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PHYSICS PERSPECTIVES ON HUMAN LOCOMOTION: INVESTIGATING THE MECHANICS OF WALKING PATTERNS

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ABSTRACT:

This study investigated the gait metric differences between males and females aged 18 to 22. Our investigation revealed some significant changes in gait metrics between the two genders. Firstly, males exhibited greater leg and step lengths than females. Males exhibited wider strides, suggesting typical anthropometric variations. Except for BMI and cadence, males had more variation in practically every other gait metric, whereas females had more variability. There was a non-significant positive connection between BMI and gait metrics such as height, stride length, and step width, with BMI having a minor effect on those measures. Overall, both genders showed a distinct pattern of variability, revealing individual variances in gait analysis across the same genders. A direct correlation was observed between the Froude number and height, indicating that individuals with a higher Froude number exhibit a more dynamic and faster walking style. This phenomenon can be ascribed to the biomechanical superiority that taller individuals may possess, enabling them to generate longer strides and achieve higher speeds.A thorough study of walking speed and gait parameters revealed difficulty in finding the right balance between stability, efficiency, and speed in human movement. Understanding these connections will help people develop more efficient training programs, assistive technologies, and more efficient and safe walking in general.

KEYWORDS: Biomechanics, gait parameters, kinematic, dynamics, gender.

1. INTRODUCTION

Studying human movement is crucial for understanding the difficulties of locomotion, especially in terms of walking biomechanics (Möller *et al*., 2018; Herssens *et al*., 2020; Wolff *et al*., 2023; Castellini *et al*., 2023) Similar to age, gait biomechanics are also affected by physiological changes, such as changes in joint flexibility, neuromuscular coordination, and musculoskeletal structure. Studying walking patterns could help us better understand the limitations of human movement throughout one's lifetime (Kirtley, 2006; Hell *et al*., 2021; M.ameen, 2024).

The study of gender differences has also attracted considerable interest and sparked debates in the field of walking biomechanics (Ahad *et al*., 2020). Several studies investigated such differences, but there is still no clear evidence on the exact extent and nature of these variances. Studies indicated that males and females have distinct spatiotemporal characteristics during walking, such as variations in stride duration, step breadth, and cadence (Ahad *et al*., 2020; Al-Makhalas *et al*., 2023). The changes in these classifications might be due to a fundamental physiological variable, such as variations in muscle mass distribution, hip width, and pelvic anatomy. The study of gender variation walking patterns is essential for therapists to evaluate rehabilitation methods to meet the unique needs of various demographic groups (Chumanov *et al*., 2008; Ahad *et al*., 2020; Al-Makhalas *et al*., 2023; Castellini *et al*., 2023).

One of the most critical parameters in walking biomechanics is height. As it directly affects stride length and width, step length and width, and joint kinematics (Ameen, 2024). Generally, taller people have longer stride lengths because of their longer leg lengths. Therefore, they modify their walking patterns to retain

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their stability (Young, 2013; Espinoza-Araneda *et al.*, 2022) Weight and gravitational forces also influence walking biomechanics. The body mass index, BMI, evaluates the quantity of body fat and influences muscle activation and joint mechanics during walking (Fan *et al.*, 2022; Rosso et al., 2019; Castellini *et al*., 2023). Investigating the effect of BMI helps us to understand the impact of obesity on individuals' walking capabilities and suggest strategies to alleviate strain on bones and muscles. The World Health Organization classified obesity and overweight based on BMI. People with a BMI ranging between 18.5 and 24.5 are classified as usual. A BMI between 25.0 and 29.9 is classified as overweight, and a BMI greater than 30 is classified as obese (Castellini *et al*., 2023; Wolff *et al*., 2023).

The primary learning outcome of this research is to improve our comprehension by gathering relevant information regarding human locomotion and optimizing walking gait in various people by investigating the complexities of gender differences in gait dynamics. Walking gait pattern analysis is usually employed to evaluate human movement. Gait analysis provides insights into human movement, enhancing our understanding of gender-specific dynamics (Boonstra *et al.*, 1993; Bohannon, 1997; Young, 2013; Möller *et al.*, 2018; Rosso *et al.*, 2019; Castellini *et al*., 2023).

2. MATERIALS AND METHODS

The current study recruited 40 healthy young individuals, both males and females, aged between 18 and 22. The participants were divided into two groups based on their gender. The mean height for males was 177 cm, while for females, it was 163 cm. Twenty participants each were included in the male and female groups. Data were extracted from retrospective studies conducted by students at the College of Engineering, University of Duhok after participants were briefed on the test procedures and objectives.

Participants walked a distance of 20 meters while data were collected. Data collection commenced only after participants had initiated walking to avoid bias from including altered steps during gait initiation. Age was determined based on the date of birth, while body weight was measured using a scale, and body height was measured using a Hengshida roll-up measuring tape. The stopwatch utilized in this study was renowned for its accuracy and reliability in measuring elapsed time.

Each participant underwent the walking procedure three times, resulting in three trials per person. The average of these trials was calculated, and the total number of right and left foot impacts across all three trials for each of the 40 participants was recorded, resulting in 40 different cadences.

Gait analysis was performed using a movement recording setup to record critical events in the gait cycle, including speed (m/s), step length (cm), step width (cm), stride length (cm), stride width (cm), cycle time (s). over a limited distance, walking speed was measured using a stopwatch. Walking speed was measured using a stopwatch over a predetermined distance. The cadence (stride/min) was calculated based on the total number of steps taken within the last 60 seconds (Ameen, 2024).

When walking on one foot, either right or left, the steps were multiplied by factor two. For example, for the 82-right foot, the cadence was 164 steps per minute. The number of steps per minute of walking per distance is defined as the stride length as depicted in Figure 1 (Ameen, 2024). To evaluate gait characteristics comprehensively, temporal-spatial parameters (TSPs) of gait, such as walking speed, cadence, and stride length, were measured (Yu *et al.*, 2023).

To standardize the approach and minimize the variations in the gait mechanics, people participating in the study were wearing the same typical footwear, such as flat shoes.

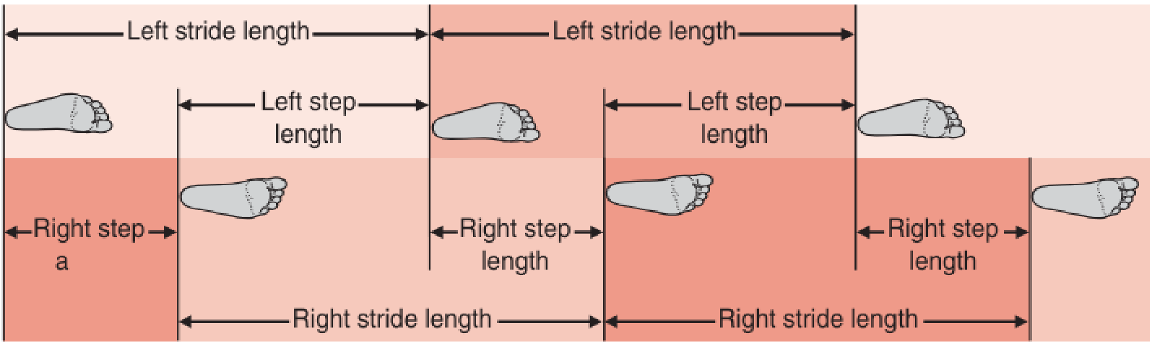

Figure 1*:* Discrepancy in Right Step Length vs. Left in Gait Analysis, Yet Equal Stride Lengths Maintained (Kirtley, 2006)**.**

The Froude number is a dimensionless number usually used in biomechanics to assess the relative impact of the gravitational and inertial forces on human locomotion. By inserting this number into the methodology, valuable information on the movement dynamic can be obtained, revealing the underlying dynamic governing the subject under study. The Froude number can be calculated using the following formula. (Donelan & Kram, 2000).

$$Fr = \frac{v^2}{\sqrt{gL}}$$

Where: vIs the walking velocity, L is a characteristic length, typically the leg length or a relevant anatomical dimension, and g is the gravitational acceleration.

3. RESULTS AND DISCUSSION

Table 1 provides information about various parameters associated with walking patterns and can be used to synthesize and explain variables between male and female subjects. These measures include age, weight, height, time to cover the limited distance, biomechanics gait parameters, speed, and BMI. The measurements in Table 1 offer valuable insights into the biomechanics of walking and running, highlighting gender differences.

Table 1 : a comprehensive analysis of various parameters associated with walking patterns, comparing male and female subjects

	Gender	Age (year)	Height (m)	Weight (Kg)	Time (Sec.-20 m)	Time (Min.)	Step (20 m)	Leg length (m ± 0.01)	Step width (m)	Stride width (m)	Step length (m)	Stride length (m)	Speed (m/s)	Cadence (steps/min.)	Froude Number	BMI
Mean	Female	20.6	1.63	62.0	23.4	0.392	35.7	0.966	0.126	0.0629	0.563	1.13	0.864	156	0.0245	23.1
	Male	20.1	1.77	73.5	20.1	0.332	31.0	1.00	0.213	0.107	0.648	1.30	1.00	158	0.0322	23.4
Median	Female	21.0	1.63	60.0	24.4	0.406	35.4	0.970	0.133	0.0663	0.564	1.13	0.820	155	0.0225	23.2
	Male	20.0	1.78	70.5	19.9	0.332	31.1	1.02	0.222	0.111	0.643	1.29	1.00	158	0.0320	23.1
Standard deviation	Female	0.945	0.0694	13.8	2.92	0.0505	2.56	0.0653	0.0298	0.0149	0.0402	0.0804	0.110	11.9	0.00549	3.79
	Male	1.21	0.0686	13.1	1.17	0.0140	1.94	0.0553	0.0533	0.0266	0.0395	0.0789	0.0428	5.52	0.0022	3.64
Minimum	Female	19	1.50	40	19.8	0.330	31.1	0.860	0.0750	0.0375	0.500	1.00	0.682	139	0.0156	17.8
	Male	18	1.67	50	18.4	0.307	28.2	0.900	0.0900	0.0450	0.577	1.15	0.954	148	0.0291	15.6
Maximum Mean	Female	22	1.77	90	29.3	0.489	40.0	1.10	0.180	0.0900	0.643	1.29	1.01	176	0.0320	29.7
	Male	22	1.90	98	23.6	0.349	34.7	1.13	0.300	0.150	0.709	1.42	1.08	169	0.0358	32.0

The effect of walking speed on the temporal phases of gait was analyzed by comparing gait parameters at varying speeds. The provided scatter plot illustrates the relationship between stride length and walking speed with a fitted regression line. The fitted regression line represents the relationship between speed and stride length. The equation of the fitted line indicates that stride length increases as walking speed increases. Specifically, for every one m/s increase in walking speed, stride length increases by 2.07 meters, considering the quadratic term (-1.77e^2). Figures 2 (b) and (d) illustrate some exciting facts about the R-squared value, indicating that 77% of the variability in stride length and step length can be explained by walking speed. The correlation coefficient (R^2 value) shows a strong link between variables. This signifies quicker walking increases with longer strides and steps (Kirtley, 2006; Błaszczyk *et al.*, 2011; M.ameen, 2024).

Cadence, step width, and speed relationships could provide a more comprehensive understanding of gait dynamics. (Kirtley, 2006). Figures 2 (a) and (c) demonstrate how walking speed affects cadence and step width. This investigation showed how gait characteristics change with speed, which is essential for understanding human locomotion and walking biomechanics and rehabilitation evaluations.

Figure 2 (a) determines step width against speed and shows a positive linear correlation ($R^2 = 0.296$), indicating that step width increases as speed increases. This moderate correlation suggests other factors also influence step width, potentially due to the need for more excellent stability at higher speeds.

Figure 2 (c) determines cadence (steps per minute) against speed and shows a positive linear association ($R^2 = 0.360$); this signifies that cadence increases with speed. The modest R^2 value suggests that other variables, such as person-specific gait characteristics, also contribute. According to the equations for measuring cadence, every one m/s increase in the speed of walking raises cadence by 1.12 steps per minute (Ameen, 2024). This suggests a modest positive correlation between variables. Higher cadences have been associated with faster walking speed (Błaszczyk *et al*., 2011).

Stride length rises non-linearly with speed, as shown by a positive quadratic correlation (R^2 = 0.76). This indicates that stride length increases faster at higher speeds, suggesting an intricate step length and cadence adjustment efficiency and safety need an understanding of these associations (Young, 2013; M.ameen, 2024).

These results affect clinical evaluations and therapies for gait disorders. Balance issues may cause step width changes, whereas muscular or neurological deficits may cause step and stride length changes. Targeted rehabilitation treatments to improve gait

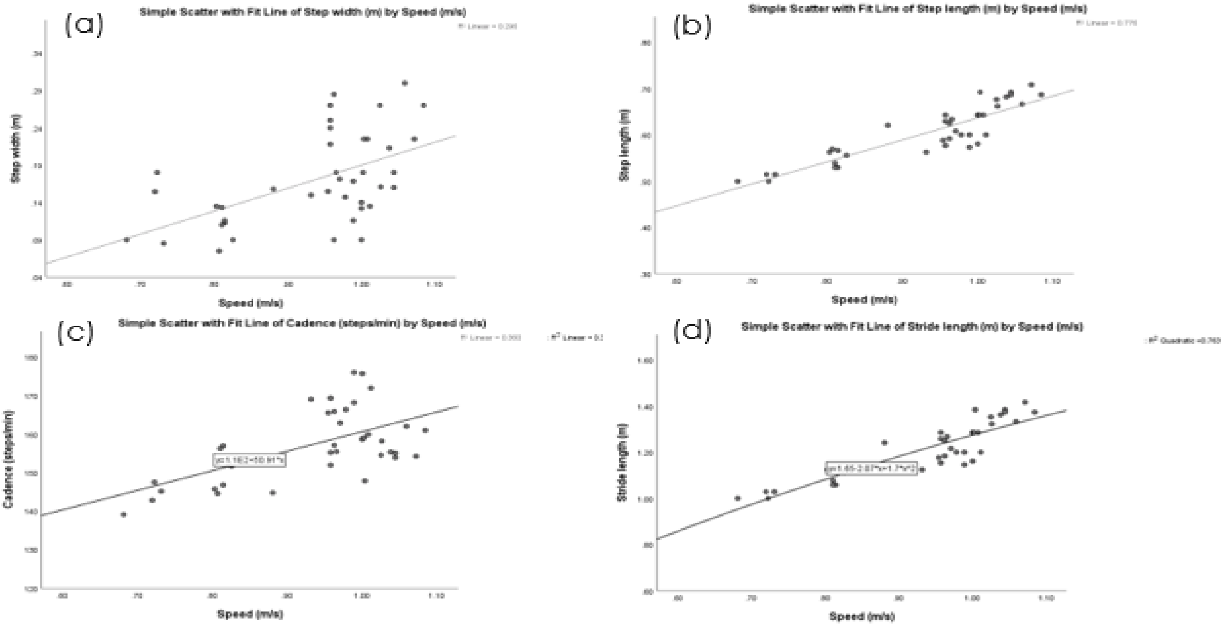

Figure 2: shows the influence of speed on gait parameters appears to compelling trends

Figure 3: investigates the relationships between various gait parameters and BMI, unveiling significant ramifications of BMI's influence on gait characteristics.

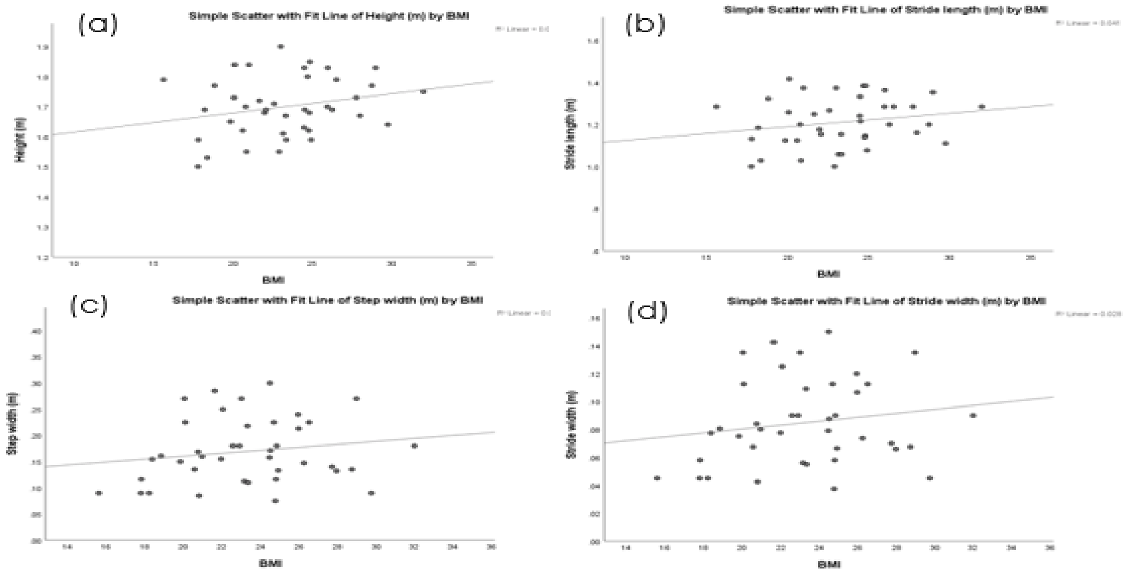

Figure 3: influence of Body Mass Index on gait parameters appears to compelling trends

Figure 3 shows that BMI does not have much of an effect on different aspects of walking. There is a weak positive association between height and BMI. This shows that genes and food factors have a more significant effect on height. There is not much of an association between stride length and BMI, which suggests that stride length is probably affected by things like leg length, muscle strength, and walking speed, not BMI. Also, the fact that there are no significant relationships between BMI and both step width and stride width suggest that balance, stability, and the way a person walks are more critical than BMI when it comes to these gait traits. This shows how important it is to look at a lot of different things when studying walking and coming up with health solutions (Hell *et al*., 2021; Fan *et al*., 2022; M.ameen, 2024).

In many ways, knowing that BMI does not have much impact on walking parameters. When designing exercise and treatment regimens, clinical and rehabilitation therapists and physicians must consider muscular strength, balance, and each patient's walking style. For researchers in gait analysis and biomechanics, these findings suggest shifting the focus from BMI to other anthropometric and physiological factors that more directly influence gait characteristics. In public health and physical activity initiatives, the results indicate that individuals with higher BMIs can achieve similar gait mechanics to those with lower BMIs, encouraging the development of inclusive physical activity programs that do not discriminate based on BMI (Fan *et al*., 2022; Wolff *et al*., 2023; Castellini *et al*., 2023; M.ameen, 2024).

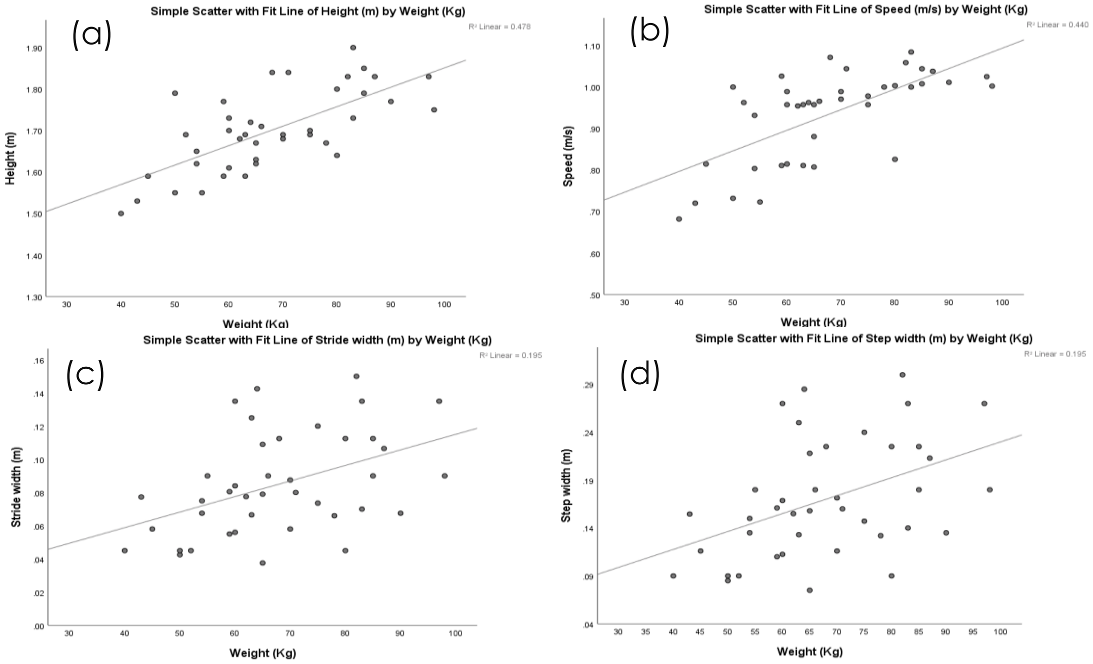

Figure 4: illustrates the relationship between weight and various gait and anthropometric parameters, including height, speed, stride width, and step width. Each plot features a fit line to highlight the linear relationship between these variab

A moderate positive correlation is observed between height and weight ($R^2 = 0.478$), indicating that heavier individuals are generally taller, as shown in Figure 4 (a). The relationship between speed and weight also shows a moderate positive correlation ($R^2 = 0.440$), illustrated in Figure 4 (b), suggesting that higher weights are associated with faster walking speeds.

The correlations between weight stride width and step width are weaker ($R^2 = 0.115$ and 0.195, respectively), as shown in Figure 4 (c) and (d). These weak positive correlations imply that while there is a slight trend for both stride width and step width to increase with weight, the relationships are not particularly strong. Balance and walking style may have a more significant influence on the dimensions of gait.

These findings have important implications for the study of human walking mechanics. The relationship between weight, height, and speed is relatively small, but it does impact these physical measurements. Taller and heavier individuals may walk at a faster pace due to their greater physical capacity and stride efficiency (Kirtley, 2006; Young, 2013; Herssens *et al*., 2020; Espinoza-Araneda *et al*., 2022;). The weak correlations between stride width and step width indicate that gait width parameters are influenced primarily by biomechanical or neuromuscular factors rather than weight (Błaszczyk *et al*., 2011).

These studies shed light on the complicated relationship that exists between weight and how people walk. Health, fitness, and rehabilitation applications need to understand these connections to optimize gait mechanics based on individual anthropometric profiles.

Figure 5 shows how the Froude number correlates with height, step length, stride length, and weight. Each figure features a regression line to show the linear association between variables.

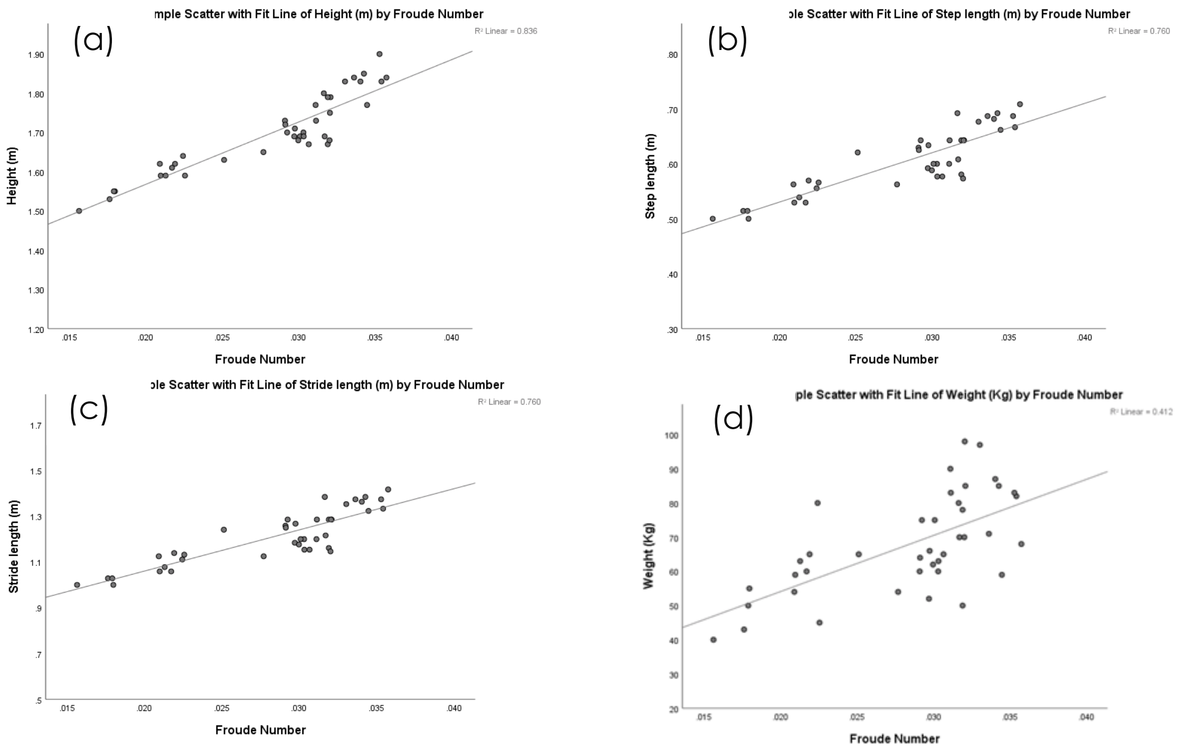

Figure 5: show that the influence of Froude Number on gait parameters appears to compelling trends

A positive correlation between height and Froude number is evident in Figure 5 (a), with a fit line and R^2 value of 0.836. This means that the Froude number increases with height. This significant relationship shows that taller persons have greater Froude numbers, indicating faster walking patterns or more dynamic. Taller persons may have a biomechanical advantage in longer strides and faster speeds (Donelan & Kram, 2000).

Figures 5 (b) and (c) demonstrate a high positive correlation between step length, stride length, and Froude number, with an R^2 value of 0.760. The substantial correlation shows that longer-steppers have higher Froude numbers. The result is consistent with the assumption that a faster walk speed (shown by a higher Froude number) necessitates longer stride lengths to maintain balance and optimize the efficiency of an individual's walking pattern. The connection is essential for the development of athletic training programs and for understanding the mechanics of effective locomotion (Donelan & Kram, 2000).

In Figure 5 (d), weight is positively correlated with the Froude number, while the R^2 value is 0.412. According to this, weight increases with Froude numbers, although the variability is much more significant than the trend. Weight alone may not predict dynamic walking performance or height, step length, or stride length, although the sample's different body compositions and fitness levels may explain this (Donelan & Kram, 2000).

These results affect gait biomechanics. The Froude number is closely associated with height, step length, and stride length, demonstrating that anthropometric parameters impact walking dynamics. Taller people with longer strides and steps had higher Froude numbers, suggesting efficient mobility. Due to the weaker weight relationship, dynamic walking may need more muscular strength and endurance (Donelan & Kram, 2000; Castellini *et al.*, 2023;). Figure 6 shows gender-based gait and anthropometric features for comparison between men and females.

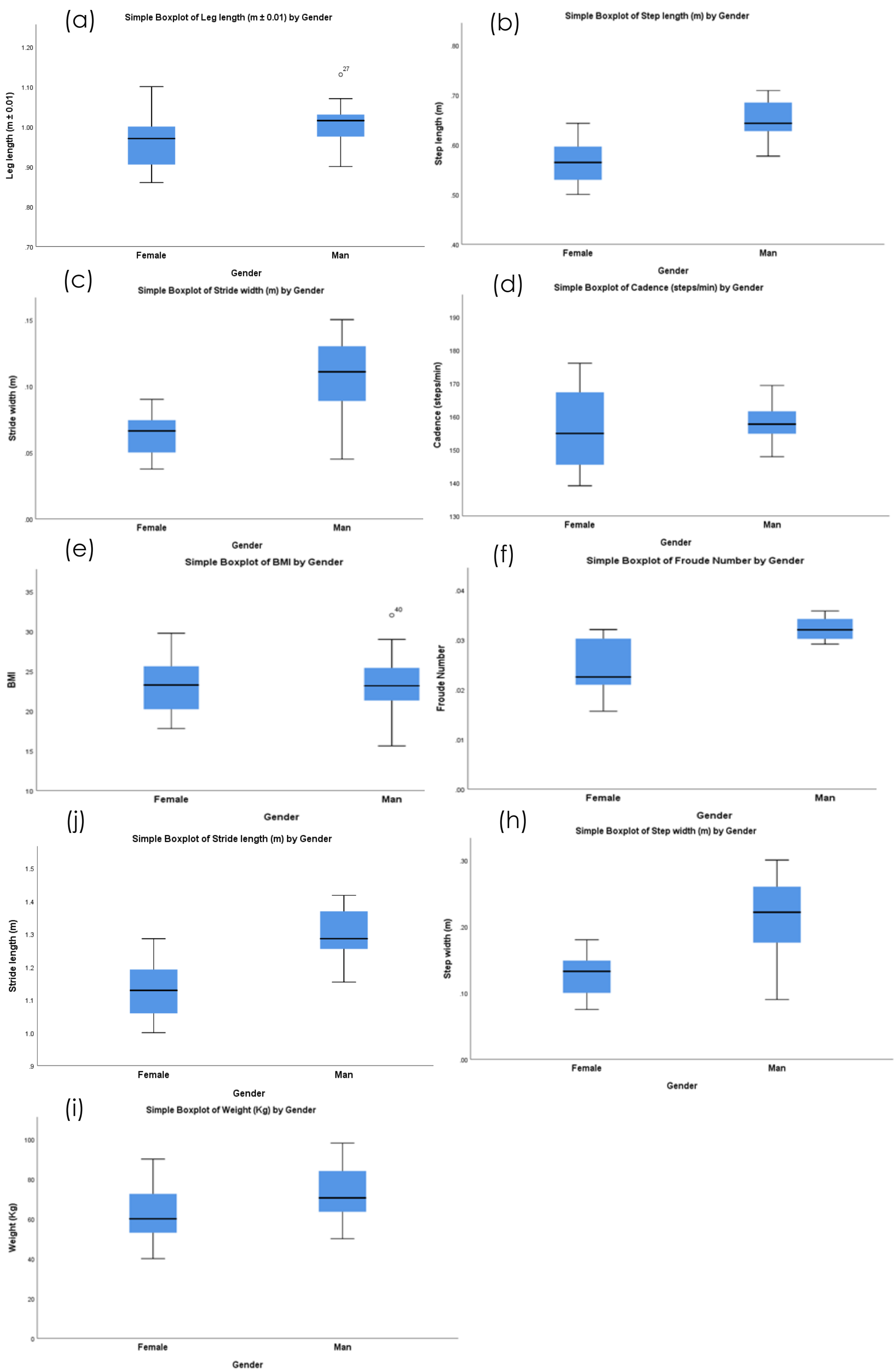

Figure 6: distribution of various gait and anthropometric parameters by gender

The results show the gender distribution of various gait and anthropometric parameters, allowing for a comparative analysis between females and males. Males generally exhibit longer leg lengths, step lengths, and wider strides compared to females, though there is one outlier for females with a leg length of around 1.10 meters and one outlier for males with a BMI of around 40 (Ameen, 2024).

Analysis of cohort BMI reveals that males present a slightly higher median BMI than females, while females display more significant BMI variability, indicated by a more comprehensive interquartile range (IQR). Females generally exhibit a higher mean cadence than males, while males generally exhibit higher values of Froude number compared to females (Ameen, 2024).

Considering stride length, step width, and weight by gender, the results show that males have longer mean stride lengths and wider mean step widths than females. The variability, indicated by the IQR, is more pronounced in males for stride length and step width. Further, males generally have higher weights, with a slightly wider IQR compared to females.

The analysis of IQR across all parameters reveals notable differences in variability between genders. Males exhibit larger IQRs for leg length, step length, stride width, and step width than females. In contrast, females show wider IQRs for BMI and cadence, suggesting more variability in these measures. In combination, these metrics represent significant differences in gait and anthropometric characteristics between the two genders. Males exhibit higher values and more significant variability in several vital parameters, including leg length, step length, stride width, and weight. In comparison, females show higher values in cadence and more significant variability in BMI. These differences are due to variations in musculoskeletal geometry leading to gender-variable ranges of motion. Additionally, males typically have larger muscle mass and, hence, muscle strength than females. This manifests as different joint torques and joint reaction forces, particularly considering the forces between the foot and the ground during walking. Since these force differences are essential in determining injuries and affect musculoskeletal function, advice on disease management and injury risk could benefit from being tailored according to gender (Möller *et al.*, 2018; Rosso *et al.*, 2019; Hell *et al.*, 2021; Fan *et al.*, 2022).

One limitation of this study is that the effect of walking speed was not considered, as only one pre-defined walking speed was used for the measurements. Another potential limitation is that the data were obtained on only participants aged 18-22; however, this was not intended to be a study that considered the effect of ageing. Future research should seek to incorporate kinetic and kinematic gait analyses across various age groups, providing insights into gait variations.

CONCLUSION

This study explores the influence of gait parameters on human locomotion, highlighting the intricate balance between stability, efficiency, and speed. Over the range presented by the participants in this study, BMI was found to have minimal impact on height, stride length, step width, and stride width. Further, gender-based differences highlighted disparities in gait and anthropometric parameters between males and females. Many researchers have focused on speed-based gait analysis. (Boonstra et al., 1993; Bohannon, 1997), however, this study demonstrates otherwise. The current research shows that the equivalent gait speed of healthy males and females of similar ages fails to account for numerous crucial parameters. Several factors impact gait speed and cadence. These results underscore the necessity of gender-specific comparisons in clinical assessments and interventions. These analyses offer valuable insights into the relationships between gait parameters and the Froude number, with implications for sports science, rehabilitation, and ergonomics. Understanding these relationships can aid in designing better training programs, developing assistive devices, and enhancing overall gait efficiency and safety. The findings are expected to be helpful in designing tailored interventions in health, fitness, and rehabilitation. Future research could explore gait under different environments using advanced motion capture, expand the sample size to include diverse age groups, and examine the impact of footwear and surfaces. Investigating psychological factors would also enhance practical applications in rehabilitation and sports performance.

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