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QUANTIFYING THE IMPACT OF RUNNING CADENCE ON BIOMECHANICS, PERFORMANCE, AND INJURY RISK: A PHYSICS-BASED ANALYSIS

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ABSTRACT:

Running cadence is crucial in running biomechanics and physiology, impacting performance and injury risk. The relationship between running cadence, height, weight, and gender is explored using data from 29 participants (14 males, 15 females) with varying attributes. Taller individuals tend to have a lower cadence due to longer stride length, while fewer steps are required by heavier individuals at the same pace. A higher cadence is observed in males, possibly due to differences in leg length and muscle fiber composition, although considerable variability exists among individuals of both genders.

Linear regression analysis revealed robust models for both genders, with negative correlations between cadence and height, indicating that increased cadence correlates with decreased height for males and females. Females typically have higher BMI than males, with BMI variability in the population. Weight influences running cadence by affecting ground force. Heavier individuals may take fewer steps, but risk increased strain on joints and muscles, raising injury risk.

Furthermore, the connection between running cadence and injury risk is investigated. It is found that adjusting cadence significantly reduces stress on weight-bearing joints and prevents common overuse running injuries. It is demonstrated by several reputable studies in the field that even minor cadence increases greatly reduce stress on knee and hip joints during running, making it a commendable method for injury prevention.

In conclusion, while height and weight impact running cadence, each person's cadence is unique and influenced by various factors beyond gender alone. Understanding the relationship between running cadence and its impact on injury prevention is crucial for runners seeking to improve performance and avoid injuries.

KEY WORDS: Biomechanics, Height, Gender, Cadence, Injury prevention, Stress on joints, Kinetics.

1. INTRODUCTION

Cadence, or the number of steps or revolutions per minute in a physical activity such as cycling or running, is an important factor that can affect an individual's performance and efficiency. Cadence can be influenced by various factors, including muscle strength, technique, and fitness level. Height, or an individual's vertical dimension, is another factor that may potentially affect cadence [1].

There is limited research on the relationship between height and cadence, and the results of studies that have been conducted are mixed. Some research suggests that taller individuals may have a slower cadence due to their longer stride length, while other studies have found no significant relationship between height and cadence [1].

Most regular runners aim to achieve three primary goals- running faster, running for longer periods without getting injured, and running further. These objectives serve as a motivation for runners to improve their endurance. At this point, one may ask, "How can I run faster?". It may be challenging to know where to begin, so having some background information is helpful. Two aspects of running could help in improving speed. The first step is to maximize the stride's distance [2]. The second strategy is to raise the stride frequency, also known as running cadence [3]. Running cadence has recently gained significant attention from researchers and the public as it is associated to improved speed, enhanced endurance, and reduce injury risk [4]. Stride studies of ultramarathon runners consistently linked faster speeds to higher striking frequencies [5].

A higher cadence is correlated with lower ground reaction forces. When the foot hits the ground, the ground applies these pressures to the body. In plainer terms, a greater cadence results in less effect [6]. Additionally, a greater cadence is linked to a lower risk of injury. In other words, the weight on the body gets lighter the shorter the stride and the more steps that take each minute. As a consequence, the biomechanical forces connected to damage shift.

The mechanical changes brought on by a higher running cadence make this intervention simple for runners to apply, and it has the potential to be effective for both treating and preventing overuse running injuries. Furthermore, runners are more likely to adopt these gait modifications as a long-term injury prevention approach if a cadence intervention may minimize potentially injurious biomechanics without degrading running efficiency.

The hypothesis suggests that running cadence decreases as height increases. This is attributed to the fact that a person's leg length, primarily determined by their height, influences their stride length. Longer legs result in a longer stride length and a slower running cadence, as each step covers more ground due to the extended time the human foot spends in the air before making contact with the ground.

The aim of this study was to determine if the effect of height and gender on running cadence results in a decrease in potentially injurious kinetics and kinematics while maintaining running efficiency in a group of healthy male and female runners. Further examine the literature research on this topic, considering the limitations and implications of these findings [7]. In this research, also the aim is to compare their findings with this study to explore potential correlations between an individual's height and the running cadence.

Additionally, the investigation analyses potential differences in running cadence between male and female runners. This additional factor aimed to provide a comprehensive understanding of how height and gender collectively influences running cadence and its associated biomechanical parameters [8].

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Unraveling the connection between height, gender, and cadence holds implications for injury prevention, training optimization, biomechanical analysis, performance assessments, and personalized interventions in the realm of running [8].

Specifically, it was hypothesized that changes in running mechanics less similar to those observed in injured runners would result from a rapid increase in cadence. However, running performance remained unaffected. Increased cadence decreased stride length, hip adduction angle, and hip abductor moment. Providing valuable insights into gender-specific biomechanical adaptations during running. Moreover, Chen et al. [9] conducted studies on the effects of running speeds and exhaustion on iliotibial band strain during running, focusing on skeletal muscle performance. Meanwhile, Taylor M. et al. [10] investigated the effect of increasing running cadence on peak impact force in an outdoor environment, Elena N. V. et al. [11] explored the relationships between running biomechanics, hip muscle strength, and running-related injury in female collegiate cross-country runners, and Kobayashi, T. et al. [12] conducted on the effects of step frequency during running in individuals with a transfemoral amputation, several potential correlations can be explored.

2. Materials and Methods

The participants walked on a level treadmill at 4 km/h for 1 minute, while data were collected. The participants were asked to walk for 1 minute straight, and recording was only commenced when the walking was already in progress to avoid bias by including altered steps upon gait initiation. Age was calculated from the date of birth. Body weight was measured with a scale. Body height was measured with a Hengshida roll-up measuring tape. The stopwatch employed for this study was the renowned for its accuracy and reliability in measuring elapsed time.

Using a measuring tape to measure each student's height and a kilogram (kg) scale to measure their weight, the experiment got underway. There were 15 female and 14 male pupils in the group, and their heights ranged from 150 to 177 cm. Each student was given the task of running on a treadmill for precisely sixty seconds, counting the number of times their right foot touched the ground, to gather data. Subsequently, the count was documented and reported. Each runner went through this procedure twice more, for a total of three trials per person. The average of the trials was computed and doubled to indicate the total number of right foot impacts after all three trials for each of the 29 runners were recorded. This produced 29 different cadences.

The experiment was conducted on the student-athletes of the College of Physical Education and Sports, University of Duhok. This was deemed important as student-athletes possess more active muscles than non-athletic individuals. The students were provided with flat shoes, which affect the running cadence as they offer more comfort compared to high-heeled shoes or other types of shoes. Before the experiment was conducted, it was ensured that all participants were in good health and free of chronic diseases and diseases of the respiratory and muscular systems, so as not to affect the running cadence.

To determine running cadence, the following steps were executed based on the described procedure:

a) A timer was set for 60 seconds, ensuring it was not allowed to expire.
b) Running was commenced at the preferred speed.
c) The timer was reset, and while running, each step (each time either foot touched the ground) was counted. It was considered simpler to count using only one foot, such as the left foot, instead of both.

The cadence was calculated based on the total number of steps taken within the last 60 seconds. If counting each stride using only one foot, the result was multiplied by 2. For instance, if 84 left-foot steps were counted in one minute, the cadence would be 168 steps per minute.

It is important to note that self-testing could introduce bias into the results due to performance bias. However, cadence can still be accurately measured by counting steps per minute.

2.1 Participants

In examining the impact of height on cadence, participant selection is a pivotal consideration that shapes study outcomes and interpretations. Key factors include participant characteristics, such as fitness levels, muscle strength, and technique, which can influence cadence and potentially confound the height-cadence relationship. Therefore, controlling for these variables in the study design or incorporating them as covariates in the analysis may prove beneficial.

Furthermore, the breadth of height variations among participants is crucial for deriving insightful findings. It is essential to ensure the representativeness of height distribution within the sample relative to the target population.

Moreover, the specific nature of physical activity under investigation, whether it involves running or cycling, may necessitate distinct techniques and height-cadence dynamics. As such, the generalizability of findings across different activities requires careful consideration.

To initiate our experiment, 29 seasoned distance runners were meticulously chosen from the University of Duhok's college of physical education and sport sciences. Emphasis was placed on aligning participants' training backgrounds, running capabilities, weight, and age. This rigorous selection process was instrumental in isolating the influence of height on running cadence, given the multiplicity of factors affecting cadence.

2.2 Increased cadence of 180 steps per minute has several positive effects.

Increasing the cadence to 180 steps per minute offers numerous benefits for running performance and efficiency. These include enhanced speed, improved running form, reduced impact forces, and increased efficiency. In the short to medium term, runners can decrease oxygen consumption and boost performance by increasing cadence by 3–4%. Long-term benefits include enhanced running economy due to factors like increased elastic recoil and decreased muscular work. While optimal cadence varies among individuals, with dedication, discovering and training preferred cadence is achievable [13]. However, it's essential to note that 180 steps per minute may not be universally suitable, requiring attentiveness to individual body signals and comfort for efficient running [8].

It is imperative to acknowledge that the enhancement of one's cadence constitutes a gradual process, necessitating both temporal investment and consistent practice. Additionally, a judicious awareness of bodily signals is paramount, guiding the identification of a cadence that facilitates both comfortable and efficient running [14].

2.3 Results and Discussion

The average running cadence for males is 169 steps per minute (SPM), with the lowest recorded cadence observed among those with a height of 177 cm (158 SPM) and the highest among individuals with a height of 161 cm (184 SPM).

Among females, the average running cadence is 161 SPM, with the highest recorded cadence at 171 SPM and the lowest at 149 SPM. Female runners exhibit a height range of 150 cm to 161 cm, with shorter individuals demonstrating higher cadences. The individuals' ages range from 18 to 23 years old, with the majority falling between 20 and 23 years old. The average height across all individuals is 162.8 cm, while their weights range from 43 to 79 kg, with an average weight of 58.97 kg. The individuals' cadence was measured in three trials, and the average cadence across the three trials was calculated to be 163.6 SPM.

Several observations can be drawn from the provided data. Firstly, there is a considerable variation in both the heights and weights of the individuals, indicating significant diversity among the participants. Secondly, the cadence of the individuals exhibits wide variability, with some individuals demonstrating notably faster or slower cadences than others. Notably, the average cadence of males is slightly higher than that of females.

The data in Table 1 provide valuable insights into the relationships between height, weight, Body Mass Index (BMI) and cadence in running. In this study, participants were categorized into two groups based on their BMI, normal weight (BMI 18.5 - 24.9 kg/m^2) and overweight (BMI 25 - 29.9 kg/m^2). Normal-weight individuals have a healthier BMI range, indicating balanced weight relative to height and a lower risk of obesity-related health issues. Conversely, overweight individuals have a higher BMI, suggesting excess weight and increased risk of obesity-related health concerns. This categorization facilitates the examination of the relationship between BMI, weight status, and health outcomes in this study.

Table 1: presents the results of descriptive statistics for the measured cadence of males and females.

		Range	Minimum	Maximum	Sum	Mean		Std. Deviation	Variance
		Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
Gender	**Male**	1.00	0.00	1.00	14.00	0.4828	0.09443	0.50855	0.259
	Female	1.00	0.00	1.00	15.00	0.5172	0.09443	0.50855	0.259
Age (Year)		5.00	18.00	23.00	598.00	20.6207	0.29114	1.56784	2.458
Height (cm)		27.00	150.00	177.00	4686.00	161.5862	1.49261	8.03793	64.608
Weight (Kg)		36	43	79	1710	58.97	1.693	9.116	83.106
Cadence (SPM)		35.00	149.00	184.00	4781.00	164.8621	1.55421	8.36969	70.052
BMI		1.00	1.00	2.00	33.00	1.1379	0.06517	0.35093	0.123

The analysis output presents a breakdown of key parameters based on gender. For males, the mean height is approximately 168.5 cm with a standard deviation of 5.29 cm, while females have a mean height of around 155.13 cm with a standard deviation of 3.29 cm. In terms of age, males exhibit a mean age of 21.36 years with a standard deviation of 1.39 years, while females have a mean age of 19.93 years with a standard deviation of 1.44 years. Regarding BMI, males show a mean of 1.07 with a standard deviation of 0.27, while females have a mean BMI of 1.20 with a standard deviation of 0.41. The mean cadence for males is 169.00 steps takes per minute (SPM) with a standard deviation of 8.14 SPM, whereas females have a mean cadence of 161.00 SPM with a standard deviation of 6.74 SPM. Combining both genders, the total mean values for height, age, BMI, and cadence are approximately 161.59 cm, 20.62 years, 1.14, and 164.86 SPM, respectively. The corresponding total standard deviations are 8.04 cm, 1.57 years, 0.35, and 8.37 units, providing insights into the overall distribution and variability of these parameters in the entire dataset.

In the results presented in Table 1, it is confirmed that the higher the length, the lower the running cadence, as indicated in the table.

Figure 1 accurately represents the relationship between gender and cadence, appropriately stratified by Body Mass Index (BMI).

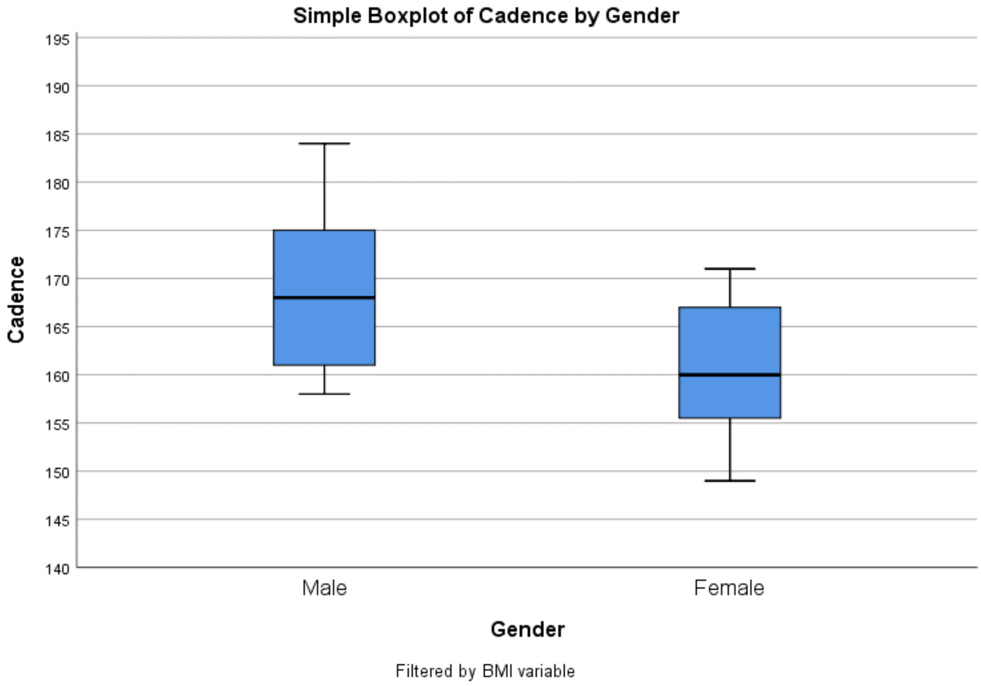

Figure 1: depicts the distribution of cadence values among male and female participants, with data stratified by Body Mass Index (BMI).

Further statistical analysis could delve into the significance of this discrepancy and explore additional factors influencing cadence, such as age or BMI. Following this examination, Figure 2 illustrates the distribution of age among male and female participants, with data stratified by BMI

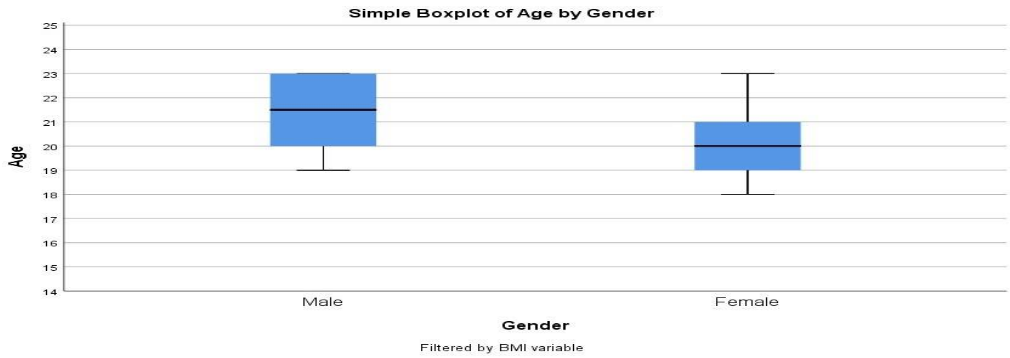

Figure 2 :distribution of age among male and female participants, with data stratified by Body Mass Index (BMI)

Figure 2 presents a chart showcasing age distribution among male and female participants, stratified by BMI. Each boxplot highlights the median age (center line), interquartile range, and overall age range, facilitating observations such as median age alignment and age spread within the interquartile range.

This study explores the influence of gender on running cadence, as well as the influence of age and BMI on this relationship. The analysis of cadence data revealed a significant difference between males and females, with males exhibiting a higher mean cadence by 8.0 steps per minute. This finding aligns with existing research on running biomechanics and physiology, which suggests that gender differences in muscle composition, limb length, and cardiovascular efficiency may contribute to variations in running cadence [7, 15].

The observed gender disparity in cadence is noteworthy, as it underscores the potential for gender-specific training and rehabilitation protocols. For instance, the higher cadence in males could be attributed to greater leg length and muscle power, allowing for quicker step turnover. Conversely, females may exhibit a lower cadence due to differences in stride mechanics and energy utilization strategies. These insights could inform tailored approaches to improve running efficiency and reduce injury risk across genders.

The age distribution of the individuals was further analysed and stratified by BMI to look into other potential cadence-influencing factors. Although gender and weight were not taken into account when providing the table, Figure 2 stratification by BMI provides a more nuanced view of the relationship between physical attributes and running habits. Previous studies have indicated that both age and BMI can affect running biomechanics, with variations in cadence potentially serving as compensatory mechanisms to optimize energy expenditure or minimize joint stress [7, 15].

The relationship between BMI and cadence, in particular, warrants further investigation. Higher BMI levels are often associated with increased load on the musculoskeletal system, which could necessitate adjustments in cadence to maintain running efficiency or comfort. Similarly, age-related changes in muscle strength, flexibility, and endurance may influence cadence, highlighting the importance of considering these factors in the analysis of running patterns.

In general, taller people have longer legs and a larger stride length, meaning that they can cover more ground with each step. This often results in a lower cadence, or the number of steps taken per minute as shown in Figures 3 and 4. However, research has also shown that running cadence can vary greatly among individuals of the same height, so it is not always a reliable predictor of performance.

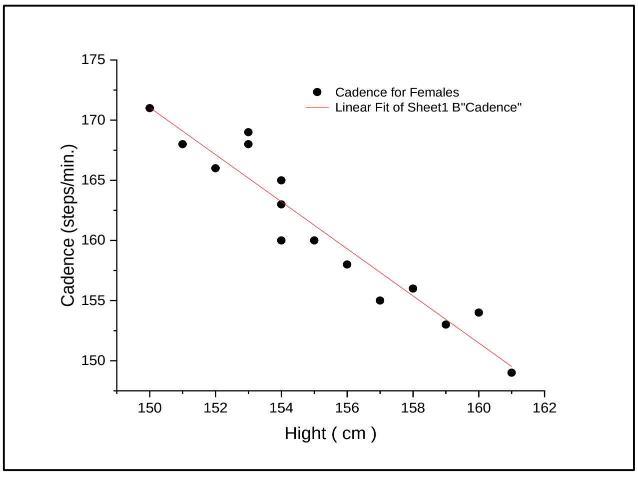

Figure 3: Variability in Cadence among female runners - Individual differences can be just as significant as gender in

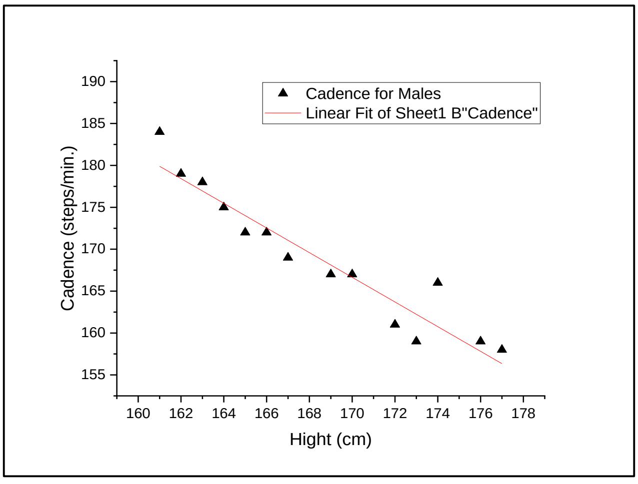

Figure 4: The range of cadence displayed by male runners

Exploring the variability in male cadence: Figure 3 illustrates the range of cadence displayed by male runners. Exploring the variability in female cadence, a wide range of cadence values among female runners can be seen, as shown in Figure 4. This highlights that individual differences can be just as significant as gender when it comes to running form. It is important to note that there are many factors that can contribute to variability in cadence among female runners, including body size and shape, fitness level, running experience, and individual running mechanics. Therefore, it is important to focus on improving overall running technique and performance, rather than simply trying to conform to a certain cadence range based on gender or other demographic factors.

The relationship between height and running cadence is a complex one, influenced by biomechanical and physiological factors. Our analysis, supported by Figures 3 and 4, demonstrates that taller individuals generally exhibit a lower cadence due to longer stride lengths. This observation aligns with biomechanical principles, as longer legs can cover more ground per step, potentially reducing the need for a higher step frequency to achieve the same pace as shorter individuals.

However, the data also reveal a significant variability in cadence among runners of similar heights, underscoring the notion that height alone is not a definitive predictor of cadence or running efficiency. This variability can be attributed to individual differences in running style, muscle composition, and flexibility, among other factors. For instance, two runners of the same height may have different leg-to-torso ratios, affecting their stride length and, consequently, their cadence.

The exploration of cadence variability within genders further highlights the individual nature of running biomechanics. Figures 3 and 4 illustrate a wide range of cadence values among both male and female runners, suggesting that personal biomechanical characteristics and training backgrounds play a crucial role in determining one's cadence. This finding is particularly relevant for coaches and athletes, as it emphasizes the importance of personalized training programs that account for individual biomechanical profiles rather than relying solely on generalizations based on height or gender.

Moreover, the observed variability in cadence, regardless of height, points to the potential for runners to optimize their cadence through targeted training interventions. Several reputable studies have suggested that adjustments to cadence can lead to improvements in running economy and reductions in injury risk, indicating that understanding and optimizing one's cadence could be beneficial for runners of all levels.

In the investigation of running biomechanics, gender disparities emerge as influential factors affecting performance metrics such as cadence and height. This study aims to scrutinize these gender-specific differentiations, employing a methodologically rigorous approach to identify patterns and correlations within the dataset. Central to this analysis is a meticulously crafted scatter plot, serving as a visual tool to explore the relationship between cadence and height across genders. Through this graphical examination, the intricate connections underlying these physical attributes are intended to be elucidated, thus advancing our comprehension of the biomechanical differentials between male and female runners

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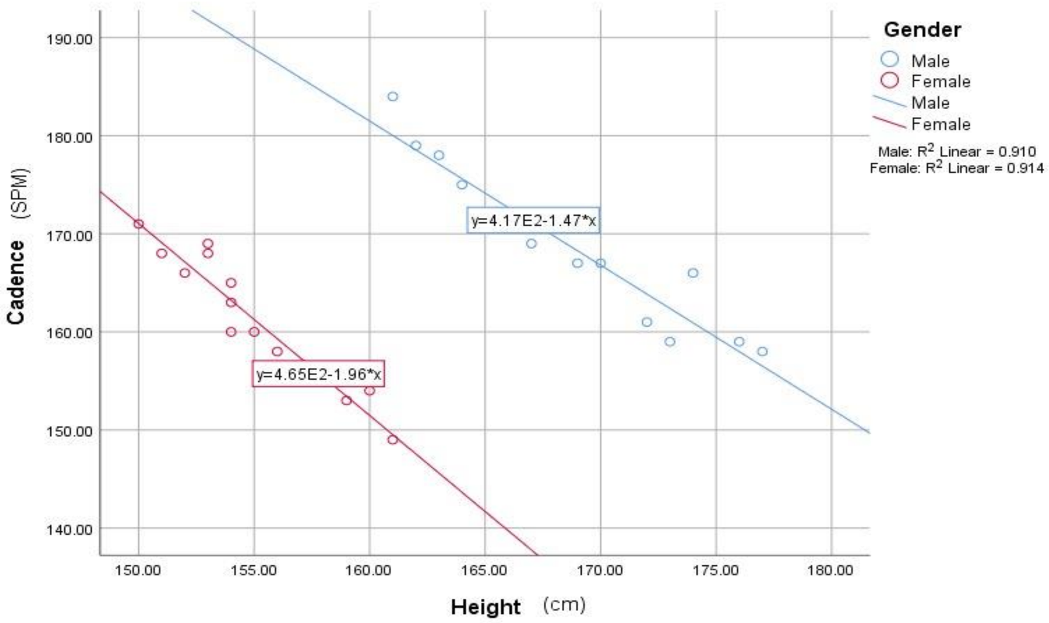

Figure 5: shows a scatter plot graph that represents the relationship between height and cadence for two groups categorized by gender: male and female.

The above plot utilized a scatter plot to elucidate the correlation between cadence and height, differentiated by gender. The graphical representation revealed two distinct clusters of data points corresponding to male and female subjects, denoted by blue and red circles, respectively. The cadence served as the independent variable and was plotted along the x-axis, ranging from 140 to 190 steps per minute. Height, the dependent variable, was measured in centimeters and displayed on the y-axis, extending from 150 to 180 cm.

Linear regression analysis yielded two trend lines, each corresponding to one of the genders. The male trend line was characterized by the equation, with a value of 0.910, indicating a negative correlation between cadence and height. Similarly, the female trend line followed the equation, with a value of 0.914. These high values suggest that the linear models are robust, explaining a significant proportion of the variance in height based on cadence for both genders. Notably, the negative slopes of these trend lines imply that within the observed range, an increase in cadence is associated with a decrease in height for both males and females.

The study's findings contribute to the broader understanding of how physical characteristics may influence or correlate with locomotive patterns. Such insights have practical applications in fields ranging from sports science to rehabilitation, where personalized cadence targets could potentially be established based on an individual's height and gender to optimize performance or recovery outcomes.

In terms of BMI, on average, females have a slightly higher BMI compared to males, and there is variability in BMI within the population. Weight can also play a role in running cadence, as it affects the amount of force that is applied to the ground with each step. A heavier individual may need to take fewer steps to maintain a similar pace, as their body weight will naturally propel them forward with more force. However, excess weight can also put additional strain on the joints and muscles, which can increase the risk of injury.

Regarding weight and cadence, it could be seen the individuals with higher body weight generally had lower average cadence values, such as males, who had an average cadence of 184 steps per minute despite being heavier. This observation is consistent with the idea that heavier individuals may need to take fewer steps to maintain a similar pace due to their greater body mass index propelling them forward with more force.

The force with which the body strikes the ground can be reduced by increasing the running cadence. A low cadence leads to spending more time in the air, causing a shift in the body's weight, resulting in a harder strike on the ground compared to a high cadence. By having more steps per minute, the time spent in the air decreases, leading to a softer landing. Improving running cadence can be beneficial for runners of all levels, from beginners to experts. Despite the initial discomfort and strangeness in changing the stride, persistence can lead to improved speed and reduced risk of injury.

The potential benefits of transitioning from a hindfoot to a forefoot strike pattern in running have been the subject of ongoing research. One study found that a forefoot strike can decrease knee joint contact forces by an average of 1.2 bodyweight (BW) and patellofemoral joint stress by an average of 27% [16,17]. Therefore, it is important to carefully consider the potential benefits and drawbacks when implementing an improving running cadence technique.

The relationship between cadence and stride length affects running dynamics. Running speed depends on both variables, with changes in one impacting the other [18]. For example, a 10% decrease in stride length reduces knee kinetics, including a 14.9% decrease in patellofemoral joint contact forces [19]. Over-striding can lead to knee locking and increased heel stress, elevating injury risk [20]. Higher cadence correlates with reduced impact and injury risk due to shorter strides and increased steps per minute [21]. Accelerating cadence shifts footfalls, shortens stride length, and increases speed with less energy expenditure [22].

The study by Elena N. V. et al. [11] examined intrinsic factors potentially increasing the risk of running-related injuries (RRI) in female collegiate cross-country runners. While their study did not directly associate hip muscle strength or running kinematics with RRI risk. It is notable that running cadence can indirectly influence injury risk. Higher cadence leads to shorter stride lengths, reducing stress on lower extremity joints like the knee and hip. Modifying cadence could potentially prevent running-related injuries by reducing stress on weight-bearing joints. Increasing cadence may thus mitigate overuse injuries associated with running [11].

The findings of this study align with Taylor M. et al.'s investigation on the effects of increased cadence on peak impact force during outdoor running [10]. Taylor M. et al. hypothesized that increasing cadence would decrease peak force, a hypothesis supported by their findings. They observed a significant decrease in peak force during a 2.4-mile run with a 7% increase in cadence, indicating that modifying cadence by increasing step frequency can reduce impact forces and potentially prevent running-related injuries [10]. Higher cadence shortens ground contact time, reducing impact forces on joints and lowering injury risk. Using a metronome, as in Taylor M. et al.'s study, confirms the impact of adjustable cadence and aids in injury prevention by cutting peak force.

Comparing with Chen S, et al.'s study [9] on ITB strain under different exhaustion states and running speeds, both studies stress managing running intensity and cadence for injury prevention. This research suggests that slight cadence results in a reduced stress on weight-bearing joints, while rapid speed increments may elevate ITB strain rates, increasing ITBS risk [9]. Connecting height, running cadence, and injury risk, our study examines biomechanical adaptations linking height, weight, gender, BMI, and cadence. Both studies contribute to running biomechanics, injury prevention, and cadence management, enhancing understanding of cadence's impact on injury risk.

The correlation between our study and Kobayashi et al.'s [12] research highlights the biomechanical influence of step frequency and emphasizes cadence adjustments for injury prevention. Despite differences in populations and objectives, complementary insights into the relationship between running cadence, biomechanics, and injury prevention are provided by both studies, fostering a deeper understanding across diverse populations, including individuals with amputations and the general running population [12].

CONCLUSIONS

The study investigates how gender, age, height, weight, and BMI impact running cadence. Males exhibit a significantly higher cadence than females, aligning with biomechanics research. Taller individuals have longer stride, resulting in lower cadence. Higher BMI may require cadence adjustments due to increased musculoskeletal load, while age-related changes in muscle affect cadence. Weight alters ground force, potentially affecting cadence and injury risk. The study informs personalized cadence targets for sports science and rehabilitation, enriching our understanding of locomotion. Running cadence reduces injury risk and improves performance. Increasing cadence lessens strain on joints, enhances biomechanics, and optimizes energy use. Further research is needed to understand cadence's complex relationship with biomechanics and injury prevention, especially for those with existing ailment

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