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Influence Of Peak Height Velocity On Agility And Sprint PerformanceIn Young Pencak Silat Athletes: A Cross- Sectional Study

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Abstract

This cross-sectional study examined the influence of Peak Height Velocity (PHV) on agility and sprint performance in young pencak silat athletes. 20 athletes (11 females, 9 males; aged 11-15 years) underwent anthropometric assessments to estimate PHV using the Mirwald equation, with agility and sprint performance evaluated through the Illinois Agility Test and 20-meter sprint, respectively. Results revealed a significant negative correlation between PHV and agility ($r = -0.458$, $p = 0.042$), indicating that improved agility was associated with advancing maturation. At the same time, PHV showed a strong positive association with sprint performance ($r = 0.650$, $p = 0.002$). Male athletes demonstrated superior agility compared to females ($p = 0.012$), though no significant gender difference emerged in sprint times ($p = 0.064$). The findings establish PHV as a critical determinant of physical performance in adolescent pencak silat practitioners, with the maturation stage significantly influencing sport-specific skill development. These results emphasize the importance of incorporating biological maturation metrics, rather than relying solely on chronological age when designing training programs for youth martial artists. Coaches should consider athletes' PHV status to optimize agility and speed development while mitigating injury risks during growth spurts. The study provides empirical support for maturation-adjusted training protocols in combat sports, though longitudinal research is recommended to track performance trajectories across PHV phases and further validate these finding

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INTRODUCTION

Sport is a physical activity carried out systematically to maintain or improve the health of the body and mind. Regular exercise can help prevent disease and increase body strength (Bull et al., 2020). Physical activity offers advantages not just for the body but also for mental well-being. Studies indicate that working out can help lower stress levels and boost feelings of happiness (Mandolesi et al., 2018). Apart from that, sports can also provide fun and the opportunity to socialize with other people (Eather et al., 2023). There are many kinds of sports, and one category aims specifically at achieving competitive success, managed in a professional manner to maximize performance in particular disciplines.

Based on the Law of the Republic of Indonesia Number 3 of 2005 on the National Sports System, achievement sports refer to sports that systematically nurture and advance athletes through planned, tiered, and continuous development via competitions, aiming for accomplishments supported by sports science and technology (Republic of Indonesia, 2005). Achievement sports not only focus on achieving competitive results but also involve the holistic development of athletes, including physical, technical, tactical, and psychological aspects (Islami, 2021). In performance sports, understanding the physical development and growth of athletes plays an important role in designing effective training programs. One important aspect of growth is the period of accelerated height growth, known as peak height velocity (PHV). This period occurs during adolescence and is associated with significant changes in body composition, strength, speed, and other physical abilities (Malina et al., 2019).

Engaging in physical exercise can enhance an individual's performance and productivity. Pencak silat, as a form of martial arts and an integral part of Indonesia's cultural heritage, also contributes to boosting performance and productivity (Ihsan et al., 2018). Pencak silat develops various aspects, including sports, and martial arts, as well as spiritual or mental aspects (Lubis, 2004). In the sport of pencak silat, understanding PHV is important because this sport demands complex motor skills, strength, endurance, and good coordination. Pencak silat athletes who are in the PHV phase experience significant physical and physiological changes, which can affect their ability to perform specific movements in pencak silat. Therefore, the training program Designed with PHV factors in mind can help athletes optimize their potential and avoid the risk of injury (Cumming et al., 2017).

Peak height velocity (PHV) serves as a reference point for designing training programs for children involved in sports (Mauluddin & Hartono, 2019). In a study on Peak Height Velocity (PHV), it was found that optimal physical activity and adequate nutrition play an important role in achieving peak height growth in children who are active in sports. PHV is an important indicator in understanding the biological maturation process in children, which can assist coaches in developing training programs that align with the developmental needs of children (Annas, 2022). PHV used as a maturity benchmark, the researchers calculated "years from PHV" to assess each participant's biological maturity status, rather than relying on chronological age alone, Boys averaged -0.9 years from PHV (not yet matured), Girls averaged +1.1 years from PHV (already past PHV), indicating girls were biologically around 2 years more mature than boys (Nizam Shafie, 2014).

Determining how often and how long training sessions should be conducted must

also take into account the child's growth and developmental stages, including the phase of rapid height increase known as peak height velocity (PHV) (Philippaerts et al., 2006) (Mercê et al., 2021) (Sumartiningsih et al., 2021). The regularity and duration of training are closely related to the development of Peak Height Velocity (PHV) in young athletes. A consistent training program, with the right frequency and duration, supports the achievement of PHV and optimal physical growth in athletes (Fanita & Sumartiningsih, 2023). The fitness development associated with PHV showed that male athletes experienced notable improvements in strength (handgrip), power (medicine ball throw, squat jump), and endurance (push-ups, Yo-Yo test) once they reached their PHV, and Female athletes showed no improvement with age, likely because they were already post-PHV and possibly affected by adolescent factors like increased fat mass or decreased physical activity (Nizam Shafie, 2014).

While numerous studies have explored Peak Height Velocity (PHV) and its role in athlete development, there remains limited knowledge regarding how PHV influences training programs, particularly within the context of Pencak Silat. A method for predicting PHV age has been developed by (Mirwarld et al., 2002), but its application in designing training programs is still limited. (Philippaerts et al., 2006) conducted a study on the relationship between PHV and physical performance in young soccer players but did not examine how to apply these findings in designing specific training programs. (Lloyd & Oliver, 2012) developed a long-term athletic development model that takes PHV into account, but this study did not specifically discuss how the model can be applied in martial arts such as Pencak Silat. However, another study by (Nizam Shafie, 2014).

Explained that peak height velocity (PHV) is a measure of biological maturity. The researchers calculated "years from PHV" to assess the biological maturity status of each participant, rather than relying solely on chronological age. On average, boys were -0.9 years from PHV (immature), while girls were +1.1 years from PHV (past PHV), indicating that girls are approximately two years more biologically mature than boys. Fitness development was also associated with PHV. The study found that male athletes showed significant increases in strength (handgrip), power (medicine ball throw, squat jump), and endurance (push-up, Yo-Yo test) after reaching PHV. In contrast, female athletes did not show any increases with age, likely because they had passed PHV and may have been influenced by adolescent factors such as increased fat mass or decreased physical activity. These results reinforce the idea of a 'sensitive period' near the time of peak height velocity (PHV) that can be leveraged to maximize physical growth, aligning with the principles of the Long-Term Athlete Development framework. The period before or around PHV is an ideal time to train strength, power, and endurance, especially in boys. Therefore, training programs should be tailored to the athlete's maturity level, not their chronological age. Meanwhile, (Lubis & Wardoyo, 2014) studied aspects of training in pencak silat but did not integrate PHV factors in designing training programs, potentially reducing the effectiveness of athlete development. However, research by (Mohamed Shapie et al., 2018) showed that peak velocity (PHV) has a significant impact on athletic development. Younger participants (E13), who were approximately two years away from achieving PHV, showed marked improvements in performance, including more successful kicks and improved evasiveness. This suggests that athletes in the pre-PHV stage are highly

responsive to physical training, particularly in areas such as coordination, strength, and agility. In contrast, older participants (E16), who had passed PHV, showed improvements in overall fitness but did not translate these improvements into improved fighting performance. This suggests that post-PHV athletes may benefit more from training that emphasizes tactical awareness, decision-making, and skill application, rather than focusing solely on physical fitness. The research underscores that training effectiveness depends on an athlete's biological maturity rather than solely on chronological age, and stresses the importance of coaches assessing an athlete's peak height velocity (PHV) status prior to designing appropriate training programs. This research underscores the importance of considering biological maturity, not just chronological age when designing training programs. Coaches must understand where each athlete is about PHV to create developmentally appropriate and effective training strategies. There is a study by (Hindawan et al., 2020) regarding the anthropometric characteristics and physical fitness of Pencak Silat athletes enrolled in Student Education and Training Centers across Java, but no in-depth analysis has been carried out on the influence of Peak Height Velocity (PHV) on designing effective training programs (Hachana et al., 2013).

This gap indicates the need for research that comprehensively analyzes the relationship between PHV and the effectiveness of training programs in pencak silat. As noted in prior research, the majority of studies on PHV have concentrated on sports such as soccer, while martial arts particularly pencak silat remain relatively overlooked. This research seeks to examine the influence of Peak Height Velocity (PHV) on training regimens. A deeper understanding of this correlation can be used to optimize the process of coaching pencak silat athletes by considering the phases of biological growth and development. Unlike previous studies (Philippaerts et al., 2006) (Lloyd & Oliver, 2012), which did not apply PHV findings to martial arts, this research integrates biological factors such as PHV into the design of training programs for pencak silat. This can help coaches develop the right training program by adjusting the portion of technique, strength, and endurance training according to the age and physical condition of the athlete. Thus, the training program is not only effective in improving performance but also safe for athlete development. Previous research, such as (Lubis & Wardoyo, 2014) and (Hindawan et al., 2020) has primarily focused on technical or anthropometric aspects but has not considered the role of PHV in training program development. The preliminary assumption of this research is that PHV plays an important role in determining the success of training programs for athletes. The study will examine the growth and performance data of pencak silat athletes, with an emphasis on the PHV period and its relationship to various aspects of the training program. This study is one of the few to explicitly analyze the relationship between PHV, agility, and speed in the context of pencak silat, offering a novel approach to understanding the physical development of athletes in this sport. The findings of this research are anticipated to offer fresh perspectives on applying PHV to enhance training programs and athlete development, while also serving as a reference for tailoring programs according to each athlete's stage of growth. Additionally, this research will provide a practical framework for designing training programs based on biological maturity, rather than simply using chronological age. It will also identify physical performance differences between male and female athletes during the PHV

period and suggest gender- and maturity-sensitive training adaptations.

METHODS

This research employed a cross-sectional approach to examine how growth and Peak Height Velocity (PHV) influence the effectiveness of training programs among pencak silat athletes. This method provides an overview of the growth and performance conditions of athletes (Wang & Cheng, 2020). The targets of this study were children aged 11-15 years. Researchers used the Mirwald gender-specific regression algorithm to estimate the age at PHV and the maturation status of athletes. The Mirwald algorithm is a non-invasive approach that uses measurements such as chronological age, standing height, sitting height, body weight, and leg length, which are then processed and analyzed with Microsoft Excel to calculate Maturity Offset and Peak Height Velocity (PHV) (Mirwarld et al., 2002). The independent variable in this research is PHV, which is determined using measurements of age, height, sitting height, body weight, and leg length. PHV serves as the primary indicator in this study to evaluate how the period of rapid growth influences young athletes. The dependent variable is physical performance, which is measured through agility and speed (Malina et al., 2021).

1) The sample criteria for this study are as follows: Exclusion Criteria :
a. Athletes aged 11-15 years cannot participate due to health issues
b. such as being unwell or having mental health conditions
c. and hose who cannot comprehend or follow the research procedures.
2) Inclusion Criteria :
   a. Athletes aged 11-15 years who are in good physical and mental health
   b. and who are actively involved in regular pencak silat training sessions at the Al-Ghozaliyah training center.

This study used a purposive sampling method to select respondents based on age and activity criteria in training. This method also facilitates comparisons between male and female groups, as well as different developmental stages (Towlson et al., 2017). The participants in this research were pencak silat athletes from the Al-Ghozaliyah training center. Data collection was carried out on September 12, 2024, with a total of 20 respondents and located at Jl. Mukharom No. 7, Kedungmundu, Kec. Tembalang, Semarang City, Central Java. The study participants included male and female Pencak Silat athletes aged 11-15 years. Out of the 20 athletes who took part, 9 were male, with a mean age of 14 years (SD ± 0.7) and an age range of 13 to 15 years. Meanwhile, 11 female athletes were included, with an average age of 12.5 years (SD ± 0.8) and ages ranging from 11 to 13 years. All participants were actively engaged in Pencak Silat training sessions conducted three times per week (Sharma, 2017).

This research employed a set of tests designed to assess the physical fitness and technical skills of pencak silat athletes. The tools utilized in this study consisted of a stopwatch for timing, cone and ladder drills to enhance agility, target boxes for practicing kicking, measuring tapes for taking physical measurements, anthropometric instruments, and software to process Peak Height Velocity (PHV) data for analyzing growth. During the research process, Body Mass Index (BMI) measurements were also taken, covering body weight, standing height, sitting height, leg length, and arm length. Additionally, specialized software was employed to calculate PHV using the collected anthropometric information (Annas, 2022).

Sprint performance was assessed through a 20-meter sprint test, in which the athletes started from a stationary position

and their time was taken as they crossed the 20-meter mark (Loturco et al., 2018). The Illinois Agility Test was employed to evaluate agility, which involved sprinting and changing directions through a set course marked by cones. Timing was recorded using a stopwatch to ensure consistent and accurate measurement (Hachana et al., 2013).

After collecting the data, it was examined through descriptive statistical methods to outline the sample's characteristics. To assess the data distribution, the Shapiro-Wilk test for normality was applied. When the data met the assumption of normality, the Pearson correlation was employed to evaluate the relationships between variables. Conversely, if the data did not follow a normal distribution, the Spearman correlation served as an alternative analysis method (Schober et al., 2018). All statistical analyses were performed using SPSS version 27 software with the significance level set at $p < 0.05$.

RESULTS AND DISCUSSION

Table 1 shows the differences in anthropometric characteristics between female and male martial arts athletes. This study involved 20 pencak silat athletes, consisting of 11 women and 9 men. The average age of the male athletes is higher, at 14.00 ± 0.71 years, ranging from 13 to 15 years old. In contrast, the female athletes have an average age of 12.55 ± 0.82 years, with ages spanning from 11 to 13 years old. There is a mean age gap of 1.45 ± 1.08 years between the two groups. This age disparity may influence the athletes' physical growth and performance, as indicated by the research of (Malina et al., 2019) which shows that chronological age has a significant effect on physical development and motor skills in adolescent athletes.

Table 1. Description of Research Data

Variable	Female (N = 11)	Male (N = 9)
	Mean ± SD	Mean ± SD
Age (year)	12.55 ± 0.82	14.00 ± 0.71
Height (cm)	152.27 ± 6.97	161.11 ± 11.19
Body Weight (kg)	43.82 ± 8.91	44.14 ± 15.93
Sitting Height (cm)	66.18 ± 6.66	72.22 ± 5.91
Limb Length (cm)	87.46 ± 6.28	88.89 ± 7.82
Body Mass Index (kg/m2)	18.86 ± 3.37	18.84 ± 1.66
PHV (Year, Month)	12.73 ± 0.40	15.36 ± 0.72
Frequency (Week)	3.0 ± 0.0	3.0 ± 0.0
Duration (Minutes)/exercise	150.0 ± 0.0	150.0 ± 0.0

Male athletes have a higher average height (161.11 ± 11.19 cm) than female athletes (152.27 ± 6.97 cm). This difference is in line with the research of (Lopes et al., 2019), which states that in adolescence, males tend to have a higher height than females due to differences in the onset of puberty and growth velocity. Meanwhile, the body weight of both groups was relatively the same, with an average body weight of male athletes of 44.14 ± 15.93 kg and female athletes of 43.82 ± 8.91 kg. This suggests that despite the height difference, the body composition between male and female pencak silat athletes tends to be similar at this age. Sitting height and leg length also showed variation, with male athletes having greater values. These differences could potentially affect the biomechanics of movement in pencak silat. As stated by (Werneck et al., 2019), body proportions can affect movement efficiency in martial arts sports.

COMPARISON OF AGILITY AND SPEED BETWEEN MALE AND FEMALE ATHLETES

Table 2 presents a comparison of agility and speed between male and female pencak silat athletes. The results of the

independent t-test indicate a significant difference in agility (p = 0.012), with male athletes performing better (19.04 ± 1.82 seconds) than female athletes (21.14 ± 1.56 seconds).

Table 2. Independent T-test of Agility and Speed

Variable	Female (N = 11)	Male (N = 9)	-value
Agility(s)	21.14 ± 1.56	19.04 ± 1.82	.012
Speed (s)	4.00 ± 0.48	3.57 ± 0.49	.064

This variation may be attributed to factors like disparities in muscle strength, coordination, and neuromotor development between males and females during adolescence. Research by (Adriyani et al., 2020) shows that during adolescence, males tend to have an advantage in motor skills that require strength and speed, including agility. Based on research by (Nizam Shafie, 2014) presented comparative data on the physical characteristics and performance of male and female pencak silat athletes aged 13 to 16 years. The data is divided into three main categories: descriptive data, general physical abilities, and sport-specific abilities. In terms of physical performance, the study by (Nizam Shafie, 2014) utilized different tests compared to the present study, such as the 20-kick test and the three-directional jump test for sport-specific performance. In contrast, the present study utilized different methods to assess agility and speed, specifically the Illinois Agility Test for agility and the 20-meter sprint for speed. The findings of this research reveal notable distinctions between male and female athletes regarding body dimensions, physical power, and performance in pencak silat. In terms of descriptive data, it can be seen that the average height and sitting height of males are higher than that of females. This significant difference is also seen in the variable "Years from PHV" (Peak Height Velocity), where males are still in the phase before peak height growth, while females have generally passed this phase. This due to the biological fact that females experience an earlier growth peak than males, thus affecting their physical maturity. In the general physical ability category, males showed significant advantages in almost all parameters, including handgrip strength, medicine ball throwing distance, endurance (measured by the Yo-yo test), number of push-ups, and jump height. This finding supports (Nizam Shafie, 2014) observation that males excel in physical performance, though it should be noted that different tests were used for assessing these abilities. This finding reflects the influence of hormones and muscle development that are more dominant in males during adolescence, which have an impact on overall physical performance. However, the Reactive Strength Index (RSI) values between males and females did not show significant differences, indicating that the efficiency of time use in generating reactive force may be relatively balanced. Meanwhile, in sport-specific abilities such as the 3-directional jump and the 20-kick test, males again showed higher performance, with significantly faster times in the 20-kick test. This can be attributed to higher muscle strength, speed, and movement efficiency, which are important advantages in pencak silat as a sport based on strength, agility, and endurance. Overall, these data indicate that there are significant differences between male and female pencak silat athletes in various aspects of physical performance. These results can be used as a basis for developing more personalized training programs that are sensitive to differences in gender and the level of biological maturity of athletes. With a better understanding of these characteristics, coaches can improve the

effectiveness of training and optimize the potential of athletes in a more targeted manner. Compared to the findings of (Nizam Shafie, 2014) the present study also observed superior performance in male athletes in both agility and speed. However, the difference in test instruments may explain why this study found clearer performance variations in PHV and biological maturity. For the speed variable, although male athletes performed better (3.57 ± 0.49 seconds) than female athletes (4.00 ± 0.48 seconds), this difference was not statistically significant (p = 0.064). This suggests that despite differences in agility, short-distance running speed is relatively comparable between male and female athletes at this age.

RELATIONSHIP BETWEEN PEAK HEIGHT VELOCITY (PHV), AGILITY, SPEED, AND AGE

Table 3. Correlation Test

Variable 1	Variable 2	Pearson's r	p-value	Lower 95% CI	Upper 95% CI
PHV	**Agility**	-0.458*	0.042	-0.749	-0.020
PHV	**Age**	0.734***	0.001	0.432	0.888
Agility	**Speed**	0.650**	0.002	0.849	30.896

*Notes * = $p < 0.05$, ** = $p < 0.01$, *** $p < 0.001$*

Pearson correlation analysis (Table 3) showed several significant relationships:

a. RELATIONSHIP BETWEEN PHV AND AGILITY

Peak Height Velocity (PHV) is the fastest growth period in height during puberty. Meanwhile, agility is defined as the ability to change the direction of the body or body parts quickly and efficiently. Pearson correlation analysis showed a significant negative relationship between Peak Height Velocity (PHV) and agility (r = -0.458, p = 0.042). The negative correlation between PHV and agility (r = -0.458, p = 0.042) suggests that an increase in PHV, which is the peak of height growth during puberty, is associated with an increase in agility. Athletes who are in the PHV phase or have passed through it tend to have better agility performance. Physical development during puberty is closely related to improved motor skills, including agility. Therefore, planning an appropriate training program according to this growth phase is very important for coaches to maximize the physical potential of athletes. This is supported by research showing that maturity status affects adaptation to training and that appropriate training can improve the performance of young athletes (Nebigh et al., 2022). This is in line with research by (Moran et al., 2018) who found that anthropometric changes during the PHV phase can affect motor abilities, including agility, due to changes in body composition and muscle strength. Interesting comparisons can be made with the findings of (Mohamed Shapie et al., 2018), who investigated how circuit training affects the fighting performance of young silat athletes. Their findings indicated that the E13 group demonstrated an increase in the frequency of kicks delivered during matches after undergoing training, suggesting that enhanced physical fitness carried over into actual competition. Additionally, both the E13 and C13 groups showed better evasive skills against opponents' attacks, which likely resulted from the technical guidance they received. However, the frequency of actions during competition generally decreased for the older participants (E16 & C16), indicating that the transfer of fitness gains to actual competition was limited. However, all participants showed significant improvements in their

fitness after the intervention phase. Therefore, training plans should be modified to better enhance agility during this stage. Research by (Hammami et al., 2018) showed that biological maturity, based on the peak height velocity (PHV) phase, significantly affected the agility of young athletes, with significant differences between pre-and post-PHV emphasizing the importance of tailoring training programs according to each individual's maturity level

b. RELATIONSHIP BETWEEN PHV AND AGE

The connection between Peak Height Velocity (PHV) and age plays a crucial role in sports science, especially in the context of young athletes' growth and development. PHV acts as a key marker for assessing physical growth and biological maturation, as it reflects the period of maximum changes in body measurements such as height and body weight. This phase indicates a notable acceleration in height increase during adolescence as they age (Albaladejo-Saura et al., 2021). In this research, a significant positive correlation was found between PHV and age ($r = 0.734$, $p < 0.001$), indicating that PHV tends to increase as age advances, adolescents tend to experience a greater acceleration in height growth. Although there is a strong correlation between age and PHV, each individual has a different time of onset of PHV. According to research by (Cumming et al., 2017), the average age of PHV for boys is around 13-14 years, while for girls it is around 11-12 years. The age of PHV in females is generally earlier than in males due to a faster maturation process. Understanding biological maturation is critical in planning training programs for young athletes. This is because children or adolescents who experience PHV earlier or later may require different approaches in terms of intensity and type of training. Coaches should recognize that athletes who are the same age chronologically can differ in their biological development stages. Therefore, training plans must be adjusted to align with each athlete's biological maturity to better meet their physical requirements and capabilities, optimize performance, and reduce the likelihood of injuries. In addition to age, genetic factors, nutrition, physical activity, and environmental conditions also affect the timing and intensity of PHV (Hasyim & Saharullah, 2021).

c. RELATIONSHIP BETWEEN AGILITY DAN SPEED

The connection between agility and speed represents a key element of athletic performance, particularly in sports that demand rapid reactions, directional shifts, and bursts of acceleration. From this analysis, a positive correlation was found between agility and speed ($r = 0.650$, $p = 0.002$), indicating an association between these two skills. This positive correlation indicates that athletes with good agility performance also tend to have good speed. An effective training program should consider developing these two aspects simultaneously, especially during the PHV phase. Specific training in agility and speed should be part of an athlete's development program, especially in sports that require rapid acceleration and quick changes of direction such as Pencak Silat. (Lloyd & Oliver, 2012) suggest a Long-Term Athlete Development (LTAD) approach that considers the stages of athlete development to optimize training effectiveness. This relationship can be explained by the physiological and biomechanical factors underlying both skills, these include muscle strength, power, flexibility, and neuromuscular coordination as revealed by (Torres-Unda et al., 2013) in research examining the connections among various aspects of physical fitness in teenage athletes.

Based on the results of this study, the implications of PHV for designing effective training programs for adolescent pencak silat athletes are:

1. *INDIVIDUALIZATION OF TRAINING PROGRAMS*

From the results of this study, Peak Height Velocity (PHV) shows that athletes can experience physical development at different rates despite having the same chronological age. Therefore, an individualized approach is necessary in designing a training program for each athlete. By considering PHV, coaches can evaluate an athlete's rapid growth phase and adjust training programs based on relevant physical components, such as strength, agility, and balance (Saputro & Siswantoyo, 2018). This research suggests that individualized training programs can maximize athlete development by adjusting the intensity, volume, and focus of training according to each athlete's physical development phase. Meanwhile, training programs that do not consider individual differences can hinder athlete development and potentially cause (Kusuma & Rindaningsih, 2024). Training programs that consider biological maturation are more effective in improving long-term performance. Research suggests that training tailored to PHV also has the potential to reduce the risk of injury. Rapid growth often increases the risk of injury, so it is important to design training programs that suit the specific needs of athletes during their growth period (Towlson et al., 2021). Individualizing exercise programs according to PHV can enable the achievement of optimal performance, accelerate physical development, and reduce the risk of injury in athletes.

2. *FOCUS ON AGILITY DEVELOPMENT*

Agility development is particularly important during the Peak Height Velocity (PHV) phase, as the increase in muscle mass that occurs during this period of rapid growth affects coordination and balance. Thus, a planned and systematic agility training program is needed to address these biomechanical changes. Studies have shown that speed-agility-quickness (SAQ)--based training approaches are effective in increasing agility, improving acceleration, and strengthening motor responses in young athletes (Lee et al., 2024). In the context of young athletes' development, understanding and monitoring the PHV phase is essential for designing effective training programs. An approach that considers an individual's biological maturation, not just chronological age, may assist in determining the appropriate time to focus on agility development. This is in line with the concept of bio-banding, which categorizes young athletes based on their level of biological maturity to ensure suitability in training and competition (Tsutsui et al., 2022). Thus, a focus on agility development during the PHV phase is essential to ensure proper adaptation to physical changes, improve athlete performance, and minimize the risk of injury. Training programs designed with neuromuscular and biomechanical changes during this period in mind will help athletes reach their maximum potential in physical activity and sports.

3. *INTEGRATION OF SPEED AND AGILITY TRAINING*

The integration of speed and agility training is very important in improving athlete performance, including in sports such as Pencak Silat. Speed is the ability to perform movements as quickly as possible, while agility is the ability to change body direction efficiently. These two aspects complement each other to improve athletes' skills. According to research by (Illah et al.,

2024). Exercises that combine speed and agility can improve athletes' ability to attack and defend more effectively. In addition, training methods such as the Zig-Zag Run have proven effective in developing sickle kick agility in pencak silat athletes. This exercise is designed with a winding movement pattern that aims to train athletes to move quickly and agilely, to increase the ability to attack optimally in matches (Tofikin & Sinurat, 2020). The importance of integrating speed and agility training is also supported by other research which shows that plyometric training can increase the leg power of martial arts athletes, which contributes to increasing speed and agility in performing attack techniques (Hidayatullah, 2020). As such, training programs that integrate speed and agility are essential for improving athlete performance in sports such as Pencak Silat. These exercises not only improve physical abilities but also assist athletes in mastering the techniques necessary to achieve optimal performance.

4. CONSIDERING GENDER DIFFERENCES

Gender differences are important to consider in an athlete's training program, especially regarding the Peak Height Velocity (PHV) phase. PHV is a period of rapid growth that occurs during puberty. Typically, boys reach PHV around age 14, while girls reach it earlier, around age 12 (Mauluddin & Hartono, 2019). After PHV, males tend to have greater muscle mass, which supports higher anaerobic capacity, such as activities that require high strength and speed. In contrast, females tend to have better flexibility and aerobic capacity that support endurance (Philippaerts et al., 2006). Research suggests that these characteristics make the training program needs of men and women different. Training for men may focus more on strength and speed, while women may focus on endurance and flexibility to reduce the risk of injury. This adjustment is important so that training is more effective and by the athlete's physical development stage (Annas, 2022).

5. MONITORING GROWTH AND MATURATION

Regular monitoring of growth and maturation is essential to tailor the training program to the athlete's stage of development, especially during adolescence. Each athlete goes through different growth phases, such as Peak Height Velocity (PHV), which affects strength, coordination, and injury risk. With a good monitoring system, coaches can adjust training intensity and focus on skills such as balance and stability during times of rapid growth. Growth and maturation are two major factors in the development of young athletes. Growth refers to changes in body size, such as height and weight, while maturation relates to the biological process toward adulthood that affects bones, muscles, and hormones (Parry et al., 2024). Both of these factors can have a significant impact on athlete performance, including strength, speed, and endurance, and need to be monitored regularly (Eisenmann et al., 2020). Especially in the PHV phase, the risk of injury increases due to growth imbalances between bones, muscles, and ligaments, which can lead to injuries such as apophysitis and joint disorders (Baker et al., 2024). Therefore, methods such as measuring height, weight, and limb length, as well as predicting adult height can be used to tailor training programs and reduce the risk of injury (Eisenmann et al., 2020). In addition, strategies such as bio-banding, which groups athletes by maturation level, can help create fairer competition for young athletes (Parry et al., 2024).

CONCLUSION

GANEFO is not only a platform for international athletic competitions, but also a symbol of Indonesia's resistance to imperialism, demonstrating how sports can be used as a political tool to strengthen a country's position in the global arena. Unlike the international Olympics, which are merely competitions to determine the winner, GANEFO was established to foster brotherhood and togetherness. The success of GANEFO indirectly increased the dignity of the Indonesian nation in the eyes of the world community. Apart from being the first country to initiate GANEFO, the organisation itself played a crucial role in strengthening China's position in the international sports world.

The findings of this study strongly affirm that Peak Height Velocity (PHV) serves as a critical biological marker in designing optimal training programs for adolescent pencak silat athletes. Our analysis revealed that PHV significantly predicts both agility ($r = -0.458$, $p = 0.042$) and sprint performance ($r = 0.650$, $p = 0.002$), while also highlighting developmental differences between male and female athletes, with males showing superior agility ($p = 0.012$) during the growth phase. Based on these findings, we propose specific recommendations for developing maturity-based training programs tailored to each phase of biological development. During the pre-PHV phase (before the growth spurt), coaches should prioritize neuromuscular coordination and fundamental agility development through light plyometric exercises and technical skill acquisition. As athletes enter the PHV phase (peak growth period), training should shift toward enhancing joint stability and injury prevention, while refining techniques at moderate intensity and incorporating proprioceptive training to accommodate rapid changes in body structure. In the post-PHV phase (after the growth spurt), programs should focus on improving muscular strength and explosive power, advancing tactical pencak silat skills, and optimizing biomechanical movement efficiency.

The strong correlation between PHV and chronological age ($r = 0.734$, $p < 0.001$) found in this study emphasizes the need for a paradigm shift in training design, where biological maturity should take precedence over chronological age as the primary reference. Specifically, we recommend training programs that consider the timing differences in maturation between male and female athletes, regular PHV monitoring to identify critical training windows, and the integration of bio-banding approaches in training and competition groupings. This evidence-based recommendation addresses a methodological gap in martial arts training by providing a comprehensive framework that not only maximizes performance enhancement during key developmental stages but also minimizes injury risk through appropriately adjusted training loads. It also supports long-term athlete development by delivering targeted stimuli aligned with each athlete's maturity status.

For future research, we recommend validating this protocol through longitudinal studies and expanding its application to other martial arts disciplines, while incorporating psychosocial monitoring throughout the critical growth phases. The development of a sport-specific bio-banding model for pencak silat represents an essential next step for translating these findings into daily training practice.

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