$), confirming age as a proxy—but not a perfect indicator—of biological maturity.

Table 3. Pearson Correlation Matrix

Variable	PHV	Agility	Speed	Age
PHV	—	-0.356**	-0.341*	0.816***
Agility		—	0.509***	0.372**
Speed			—	-0.410**
Age				—

Visualization of Relationships

To illustrate the nature of the observed correlations, scatterplots were generated and are presented as figures. Figure 1 displays the relationship between PHV and agility. The downward trend indicates that as PHV increases (i.e., athletes are further past their peak growth), agility times decrease, reflecting improved performance. This visual pattern supports the significant negative correlation (r = -0.356, p = 0.009).

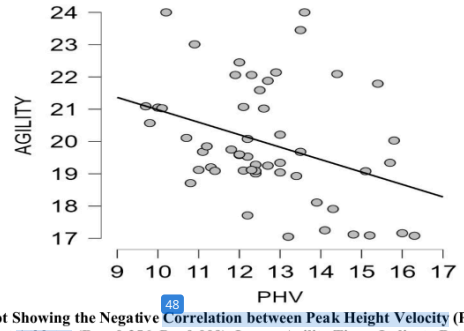

Figure 1. Scatterplot Showing the Negative Correlation between Peak Height Velocity (PHV) and Agility Time in Pencak Silat Athletes (R = -0.356, P = 0.009). Lower Agility Times Indicate Better Performance

Figure 2 illustrates the relationship between PHV and 20-meter sprint time. The negative slope confirms that athletes who have passed PHV tend to have faster sprint times. This aligns with the statistically significant correlation (r = -0.341, p = 0.013).

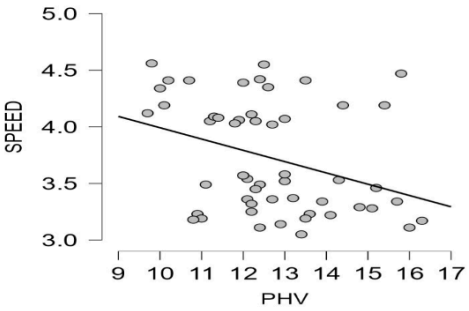

Figure 2. Scatterplot Showing the Negative Correlation Between Peak Height Velocity (PHV) and 20-Meter Sprint Time (*R* = -0.341, *P* = 0.013). Shorter Sprint Times Indicate Better Speed Performance

Figure 3 presents the positive correlation between agility and speed. Athletes with faster sprint times also tend to perform better in the Illinois Agility Test, as shown by the upward trend. This supports the strong and significant relationship ($r = 0.509$, $p < 0.001$).

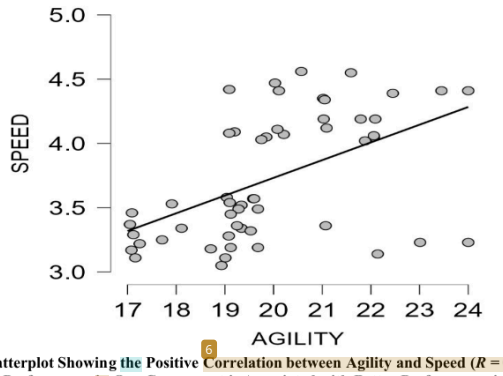

Figure 3. Scatterplot Showing the Positive Correlation between Agility and Speed ($R = 0.509$, $P < 0.001$). Better Performance in One Component is Associated with Better Performance in the Other

Discussion

This study examined the association between PHV, speed, and agility in adolescent pencak silat athletes, revealing significant relationships that have important implications for training design. The finding supports the growing body of evidence that biological maturity, rather than chronological age, should guide youth athletic development programs.

PHV and Physical Performance: Support from Contemporary Literatur

The significant negative correlations between PHV and both agility ($r = -0.356$, $p = 0.009$) and speed ($r = -0.341$, $p = 0.013$) indicate that athletes who have passed or are near their PHV demonstrate superior physical performance. This finding is strongly supported by recent research in youth sports. For example, Malina et al. (2021) found that post PHV soccer players exhibited significantly greater gains in sprint speed and change of direction ability compared to their pre-PHV peers, attributing this to increased muscle mass and neuromuscular efficiency during and after the peak growth phase.

Similarly, Moran et al. (2018) reported that youth athletes post-PHV showed greater responsiveness to sprint and plyometric training, suggesting a "sensitive period" for power development. These results align with our data, where higher PHV status was linked to better speed and agility, reinforcing the importance of timing training interventions to coincide with biological maturation.

However, this contrasts with Nebigh et al. (2022) who found no significant improvement in agility among post-PHV handball players following eccentric hamstring training. The discrepancy may stem from sport specific demands: pencak silat requires rapid directional changes and explosive coordination, which may benefit more than post-PHV neuromuscular adaptations than team sports focused on linear sprinting or strength.

Gender Differences in Performance: Timing of Maturation Matters

Male athletes outperformed females in both speed and agility, consistent with previous findings in martial arts and team sports (Andriyani et al., 2020; Hammami et al., 2018). However, this difference is better explained by biological maturation timing than sex alone. Female athletes in this study were younger (12.25

± 0.80 years) and had already passed PHV (11.85 ± 0.32 years), while males were older (13.91 ± 0.77 years) and approaching PHV (14.22 ± 0.57 years).

This supports Cumming et al. (2017) who emphasized that girls typically reach PHV 1–2 years earlier than boys, leading to temporary performance advantages in early adolescence. By mid-adolescence, males surpass females in power and speed due to increased testosterone and muscle hypertrophy (Malina et al., 2019). Our results reflect this transition: males, though still in or approaching PHV, demonstrated better performance, possibly due to emerging anabolic responses and longer training exposure.

This finding contradicts earlier assumptions that female athletes are inherently less capable in explosive tasks. Instead, it highlights the need to individualize training based on maturity status, not gender. As noted by Parry et al. (2024) grouping athletes by chronological age can disadvantage late-maturing males and over-challenge early maturing females.

Interrelationship Between Speed and Agility: Shared Neuromuscular Basis

A strong positive correlation was observed between agility and speed ($r = 0.509$, $p < 0.001$), indicating that these components are closely related. This supports Torres-Unda et al. (2012) who identified shared physiological underpinnings—such as fast-twitch fiber recruitment, reactive strength, and neuromuscular coordination—that contribute to both abilities.

The finding also aligns with Lee et al. (2024) who demonstrated that SAQ (Speed, Agility, Quickness) training significantly improved both sprint and change-of-direction performance in youth athletes. This suggests that integrated training programs can simultaneously enhance multiple physical qualities, which is particularly relevant for pencak silat, where rapid attacks and directional changes are essential.

In contrast, Mohamed Shapie et al. (2018) found that while fitness improved in young *silat* athletes after circuit training, this did not always translate into better fighting performance, especially in older (E16) groups. Our study adds nuance: while general fitness training may not transfer directly to sport-specific performance, targeted speed and agility drills—especially when timed to PHV—are more likely to enhance functional movement efficiency.

Implications for Training: From Chronological to Biological Age

The current findings reinforce the Youth Physical Development Model (Lloyd & Oliver, 2012), which advocates for maturity-based programming. Pre-PHV athletes benefit most from coordination and skill acquisition; during PHV, focus should shift to balance and injury prevention; post-PHV, strength and power training become more effective.

Our data support the application of bio-banding grouping athletes by biological maturity rather than age to ensure equitable competition and training load (Tsutsui et al., 2022; Cumming et al., 2017). In pencak silat, where technique and timing are critical, this approach can prevent early maturing athletes from dominating competitions and allow late developers to thrive in supportive environments.

Furthermore, regular monitoring of PHV using non-invasive methods (e.g., Mirwald equation) enables coaches to adjust training volume and intensity in real time. As shown by Annas and Sumartiningsih (2022) and Fanita and Sumartiningsih (2023) tracking PHV helps optimize training frequency and duration, particularly in young athletes undergoing rapid growth.

Limitations and Future Research

This study used a cross-sectional design, limiting causal inference. Longitudinal monitoring of PHV and performance would provide stronger evidence. The sample was drawn from a single training center, which may affect generalizability. Future studies should: 1) Include larger, multi-center samples, 2) Use longitudinal designs to track changes around PHV, 3) Explore PHV's impact on technical and tactical performance in pencak silat, 4) Investigate the effectiveness of bio-banding in martial arts competitions.

CONCLUSION

This study shows that biological maturity, indicated by Peak Height Velocity (PHV), is a key factor in the physical performance of young pencak silat athletes. Around 36% of the variation in agility and 34% in speed can be linked to PHV status, with better performance seen in athletes past their peak growth phase. Male athletes also performed better than females, reflecting differences in maturation timing. These results highlight that training programs should be based on biological development, not just age. Coaches are encouraged to monitor PHV and use maturity-based grouping (bio-banding) to improve training effectiveness and reduce injury risk. Future research should test this approach over time in other martial arts.

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