

Gait Pattern Analysis in Transgender Individuals Compared to Cisgender Males and Females

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Abstract—Gait pattern analysis is an emerging field within forensic science that focuses on identifying individuals based on their walking style. This study examines the gait characteristics of transgender individuals in comparison with cisgender males and females. Gait, defined as the manner of walking, is influenced by anatomical, biomechanical, and physiological factors and is considered a unique behavioral biometric trait. In this research, gait samples were collected using a forensic thumbprint ink method, which provided clear footprint impressions for analysis. Key parameters such as step length, stride length, step width, foot angle, swing time, and stance time were measured and compared across three groups consisting of transgender women, cisgender males, and cisgender females within the same age range. Statistical analysis was performed using One-Way ANOVA to determine the significance of differences among groups. The results indicated that transgender individuals exhibited intermediate gait characteristics, sharing similarities with both cisgender males and females. Spatial parameters showed closer resemblance to female gait, while certain temporal parameters aligned more with male gait. The findings highlight the complexity of gait as a biometric tool and emphasize the importance of inclusive forensic analysis. This study contributes to both forensic identification research and the broader understanding of gender-related biomechanical variations.

Keywords— *Gait Pattern; Transgender; Forensic Identification; Biomechanics.*

I. INTRODUCTION

Forensic science plays a vital role in criminal investigations by applying scientific techniques to analyze evidence and reconstruct events. Among the various branches of forensic science, human identification is one of the most critical areas. Traditionally, identification relies on fingerprints, DNA profiling, and facial recognition. However, in situations where such evidence is unavailable,

alternative methods like gait analysis become highly valuable. Gait refers to the manner in which an individual walks and is considered a unique behavioral trait influenced by multiple biological and environmental factors. Gait analysis has gained prominence due to its non-invasive and unobtrusive nature. Unlike fingerprints or DNA, gait can be captured from a distance using surveillance cameras. This makes it particularly useful in cases involving CCTV footage where facial features may not be clearly visible. The uniqueness of gait arises from the coordination of the musculoskeletal and nervous systems, which produce consistent walking patterns. Parameters such as stride length, step width, cadence, and foot angle contribute to identifying individuals based on their gait.

Historically, gait studies have focused primarily on differences between males and females. Biological factors such as skeletal structure, muscle distribution, and hormonal influences contribute to observable variations. Males typically exhibit longer strides and broader steps due to greater muscle mass and limb length, whereas females tend to have shorter strides and narrower step width due to differences in pelvic structure and body composition. In recent years, increasing attention has been given to transgender individuals, whose gait patterns may not strictly align with traditional male or female categories. Transgender individuals may undergo hormonal therapy or social transition, which can influence body composition and movement patterns. For instance, hormone replacement therapy can alter fat distribution, muscle mass, and pelvic tilt, all of which may impact gait.

Despite growing recognition, there is limited research exploring gait patterns in transgender populations. This gap highlights the importance of conducting systematic studies to understand how gender identity

and biological factors interact to influence walking patterns. Such research is essential not only for scientific knowledge but also for improving the accuracy and fairness of forensic identification. The present study aims to compare gait patterns among transgender individuals, cisgender males, and cisgender females using measurable parameters. By analyzing similarities and differences, the research contributes to a more inclusive understanding of human biomechanics. It also emphasizes the need for forensic scientists to consider gender diversity when interpreting gait evidence, ensuring that conclusions are scientifically valid and unbiased.

II. OVERVIEW OF GAIT PATTERN

Human gait is a complex biomechanical process involving coordinated movements of the lower limbs, upper body, and nervous system. It consists of two primary phases: the stance phase, where the foot is in contact with the ground, and the swing phase, where the foot moves forward. Together, these phases form a gait cycle, which repeats continuously during walking. Several parameters define gait patterns. Step length refers to the distance between successive footprints of opposite feet, while stride length measures the distance between footprints of the same foot. Step width indicates the lateral distance between footprints, reflecting balance and stability. Foot angle describes the orientation of the foot relative to the direction of movement. These parameters collectively provide a detailed understanding of walking behavior.

Gait is influenced by various intrinsic factors such as age, gender, height, body weight, and health conditions. Extrinsic factors like footwear, walking surface, and environmental conditions also play a role. Psychological factors, including mood and confidence, can subtly affect walking style. Advancements in technology have enhanced gait analysis through motion capture systems, wearable sensors, and machine learning algorithms. However, traditional methods such as footprint analysis remain valuable due to their simplicity and cost-effectiveness. These methods allow researchers to measure gait parameters accurately without requiring sophisticated equipment.

In forensic science, gait serves as a behavioral biometric identifier. While it may not provide absolute identification like DNA, it offers supportive

evidence that can strengthen investigations. The uniqueness of gait lies in its consistency over time, although it may vary under certain conditions. Understanding gait patterns is essential not only in forensic science but also in medical and rehabilitation fields. Abnormal gait can indicate underlying health issues such as neurological disorders or musculoskeletal injuries. Therefore, gait analysis has interdisciplinary applications that extend beyond criminal investigations.

III. GAIT IN FORENSIC INVESTIGATION

Gait analysis has become increasingly important in forensic investigations, particularly in cases involving surveillance footage. When facial recognition fails due to poor image quality or disguise, gait provides an alternative means of identifying individuals. Experts analyze walking patterns by examining features such as stride length, posture, and limb movement.

Unlike fingerprints, gait is considered class evidence rather than individual evidence. This means it can narrow down suspects but may not uniquely identify a person. Nevertheless, it plays a crucial role in supporting other forms of evidence. The reliability of gait analysis depends on factors such as video quality, camera angle, and environmental conditions. Poor lighting, occlusion, and variations in walking speed can affect accuracy. Therefore, forensic experts must interpret gait evidence cautiously.

Databases of gait patterns have been developed to improve analysis. These databases provide reference data on common gait features, helping experts assess the likelihood of matches. However, more research is needed to establish standardized protocols and error rates. Despite its limitations, gait analysis remains a valuable tool in forensic science. Its ability to capture behavioral characteristics makes it particularly useful in situations where other evidence is unavailable.

IV. FORENSIC THUMBPRINT INK METHOD

The forensic thumbprint ink method is a traditional technique used to record footprints for gait analysis. In this method, ink is applied to the soles of the feet, and participants walk on a paper surface, leaving clear impressions. This method provides a two-dimensional representation of gait, allowing researchers to measure parameters such as step

length, stride length, and foot angle. It is cost-effective and easy to implement, making it suitable for academic research.

Footprint analysis has been used in forensic investigations for decades. Footprints can reveal information about an individual's height, weight, and walking pattern. In some cases, they have been crucial in linking suspects to crime scenes. Although modern technologies offer more advanced analysis, the ink method remains relevant due to its simplicity and reliability. It is particularly useful in controlled environments where precise measurements are required.

V. TRANSGENDER GAIT PATTERN ANALYSIS

Transgender gait patterns represent a complex interaction between biological and social factors. Individuals assigned male at birth may retain certain skeletal characteristics, while hormonal therapy and gender expression influence movement patterns. Studies suggest that transgender individuals often exhibit intermediate gait characteristics. Spatial parameters such as step width and gait angle may resemble female patterns, while temporal parameters may align with male patterns.

Behavioral adaptation plays a significant role. Transgender individuals may consciously modify their walking style to align with their gender identity. Over time, these adaptations can influence gait patterns. Understanding transgender gait is important for both forensic and social perspectives. It ensures that forensic analysis is inclusive and avoids misinterpretation based on traditional gender assumptions.

VI. LIMITATIONS IN GAIT ANALYSIS

Gait analysis faces several challenges due to variability in human movement. Factors such as fatigue, injuries, footwear, and emotional state can alter walking patterns. Environmental conditions also affect gait analysis. Uneven surfaces, lighting conditions, and camera angles can impact accuracy. In real-world scenarios, these factors make it difficult to obtain consistent data.

Another limitation is the lack of standardized protocols. Without established guidelines, interpretations may vary among experts. This reduces

the reliability of gait evidence in legal contexts. Despite these limitations, ongoing research aims to improve accuracy through advanced technologies and statistical methods.

VII. STATISTICAL ANALYSIS USING ANOVA

One-Way ANOVA is a statistical method used to compare means across multiple groups. In this study, it was used to analyze differences in gait parameters among three groups. The results showed no statistically significant difference, indicating overlap between groups. This suggests that while patterns exist, they are not distinct enough for definitive classification. ANOVA helps identify trends but has limitations. It does not specify which groups differ without further analysis. Additionally, it assumes normal distribution and equal variance. Despite these limitations, ANOVA remains a useful tool for analyzing gait data and identifying patterns.

VIII. DISCUSSION

The findings highlight the complexity of gait patterns. Cisgender males exhibited longer strides and wider steps, while females showed narrower and shorter patterns. Transgender individuals displayed intermediate characteristics. These results emphasize the influence of both biological and behavioral factors. Gait is not solely determined by anatomy but also by social and psychological influences. From a forensic perspective, these findings underscore the importance of considering gender diversity. Misinterpretation of gait evidence can lead to incorrect conclusions. Future research should explore larger sample sizes and additional parameters to improve understanding.

IX. CONCLUSION

This study demonstrates that gait patterns vary across gender groups, with transgender individuals exhibiting intermediate characteristics. The findings highlight the importance of inclusive research in forensic science. Gait analysis remains a valuable tool for identification, but it should be used alongside other evidence. Understanding its limitations is essential for accurate interpretation. The study contributes to both forensic science and biomechanics by providing insights into gender-related variations in gait. Future research should

focus on improving methodologies and expanding datasets.

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