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# Urban Mobility in Istanbul: Unveiling Gender and Group Dynamics in Pedestrian Walking Speed

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## ABSTRACT

Urban mobility is influenced by a complex interplay between pedestrian behavior, urban design, and social dynamics such as gender and group interactions. This study investigates how these factors shape walking speeds in Istanbul, aiming to inform more efficient and equitable urban design practices. Using advanced video analysis techniques on 1,177 individuals along a major thoroughfare, this research reveals an average walking speed of 1.37 meters per second (m/s). Analysis revealed men (1.41 m/s, N=610) walking faster than women (1.32 m/s, N=567), and groups (1.26 m/s, N=287) slower than solo walkers (1.40 m/s, N=890). These findings underscore the importance of considering diverse user needs and social dynamics in urban planning. By accounting for gender-specific speeds and group behaviors, Istanbul's urban planners can better optimize sidewalk widths, intersection layouts, and social spaces to accommodate a variety of pedestrian experiences. This study contributes to a deeper understanding of pedestrian behavior in a non-Western context, providing valuable insights for creating safer, more accessible, and equitable urban environments in Istanbul.

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## 1. Introduction

Pedestrian movement forms the lifeblood of urban areas, shaping how cities function and how livable they are (Bohannon & Williams Andrews, 2011; Qian *et al*., 2020). As urbanization intensifies, understanding pedestrian behavior becomes paramount for developing sustainable transportation systems and mitigating congestion. The interplay between urban design, pedestrian movement, and public health is well-documented (Guo *et al*., 2019; Sharifi *et al*., 2015), highlighting the need for pedestrian-friendly environments that promote physical activity and well-being.

However, current pedestrian infrastructure design often relies on data primarily gathered from Western countries (Martin *et al*., 2016). This reliance presents a significant challenge for cities like

Istanbul, where cultural norms, social interactions, and the built environment may significantly differ from Western contexts. Applying Western pedestrian data to Istanbul could lead to several critical issues, including mistimed pedestrian signals at intersections, inadequate sidewalk widths to accommodate pedestrian flow, and potentially ineffective evacuation plans in emergencies. The lack of locally relevant data hinders the development of truly effective and safe urban spaces.

Istanbul, a vibrant metropolis bridging East and West, offers a compelling case study for exploring pedestrian behavior. Factors such as cultural conventions regarding personal space and the unique characteristics of Istanbul's urban fabric may influence walking speeds and patterns (Almejmaj *et al.*, 2015; Bouterse & Wall-Scheffler, 2018). This study addresses the gap in existing research by investigating pedestrian walking speed in Istanbul, with a particular focus on gender and group dynamics. In this study, "group" is defined as two or more individuals walking together, such as friends, families, or colleagues. Understanding these dynamics is crucial for developing context-specific urban design solutions.

Recent studies on spatial configuration and navigation in complex environments (Fezzai *et al.*, 2020) and the influence of personality traits on walking behavior (Bashri & Che Amat, 2021) underscore the multiple factors affecting pedestrian movement. While these studies provide valuable insights, they haven't addressed the specific conditions of Istanbul.

This research aims to provide empirical data on pedestrian walking speed in Istanbul to inform the optimization of pedestrian infrastructure. Specifically, we investigate differences in walking speed between genders and examine the influence of group size on pedestrian movement. This data is critical for several reasons, including improving traffic management, enhancing walkability, and developing more effective evacuation strategies. Accurate walking speed data for Istanbul, particularly in high-density areas and high-rise buildings, can significantly improve the accuracy of evacuation models and, consequently, public safety in emergency situations. By addressing these key questions, this study seeks to contribute to a deeper understanding of pedestrian dynamics in a non-Western context and to provide evidence-based recommendations for creating a safer, more accessible, and equitable urban environment in Istanbul.

## 2. Literature Review

### *2.1 Previous Research on Pedestrian Behavior and Walking Speed*

Understanding pedestrian behavior is crucial for enhancing pedestrian safety and urban planning (Guo *et al.*, 2019; Sharifi *et al.*, 2015). Numerous studies have been conducted to understand pedestrian behavior and walking speed. These studies have explored various factors influencing walking speed, such as age, gender, physical health, and environmental conditions. For instance, research has shown that walking speed can vary significantly with age, with younger adults typically walking faster than older adults (Bohannon, 1997). Similarly, gender differences in walking speed have been reported, with men generally walking faster than women (Chandra & Bharti, 2013). Additionally, Ghani *et al.* explored gender and age differences in walking for transport and recreation, highlighting the need to understand these relationships across different neighborhoods (Ghani *et al.*, 2016).

Furthermore, studies to understand pedestrian dynamics have utilized methodologies ranging from observational analysis to advanced video analysis techniques. Findings have highlighted the impact of elements such as sidewalk width, amenities availability, and street design on walking speed (Daamen & Hoogendoorn, 2003; Gates *et al.*, 2006; Montufar *et al.*, 2007; Park *et al.*, 2014; Sharifi *et al.*, 2015).

Pedestrian walking speed has been recognized as a critical parameter for designing traffic signals at intersections, especially in crowded areas (Daamen & Hoogendoorn, 2003) and used as a basic parameter for evacuation studies (Satır & Topraklı, 2021, 2024; Topraklı & Satır, 2024). Lack of walking speed in-country data makes it impossible to calculate exact evacuation times, fezzaiespecially in high-rise buildings (Satır & Topraklı, 2020, 2023). Factors such as age, disability, traffic conditions, group size, gender, and social group dynamics have been identified as determinants of pedestrian walking speed (Gates *et al.*, 2006; Park *et al.*, 2014; Sharifi *et al.*, 2015)) and walking speed is crucially important for evacuation calculations (Topraklı *et al.*, 2019). Additionally, studies have emphasized the importance of considering vulnerable populations, such as individuals with disabilities (Ford *et al.*, 2017).

#### 2.1.1 Measuring Walking Speed

A variety of gait analysis tests exist in the literature. Some tests are performed in a controlled laboratory setting, while others are done outdoors. Laboratory-based tests typically involve walking paths of varying lengths, such as 2.4 m (Master *et al.*, 2020), 4 m (Johnson *et al.*, 2020), 5 m (Kawai *et al.*, 2020), 6 m (Fritz *et al.*, 2012), 8 m (Ng *et al.*, 2013), 10 m (Røislien *et al.*, 2009), and 20 m (Tipakornkiat *et al.*, 2012). Although slight discrepancies in outcomes can be observed across these tests, they generally yield consistent results (Ng *et al.*, 2013). The time subjects take to complete the path is often measured using a digital stopwatch, and walking speed is calculated by dividing the distance covered by this time (Bohannon, 1997; Majed *et al.*, 2022; Master *et al.*, 2020).

Another crucial consideration when selecting a walking test is achieving a steady-state walking speed. Generally, when transitioning from a standstill to walking (static tests), individuals require approximately three steps to reach a steady pace (Strutzenberger *et al.*, 2021). Therefore, it is advisable to include an acceleration and deceleration zone of around 2.5 m (Fritz *et al.*, 2012) (or 2-5 steps (Strutzenberger *et al.*, 2021)) at the start and end of the measurement area in static tests. Alternatively, some tests are conducted on treadmills, often involving the placement of reflective markers on key points of participants' bodies for subsequent analysis based on camera recordings (Stimpson *et al.*, 2018; Strutzenberger *et al.*, 2021).

Thompson and Heydon introduced the concept of gait analysis through video recordings, which involves capturing video footage of individuals walking within a known area. Subsequent analysis of these recordings captures natural walking behaviors since subjects are unaware of being observed (Al-Azzawi & Raeside, 2007). Researchers have noted that subjects tend to exhibit altered walking behaviors and varying speed when aware of being recorded (Al-Azzawi & Raeside, 2007; Brown *et al.*, 2017; Hutchinson *et al.*, 2019; Kawai *et al.*, 2020), prompting some studies to conduct measurements without subjects being aware. Such studies are frequently conducted in heavily trafficked walkways, sidewalks (Tipakornkiat *et al.*, 2012), parks (Liang *et al.*, 2020), or shopping centers (Almejmaj *et al.*, 2015).

Liang *et al.* utilized an overhead camera (10 m high) to monitor a park square and performed gait analysis on video recordings (Liang *et al.*, 2020). By analyzing data collected over 14 different days, they compiled walking data from a total of 446 individuals. Tipakornkiat *et al.* placed a camera along a walking path in Bangkok and examined the impact of crowd density on walking speed using 719 subjects (Tipakornkiat *et al.*, 2012). Measurement area selection accounted for maintaining distance from intersection points. Chandra and Bharti positioned cameras at seven locations in India to assess the distribution of pedestrian walking speed. Almejmaj *et al.* studied walking behavior in a Saudi Arabian shopping mall using security cameras (Almejmaj *et al.*, 2015), highlighting the significant influence of local attire, particularly on women's walking speed.

### 2.1.2 Culture & Walking Speed

Cultural factors emerge as one of the many elements influencing walking speed, as evidenced by worldwide gait analyses. However, these studies have predominantly been conducted in Western countries. To illustrate, Martin *et al.* conducted a systematic review and meta-analysis emphasizing the importance of walking habits in Western populations (Martin *et al.*, 2016).

Walking speed vary across different cultural contexts, as evidenced by several studies. Levine & Norenzayan found faster walking speed in large cities compared to medium-sized cities in six different countries (Levine & Norenzayan, 1999). Bouterse & Wall-Scheffler explored cultural influences on walking behaviors, providing detailed data on the factors affecting walking speed (Bouterse & Wall-Scheffler, 2018). Almejmaj *et al.* compared walking speed between Western cultures and Saudi Arabia, highlighting the impact of cultural differences on walking behaviors (Almejmaj *et al.*, 2015). Furthermore, Capistrant *et al.* reported variations in average walking speed across different countries, with Russia having the slowest speed and China the fastest (Capistrant *et al.*, 2014). Additionally, Liao *et al.* discussed how cultural, economic, and environmental contexts influence the "Walk Score" and its implications for public health, underscoring the cultural nuances in walking habits (Liao *et al.*, 2019).

Moreover, Capistrant *et al.* discussed walking speed in different countries, noting that five out of six SAGE countries had average walking speed of 0.83 m/s or slower (Capistrant *et al.*, 2014). Nindorera *et al.* emphasized the importance of studying walking speed in various countries by pointing out the need for more research on walking speed and stroke outcomes in Burundi (Nindorera *et al.*, 2022).

Experimental outcomes across the globe reveal a wide range of walking speed (0.5-2.1 m/s (Brinkerhoff *et al.*, 2022)). Consequently, each country is urged to define its own walking speed standards, as a universal standard is unattainable. Notably, the study by Levie *et al.*, Majed *et al.*, and Rahman *et al.* contributed data compiled in Table 1 (Levine and Norenzayan's data was converted to m/s) (Levine & Norenzayan, 1999; Majed *et al.*, 2022; Rahman & Ghani, 2012).

**Table 1.** Walking speed across the world (Levine & Norenzayan, 1999; Majed *et al.*, 2022; Rahman & Ghani, 2012)

| COUNTRIES | | References | | | | COUNTRIES | | References | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | (Levine & Norenzayan, 1999) | (Majed *et al.*, 2022) | | (Rahman & Ghani, 2012) | | | (Levine & Norenzayan. | (Majed *et al.*, 2022) | | (Rahman & Ghani, 2012) |
| | | | Males | Females | | | | | Males | Females | |
| | | Walking Speed (m/s) | | | | | | Walking Speed (m/s) | | | |
| **1** | Brazil | 1.09 | | | | **23** | Kenya | 1.45 | | | |
| **2** | Romania | 1.09 | | | | **24** | France | 1.48 | 1.35 | | |
| **3** | Syria | 1.15 | | | | **25** | Japan | 1.51 | | | |
| **4** | Jordan | 1.16 | | | | **26** | United States | 1.52 | 1.38 | 1.35 | 1.47 |
| **5** | Bulgaria | 1.17 | | | | | | | 1.39 | 1.37 | 1.35 |
| **6** | Indonesia | 1.23 | | | | | | | | 1.39 | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **7** | Singapore | 1.24 | | | 1.23 | | | | | 1.41 | |
| **8** | China | 1.28 | | | 1.20 | **27** | Germany | 1.52 | | | |
| **9** | Austria | 1.30 | | | 1.54 | **28** | England | 1.52 | 1.47 | 1.45 | |
| **10** | El Salvador | 1.30 | | | | | | | | 1.50 | 1.47 |
| **11** | Czech Republic | 1.33 | | | | **29** | Switzerland | 1.55 | | | |
| **12** | South Korea | 1.33 | | | | **30** | Netherlands | 1.60 | | | |
| **13** | Hungary | 1.33 | | | | **31** | Ireland | 1.64 | | | |
| **14** | Taiwan | 1.35 | | | | **32** | Saudi Arabia | | | | 1.08 |
| **15** | Mexico | 1.35 | | | | **33** | India | | | | 1.20 |
| **16** | Costa Rica | 1.37 | | | | **34** | Bangladesh | | | | 1.20 |
| **17** | Hong Kong | 1.40 | | | | **35** | Thailand | | | | 1.22 |
| **18** | Greece | 1.40 | | | | **36** | Sri Lanka | | | | 1.25 |
| **19** | Sweden | 1.42 | | | | **37** | Israel | | 1.47 | 1.45 | 1.31 |
| **20** | Poland | 1.42 | | | | **38** | Tunisia | | 1.20 | | |
| **21** | Canada | 1.42 | | | 1.40 | **39** | Kuwait | | 1.22 | 1.08 | |
| **22** | Italy | 1.43 | 1.31 | 1.27 | | **40** | Australia | | 1.41 | | |

These studies underscore the importance of considering cultural contexts when examining walking speed. Factors such as urbanization, social norms, and environmental influences play a crucial role in shaping walking behaviors. Understanding these cultural variations is essential for developing tailored interventions to promote physical activity and mobility in diverse populations.

#### 2.1.3 Culture & Walking Speed

Gender differences in pedestrian behavior have been a significant focus in urban studies literature, with research indicating that men and women may demonstrate distinct walking patterns and preferences influenced by various factors (Moussaïd *et al*., 2010). For instance, studies have shown that men tend to comply with crosswalk lights less than women (Granié *et al*., 2013).

While some studies suggest differences in pedestrian behavior based on gender, Subaih *et al*. found no significant gender disparities in pedestrian movement behavior (Subaih *et al*., 2020). However, they have shown that the behavior of pedestrians walking within groups of the same gender may differ from mixed-gender groups (Subaih *et al*., 2020).

#### 2.1.4 Group Dynamics on Walking Speed

Group dynamics significantly influence pedestrian movement, with individuals often adjusting their walking speed to synchronize with others in their group. Research has shown that larger groups tend to move more slowly compared to individuals or smaller groups (Zanlungo *et al*., 2017). The dynamics of pedestrian groups are influenced by intrinsic properties such as the purpose of the pedestrians, their personal relationships, gender, age, and body size (Zanlungo *et al*., 2017). Furthermore, the presence of individuals with disabilities in a crowd has been shown to reduce the overall crowd speed (Sharifi *et al*., 2016). Moreover, pedestrian movements are influenced by group size and composition and factors like age, sex, height, and weight (Simeunović *et al*., 2021). The presence of obstacles and the geometry of stairs can impact the characteristics of group movement (Shi *et al*., 2022). The study of pedestrian group dynamics is multidimensional, encompassing factors such as group size, composition, intrinsic properties of individuals, emotions, presence of obstacles, and design of walking facilities (Rahman *et al*., 2013). Understanding these dynamics is crucial for managing pedestrian flow and improving the efficiency of urban spaces, especially in scenarios where quick movement of crowds is necessary, such as in emergencies (Shahhoseini *et al*., 2017).

### *2.2 Gaps in the Existing Literature and Rationale for the Current Study*

Walking speed is a critical aspect of pedestrian behavior influenced by factors such as age, gender, and cultural context. While existing research has shed light on walking speed, there is a notable gap in comprehensive studies focusing on non-Western contexts like Turkey, particularly in outdoor urban settings (Martin *et al*., 2016). The influence of cultural factors on walking speed, including the impact of personal space norms on pedestrian flows, remains understudied (Willis *et al*., 2004). Understanding these dynamics is crucial for accurate urban planning, especially in diverse urban environments like Istanbul (Yıldırım & Çelik, 2023).

Gender also significantly affects walking behavior, with studies indicating that males generally walk faster than females (Almejmaj *et al*., 2015; Chandra & Bharti, 2013; Montufar *et al*., 2007). Additionally, research emphasizes the importance of considering age and gender when studying pedestrian walking speed, as these factors can notably influence preferred speed (Ananda *et al*., 2022;

Pinna & Murrau, 2017). Furthermore, gender influences recreational walking, with women exhibiting stronger associations between the perception of crime/safety and recreational walking compared to men (Loukaitou-Sideris & Fink, 2009).

Walking speed is an imperative parameter for urban studies, traffic planning, and evacuation scenarios (Fitzpatrick *et al.*, 2006). In Turkey, where no prior studies on walking speed have been conducted, this research aims to establish walking speed parameters. Moreover, Istanbul's unique spatial characteristics offer an opportunity to explore pedestrian behavior in a culturally rich urban setting, providing valuable insights for global urban planners and policymakers (Yıldırım & Çelik, 2023).
By addressing gaps in understanding pedestrian behavior, particularly concerning gender and group dynamics in urban contexts like Istanbul, this study aims to contribute new knowledge to the field and provide data on walking speed in diverse cultural settings.

## 3. Methodology

### *3.1 Study Site and Data Collection*

The study was conducted on a bustling thoroughfare in Istanbul, Turkey (Figure 1), chosen for its representative nature and significant pedestrian activity. The selected site encompasses a mix of commercial, residential, and recreational areas, reflecting the diverse urban fabric of Istanbul.

Istanbul, boasting a population nearing 16 million, holds the distinction of being Turkey's most populous city (Adrese Dayalı Nüfus Kayıt Sistemi Sonuçları, 2022, 2023). Its climatic characteristics are defined by a transitional climate bridging the Black Sea and Mediterranean regions, resulting in substantial precipitation in the Marmara Region. Throughout the year, Istanbul experiences temperature extremes from a low of -11°C to a high of +40°C, accompanied by an average relative humidity of 75% (İklim, 2023).

This study is centered in the Zeytinburnu district of Istanbul, specifically along the thoroughfare adjacent to the Kazlıçeşme stop (Figure 1). This stop represents a pivotal point on the Marmaray rail system, which connects Asia and Europe beneath the Bosphorus. The rationale behind this choice rests upon the presence of a consistently uniform pedestrian demographic throughout the day. Due to its proximity to a heavily frequented rail system station, this street witnesses substantial foot traffic from the local populace. Furthermore, the pedestrians utilizing this route primarily demonstrate an intent-driven walking pattern rather than leisurely strolls. Hence, the study area aligns coherently with the study's objectives.

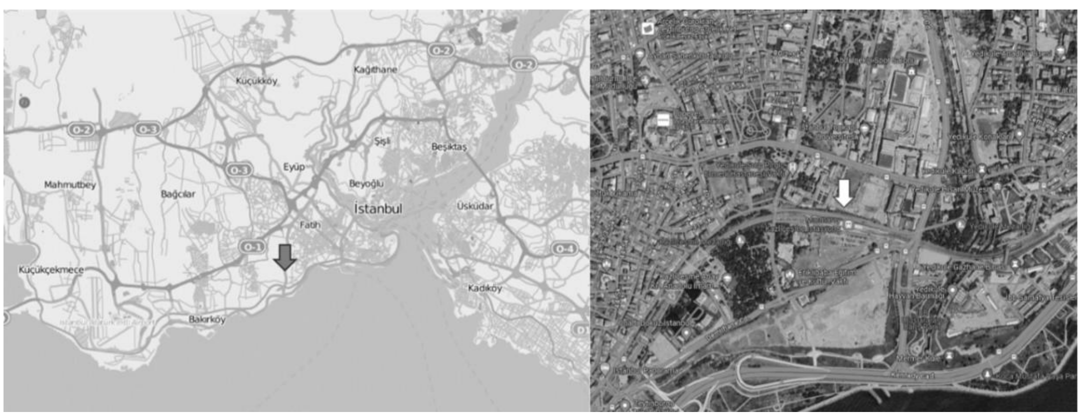


**Figure 1.** Location of Zeytinburnu and Kazlıçeşme (Google Maps, 2024; İstanbul Üzerinde Kazlıçeşme, 2016)

Figure 2, provided below, offers both a street-level view and an aerial perspective of the study area. The delineated Calculation Zone is strategically positioned away from intersections, the bus stop, and the juncture where the sidewalk width undergoes alterations. The diagram presented in Figure 3 illustrates both the plan and the section of the street where the study was executed.

The specific zone subject to video analysis is denoted as the "Calculation Zone." This designated area spans a length of 25.1 meters and possesses a width of 2.05 meters. The camera responsible for recording is situated at a distance of 26.05 meters from the Calculation Zone (with a height of 8.5 meters above the ground).


**Figure 2.** Aerial photo and street view of study zone (Google Maps-Street View, 2024)

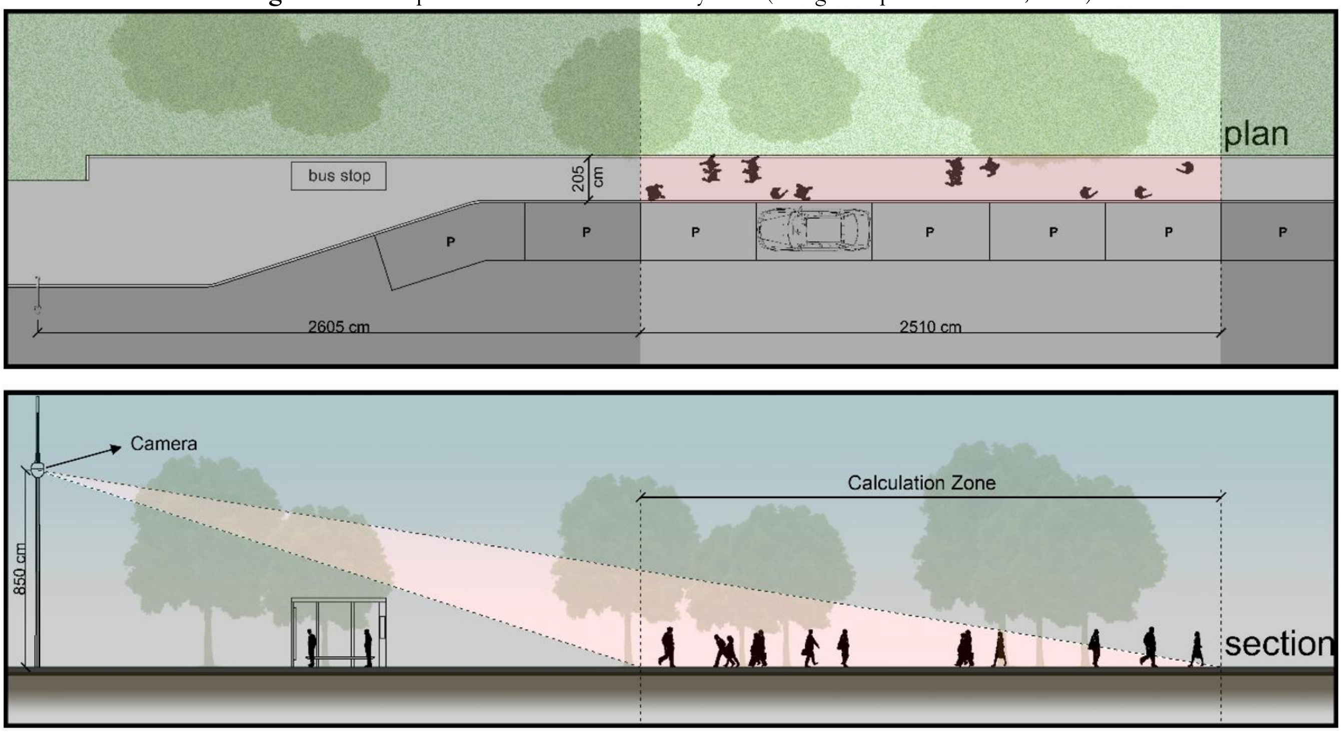


**Figure 3.** Plan and section drawings of study site

The visual depiction provided in Figure 4 shows the camera perspective. Notably, lines delineate the commencement and termination points of the study area. As individuals traverse this demarcated space, their entry and exit times are meticulously recorded within the Microsoft Excel software. Upon the study's culmination, the 25.1-meter length of the designated area is partitioned based on the acquired time intervals. Consequently, the average speed for each individual is computed in meters per second (m/s).

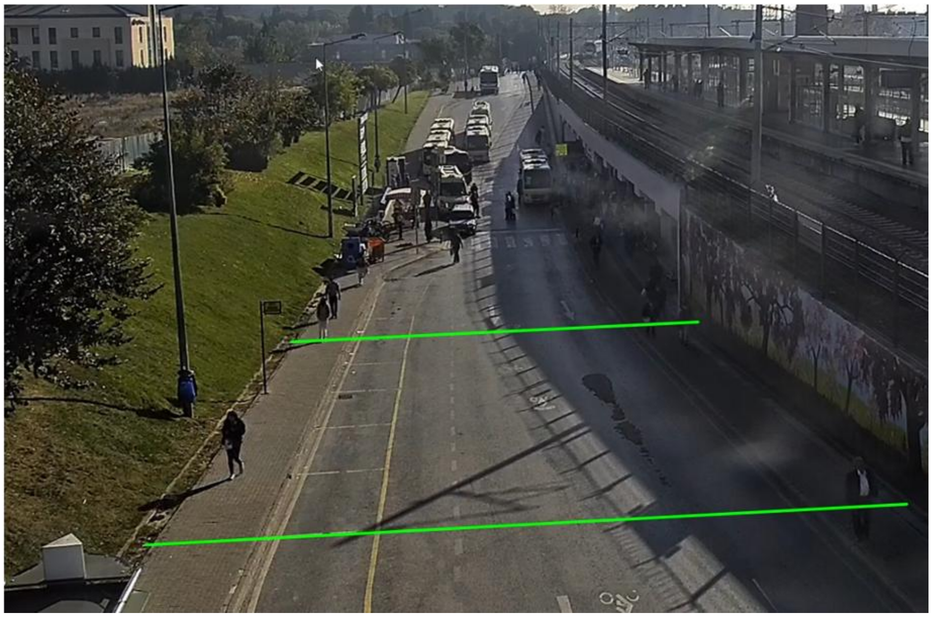

**Figure 4.** Camera view

The video recording commenced on October 24, 2022, at 09:00. The recording concluded at 17:08, primarily prompted by the decline in video resolution as daylight diminished and darkness set in post-17:00. Consequently, a comprehensive recording spanning over 8 hours was obtained. On the specific video recording date, Istanbul experienced a range of temperatures, with a minimum of 12°C and a maximum of 20°C. Notably, there was no recorded instance of precipitation during this period.

The data collection process was conducted carefully, considering ethical principles, particularly in ensuring the privacy and anonymity of the participants. Stringent measures were implemented to safeguard their privacy. Recorded images were processed to ensure that individuals' faces were not distinctive, thus preserving anonymity. Furthermore, the data collected is securely stored and will not be shared with any third parties, adhering to principles of confidentiality.

## *3.2 Video Analysis Technique*

### 3.2.1 Data Analysis

The data was analyzed using meticulous methods to ensure accuracy. The walking speed of the individuals in the footage were calculated by measuring the time taken to cover a known distance. The average walking speed was then calculated for the entire sample. Gender differentiation and group walking effect analyses were also conducted. The findings were then interpreted in the global framework of walking speed and the specific cultural context of Turkey.

The average speed of a person was ascertained by dividing the path length by the time to traverse the path. Figure 5 depicts an individual entering and exiting the designated calculation area. Entry and exit times were manually established down to 100ths of a second. For instance, the person in question entered at 09:05:06:23 and exited at 09:05:24:17, resulting in an elapsed time of 17.94 seconds. Dividing the path length of 25.1 meters by this time yielded an average walking speed of 1.40 m/s. By conducting such analyses, the walking speed of 1177 individuals was ascertained.

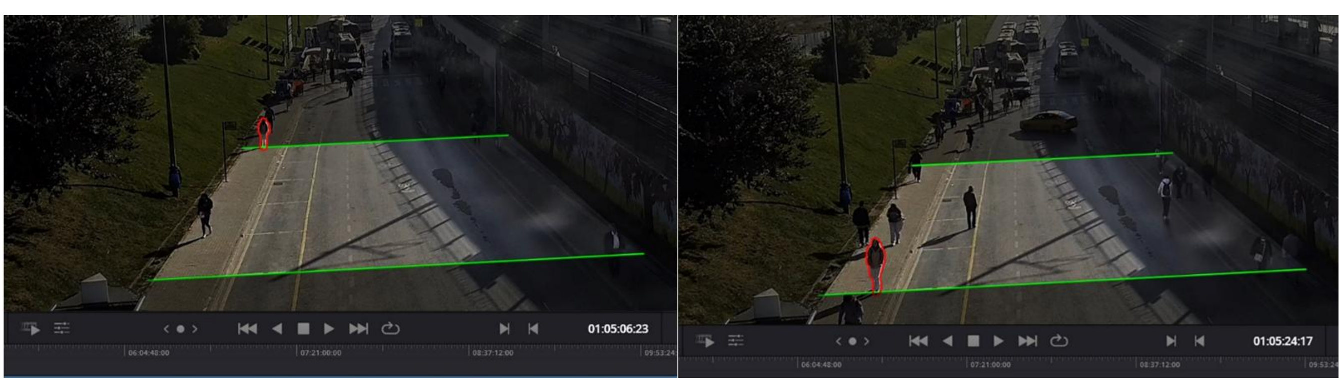


**Figure 5.** Entering and exiting the calculation area of a person

Additionally, individuals were categorized based on gender and whether they walked alone or in a group. This allowed for extracting distinct male/female and group/solo walking speed. Subsequently, the dataset underwent rigorous analysis using SPSS® for Windows, Version 27.0 (IBM SPSS Statistics for Windows, 2020). Descriptive statistics were initially computed, followed by assessments of normal distribution within the sample. Independent variable t-tests were employed to ascertain significant differences between the identified classes. These meticulous, analytical steps provide valuable insights into the dynamics of pedestrian movement within crowded urban environments.

#### 3.2.2 Calibration and Validation

To ensure the accuracy of the walking speed measurements, our study employed a multi-step calibration process. Initially, we calibrated the video recording equipment using a standardized speed measurement tool to verify the frame rate and timing accuracy. We then conducted a series of pre-study trials with known speed to fine-tune our measurement techniques. The stopwatch method was used to measure 5% of the sample on-site during recordings. It presents consistent results with measurements made via video recording. This rigorous approach ensured that our walking speed measurements were accurate and comparable to existing research.

#### 3.2.3 Ethical Considerations

The study adhered to ethical guidelines to protect the privacy and anonymity of participants. Faces were blurred in the video recordings to prevent individual identification. The data collected is stored securely and will not be shared with any third parties. No personally identifiable information was collected.

### *3.3 Sample Selection and Description*

During the analysis phase, the approach outlined in Fossum and Ryeng's study was adopted, wherein individuals were classified based on their observable external traits, identifying them as either male or female (Fossum & Ryeng, 2021). Among those distinguishable by appearance, 610 were identified as male, and 567 were identified as female. Additionally, people walking in groups or alone were labeled separately. Notably, 287 of the 1177 individuals walked in groups comprising two or more people. All individuals in the sample were evidently healthy adults, ensuring that the data collected was representative of the average walking speed of the general population in Istanbul. Since the main objective of the article is to assess healthy adults' walking speed, children, elderly, people driving baby strollers and runners were excluded by the authors. All exclusions constitute only 3.35% of the sample. Considering that the excluded subjects showed extreme walking speeds, this exclusion process was performed in order to obtain a distribution that is statistically closer to normal.

Notably, specific criteria guided the inclusion and exclusion of cases during the sample selection stage:

- Individuals solely proceeding in a straight path were included; those entering or exiting the Calculation Zone from the sides were excluded.
- People displaying conspicuous fluctuations in speed, such as halting or pausing, were excluded.
- Individuals engaging in running were excluded.
- Pedestrians carrying heavy loads were excluded.
- Those walking in the calculation zone while looking at their phones were excluded.
- Those who walked with a cane or crutches were excluded.
- Children were excluded.
- Elderly people were excluded.
- People driving baby strollers were excluded.
- People whose gender could not be determined by their appearance were excluded.

## 4. Results

### *4.1 Overall Average Walking Speed of Pedestrians in Istanbul*

The study found that the sampled population walks at an average speed of 1.37 meters per second (m/s). This metric serves as a crucial baseline for comprehending pedestrian mobility within the city. By establishing this average walking speed, researchers and urban planners can gain insights into the pace at which pedestrians navigate the urban environment in Istanbul.

The resulting data from the 1177 individuals who underwent walking speed analysis in the study is provided in this section. The obtained data was transferred to SPSS® for Windows, Version 27.0 (IBM SPSS Statistics for Windows, 2020) and subjected to additional tests. Figure 6 shows the distribution frequency of walking speed of the 1177 individuals in intervals of 0.1 m/s. The highest frequency is observed between 1.3 m/s and 1.4 m/s. This is followed by the range of 1.4 m/s to 1.5 m/s.

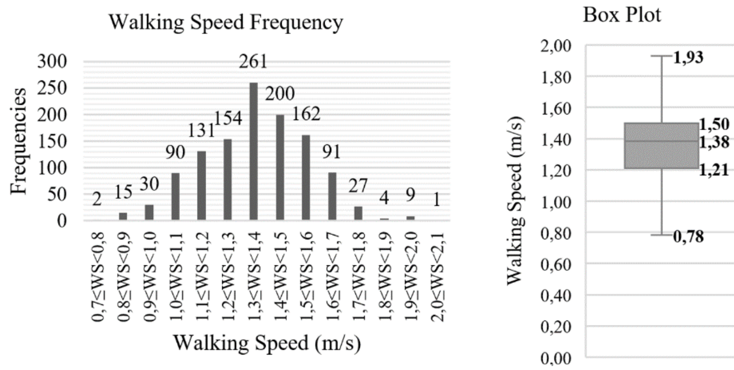


**Figure 6.** Frequency distribution and box plot graphics of 1177 people

As seen in Table 2, the average walking speed is 1.37 m/s and the median value is 1.38 m/s. The average walking speed in a 95% confidence interval is between 1.35 m/s and 1.38 m/s. The walking speed of the 1177 individuals ranged from 0.77 m/s to 2.09 m/s.

**Table 2.** Descriptive statistics of the general results

| Descriptives | | | |
|---|---|---|---|
| | | Statistic | Std. Error |
| N | | 1177 | |
| Mean | | 1,3662 | ,00613 |
| 95% Confidence Interval for Mean | Lower Bound | 1,3542 | |
| | Upper Bound | 1,3782 | |
| 5% Trimmed Mean | | 1,3670 | |
| Median | | 1,3800 | |
| Variance | | ,044 | |
| Std. Deviation | | ,21039 | |
| Minimum | | ,77 | |
| Maximum | | 2,09 | |
| Range | | 1,32 | |
| Interquartile Range | | ,29 | |
| Skewness | | -,033 | ,071 |
| Kurtosis | | -,173 | ,142 |

### *4.2 Gender-Specific Walking Speed and Analysis of Disparities*

Gender-specific analysis unveiled notable disparities in walking speed between men and women. Men exhibited a slightly higher average walking speed of 1.41 m/s, while women maintained a slightly slower pace at 1.32 m/s. This discrepancy in walking speed highlights the importance of considering gender dynamics in urban planning and infrastructure design.

Figure 7 represents the frequency distributions of walking speed by gender. As can be seen, both male and female walking speed are concentrated between 1.3 m/s and 1.4 m/s. As indicated by the skewness values in Table 3, the distribution of female walking speed is more symmetrical than that of males. As seen in Figure 7, males' walking speed is relatively more right-skewed (negative skewness). As shown in Table 3, the average walking speed of males (N=610) (1.41 m/s) is higher than that of females (N=567) (1.32 m/s). In a 95% confidence interval, the walking speed of male's ranges from 1.39 m/s to 1.42 m/s, while the walking speed of females ranges from 1.31 m/s to 1.34 m/s.

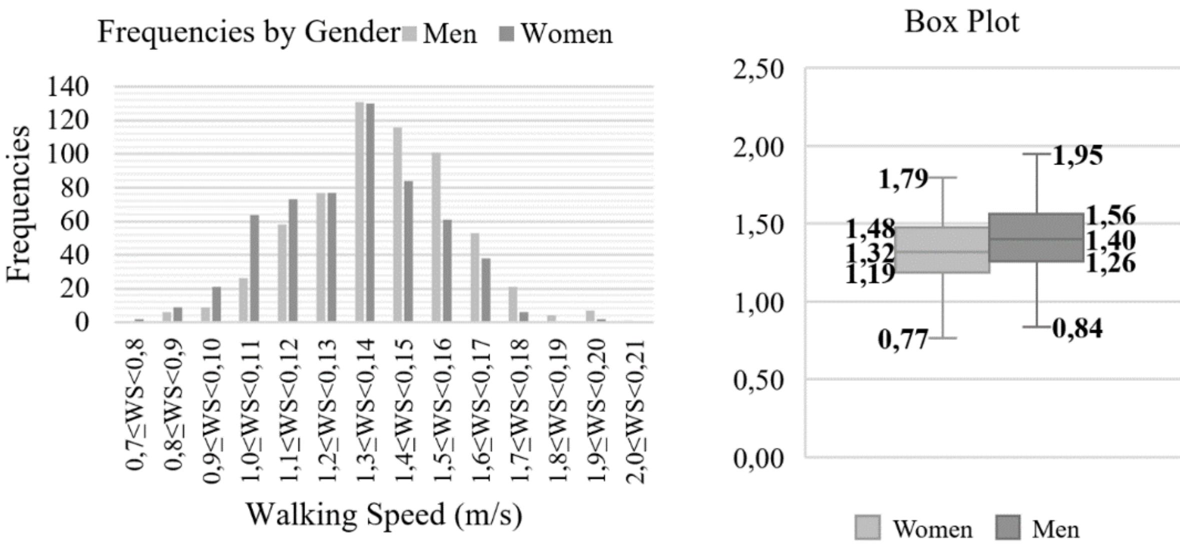


**Figure 7.** Frequency distribution and box plots of walking speed by gender

**Table 3.** Descriptive statistics of walking speed (gender distributed)

| Descriptives | | | | | |
|---|---|---|---|---|---|
| | | Male | | Female | |
| **Gender** | | **Statistic** | **Std. Error** | **Statistic** | **Std. Error** |
| N | | 610 | | 567 | |
| Mean | | 1,4072 | ,00835 | 1,3221 | ,00866 |
| 95% Confidence Interval for Mean | Lower Bound | 1,3908 | | 1,3051 | |
| | Upper Bound | 1,4236 | | 1,3391 | |
| 5% Trimmed Mean | | 1,4081 | | 1,3231 | |
| Median | | 1,4000 | | 1,3200 | |
| Variance | | ,042 | | ,042 | |
| Std. Deviation | | ,20614 | | ,20611 | |
| Minimum | | ,84 | | ,77 | |
| Maximum | | 2,09 | | 1,95 | |
| Range | | 1,25 | | 1,18 | |
| Interquartile Range | | ,30 | | ,29 | |
| Skewness | | -,058 | ,099 | -,009 | ,103 |
| Kurtosis | | ,034 | ,198 | -,370 | ,205 |

An independent samples t-test was conducted to determine if there was a significant difference in walking speed between men and women. The t-test (Table 4) yielded a significant difference in walking speed between men and women (since $p \leq 0.05$).

**Table 4.** Independent samples t -test results for men and women walking speed

| Independent Samples Test | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Levene's Test for Equality of Variances | | t-test for Equality of Means | | | | | | |
| | | F | Sig. | t | df | Sig. (2-tailed) | Mean Difference | Std. Error Difference | 95% Confidence Interval of the Difference | |
| | | | | | | | | | Lower | Upper |
| Walking Speed | Equal variances assumed | ,112 | ,738 | 7,081 | 1175 | ,000 | ,08515 | ,01202 | ,06156 | ,10874 |
| | Equal variances not assumed | | | 7,081 | 1168,764 | ,000 | ,08515 | ,01202 | ,06156 | ,10874 |

### *4.3 Impact of Group Dynamics on Pedestrian Movement*

The influence of group dynamics on pedestrian movement was also examined, revealing interesting insights. Individuals walking in groups demonstrated a significantly slower average speed of 1.26 m/s compared to solo walkers, who navigated at a swifter pace of 1.40 m/s. This finding suggests that social interactions and group cohesion exert a tangible influence on pedestrian behavior, with implications for urban planning strategies to manage pedestrian flow and enhance walkability.

This difference in walking speed between group and solo pedestrians highlights the influence of social dynamics and group cohesion on pedestrian movement. The presence of others in a group may lead to increased social interactions, coordination efforts, and decision-making processes, all of which can contribute to a slower pace of movement. In contrast, solo walkers may have more autonomy and freedom in their movement decisions, allowing them to navigate at a swifter pace.

Figure 8 shows the frequency distribution of walking speed measured based on whether individuals walk alone or in groups. As seen in Table 5, 890 individuals walked alone, and 287 individuals walked in groups. The statistical analysis showed that the mean and median walking speed of individuals walking alone were 1.40 m/s. On the other hand, the mean and median walking speed of individuals walking in groups were 1.26 m/s. Therefore, individuals walking alone walked approximately 11% faster than those walking in groups.

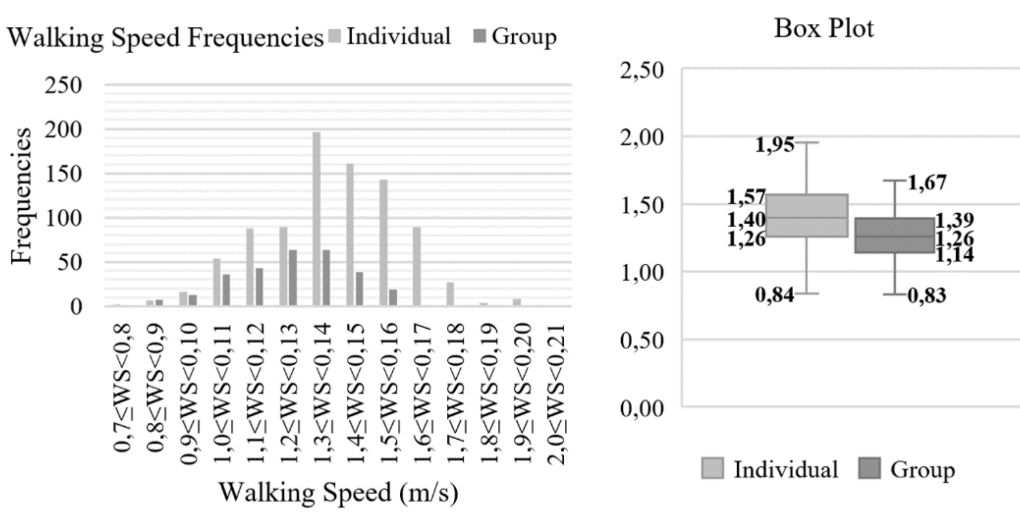


**Figure 8.** Frequency distribution and box plots according to walking alone or in a group

**Table 5.** Descriptive statistics according to walking alone or in a group

| **Descriptives** | | | | | |
|---|---|---|---|---|---|
| | | **Individual** | | **Group** | |
| | | **Statistic** | **Std. Error** | **Statistic** | **Std. Error** |
| N | | 890 | | 287 | |
| Mean | | 1,4004 | ,00704 | 1,2602 | ,01025 |
| 95% Confidence Interval for Mean | Lower Bound | 1,3866 | | 1,2400 | |
| | Upper Bound | 1,4142 | | 1,2804 | |
| 5% Trimmed Mean | | 1,4018 | | 1,2633 | |
| Median | | 1,4000 | | 1,2600 | |
| Variance | | ,044 | | ,030 | |
| Std. Deviation | | ,20992 | | ,17358 | |
| Minimum | | ,77 | | ,83 | |
| Maximum | | 2,09 | | 1,67 | |
| Range | | 1,32 | | ,84 | |
| Interquartile Range | | ,31 | | ,25 | |
| Skewness | | -,124 | ,082 | -,213 | ,144 |
| Kurtosis | | -,147 | ,164 | -,274 | ,287 |

An independent samples t-test (Table 6) was conducted to determine if there is a significant difference in walking speed between individuals walking in groups and individuals walking alone. According to the test results, there is a significant difference in walking speed between individuals walking in groups and individuals walking alone. These findings provide valuable insights into the walking speed of individuals in Istanbul, Turkey, and highlight the influence of gender on walking speed.

**Table 6.** Independent samples t-test results for group and individual walking speed

| **Independent Samples Test** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Levene's Test for Equality of Variances** | | **t-test for Equality of Means** | | | | | | |
| | | | | | | | | **95% Confidence Interval of the Difference** | |
| | **F** | **Sig.** | **t** | **df** | **Sig. (2-tailed)** | **Mean Difference** | **Std. Error Difference** | **Lower** | **Upper** |
| Equal variances assumed | 15,286 | ,000 | 10,238 | 1175 | ,000 | ,14016 | ,01369 | ,11330 | ,16702 |
| Equal variances not assumed | | | 11,277 | 578,026 | ,000 | ,14016 | ,01243 | ,11575 | ,16457 |

## 5. Discussion

### *5.1 Interpretation of Findings in Relation to Existing Literature*

This study's findings provide valuable insights into pedestrian walking speeds in Istanbul, contributing to our understanding of pedestrian behavior in a non-Western context. The observed average walking speed of 1.37 m/s (N=1177) establishes a crucial baseline sample for the city. This aligns closely with the global average of 1.32 m/s reported by (Muhdi *et al.*, 2006), suggesting that Istanbul's pedestrian pace falls within the expected range. However, it's notably slower than the 1.69 m/s average found in Padang, Indonesia, by (Yosritzal *et al.*, 2020). This discrepancy underscores the importance of considering the local context. While both are bustling cities, Padang might have a denser, more pedestrian-oriented urban form compared to the specific area studied in Istanbul, potentially encouraging faster movement. Furthermore, cultural norms regarding appropriate walking paces could differ between Turkey and Indonesia. Methodologically, Yosritzal *et al*.'s (2020) focus on evacuation walking speeds may not represent typical daily pedestrian behavior, potentially inflating their average.

The gender difference observed, with men (1.41 m/s, N=610) walking faster on average than women (1.32 m/s, N=567), aligns with previous research (Almejmaj *et al*., 2015; Chandra & Bharti, 2013; Montufar *et al*., 2007), emphasizing the need for gender-sensitive urban design. Interestingly, unlike the bimodal distribution reported by (Chandra & Bharti, 2013), our data revealed a single concentration around 1.3-1.4 m/s for both genders. Methodologically, our larger sample size might have obscured a more subtle bimodal pattern. Variations in measurement techniques, the specific location and length of the measurement zones, and the statistical methods used for data analysis could also contribute to these differences. Culturally, Istanbul might have social norms that encourage a more uniform walking pace for both men and women, resulting in the observed unimodal distribution. Furthermore, site-specific characteristics such as pedestrian density, sidewalk width, and street slope could influence walking speeds and contribute to the differing results.

The finding that groups (1.26 m/s, N=287) walk slower than solo pedestrians (1.40 m/s, N=890) supports existing research on social dynamics (Delin *et al*., 2017; Reynolds, 2018). This reinforces the importance of accommodating group behavior in pedestrian space design, particularly in high-density areas.

Internationally (Table 1), Istanbul's average walking speed is higher than reported for some less developed nations (Capistrant *et al*., 2014), potentially reflecting differences in demographics and urban development levels. However, pedestrians in many Western European, East Asian, and North American cities tend to walk at faster paces. This could be due to several factors, including better pedestrian infrastructure, cultural norms that value efficiency and a faster pace of life, and even the influence of climate. However, further research is needed to fully understand these cross-cultural variations. These international comparisons underscore the importance of using locally-grounded data for effective urban planning, as pedestrian behavior varies significantly across global contexts.

### *5.2 Implications for Urban Design and Pedestrian Infrastructure Planning in Istanbul*

This study's findings have significant implications for urban design and pedestrian infrastructure planning in Istanbul. By understanding the nuances of pedestrian walking speeds, urban planners can create a more efficient, safe, and inclusive urban environment.

**Intersection Design:** Pedestrian signal timing at intersections should be optimized using the locally measured walking speeds from this study. Current signal timings, if based on Western data or generic standards, might be inadequate for Istanbul's pedestrian population, particularly for women and older adults, potentially leading to dangerous crossing behavior. Adjusting crossing times based on the slower observed speeds for women and groups can significantly enhance pedestrian safety and reduce the incidence of pedestrian-vehicle conflicts.

**Evacuation Planning:** Accurate walking speed data is paramount for developing effective evacuation plans, especially in high-rise buildings and densely populated areas. Incorporating this study's findings into pedestrian flow models will significantly improve the accuracy of evacuation time estimations. The difference in walking speeds between men and women, and the slower pace of groups, should also inform evacuation strategies. This might involve phased evacuation procedures or designated routes that accommodate varying speeds, ensuring no group is left behind during an emergency.

**Public Space Design:** The influence of group dynamics on walking speed has direct implications for public space design. Creating dedicated zones for social interaction and slower-paced movement within public spaces can foster a more welcoming and inclusive environment. This might involve incorporating seating areas, wider plazas, or designated pedestrian-only zones where slower movement is accepted and encouraged. Such design considerations can improve pedestrian comfort and enhance the overall social experience of urban spaces.

**Sidewalk Design:** The observed differences in walking speeds between men and women, and between individuals and groups, underscore the need for carefully considered sidewalk widths. Simply providing a minimum width may not suffice. In high-traffic areas, wider sidewalks are crucial to accommodate diverse pedestrian flows comfortably and minimize conflicts between faster and slower walkers. This is especially important in areas near transit hubs, commercial centers, and popular pedestrian destinations. Providing separate lanes or designated areas for faster and slower pedestrian traffic could also be explored.

## 6. Conclusion

This study investigated the walking speed of healthy adults in Istanbul, Turkey, focusing on gender and group dynamics. The analysis of 1,177 pedestrians revealed an average walking speed of 1.37 m/s (95% CI: 1.35-1.38 m/s). Men exhibited a slightly faster average speed (1.41 m/s) compared to women (1.32 m/s), a difference of approximately 7%. Individuals walking alone (1.40 m/s) were approximately 11% faster than those in groups (1.26 m/s).

These findings highlight the importance of incorporating gender and group dynamics into urban planning and pedestrian infrastructure design. Recognizing and accommodating these differences is crucial for creating more equitable and user-friendly urban environments. Addressing disparities in walking speeds, especially between genders and group types, can contribute to enhanced accessibility, safety, and overall pedestrian experience.

This study contributes valuable data from a non-Western context to the global understanding of walking speeds, improving the diversity and representativeness of existing research. It also emphasizes the need for culturally relevant and locally specific data in traffic management and evacuation planning.

The findings suggest several key recommendations for policymakers and urban designers:

- **Incorporate Gender-Sensitive Design:** Integrate design principles that consider the different needs and behaviors of men and women, enhancing safety, comfort, and accessibility for all pedestrians.
- **Accommodate Group Travel:** Implement strategies that facilitate group movement, such as wider sidewalks and designated social spaces, improving comfort and encouraging walking as a mode of transport.
- **Pedestrian-Friendly Urban Design:** Integrate pedestrian-centric features into urban design to create more inclusive and accessible environments, promoting active transportation and enhancing urban life quality.

By prioritizing pedestrian needs and considering the diverse characteristics of pedestrian populations, Istanbul can create more sustainable, livable, and vibrant urban spaces.

### *6.1 Limitations of the Study*

This study has limitations that should be considered when interpreting the findings. The data collection was limited to a single location in Istanbul and daytime hours due to technical constraints related to video recording quality in low-light conditions. Nighttime pedestrian behavior may differ and warrants further investigation. The exclusive focus on healthy adults limits the generalizability of the findings to other demographic groups, such as children, older adults, and individuals with mobility impairments. Future studies should encompass a broader range of pedestrian characteristics. Additionally, the analysis did not account for other potential influencing factors, including individual fitness levels, trip purpose (commuting vs. leisure), or the presence of luggage or other carried items.

### *6.2 Suggestions for Future Research*

Several avenues for future research emerge from this study:

- **Multi-location Studies:** Conducting similar studies in diverse locations across Istanbul and other Turkish cities will provide a more comprehensive understanding of pedestrian walking speeds and account for variations in urban form, pedestrian density, and cultural contexts.
- **Inclusive Demographics:** Future studies should include children, older adults, and individuals with mobility impairments to ensure a representative sample of the pedestrian population and inform truly inclusive urban design.
- **Day/Night Comparisons:** Collecting data during both daytime and nighttime hours will allow for a comparative analysis of pedestrian behavior and inform lighting design and safety strategies for nighttime pedestrian activity.
- **Cultural Context Analysis:** Investigating the cultural factors that influence walking speeds in Istanbul, and comparing these with other cultural contexts, will contribute to a deeper understanding of the interplay between culture and pedestrian behavior.
- **Multi-factor Analysis:** Exploring the combined effects of age, gender, group dynamics, trip purpose, environmental factors (weather, street characteristics), and individual characteristics (fitness level, carried loads) will provide a more nuanced understanding of the determinants of pedestrian walking speed.
- **Longitudinal Studies:** Tracking walking speeds over time can reveal trends and patterns related to urban development, lifestyle changes, and technological advancements.

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