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Spatiotemporal Variation in Spatial Vitality Reveals Gender Differences in Park Usage: An Empirical Study from Dalian, China

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Abstract

Based on multi-source data including mobile signaling data and remote sensing imagery, this research constructed human activity indicators and applied spatial analysis methods to identify gender-specific patterns in green space usage across different types of days. A Standardized Gender Difference Index (SDI) was developed to quantify gender-based disparities in both temporal and spatial dimensions. Correlation analysis was employed to examine spatial influencing factors and their interrelationships. The results indicate that on holidays, a stable male-dominant usage pattern was observed across all parks, with males showing a preference for cultural parks. On weekdays, although male users remain predominant overall, considerable variations exist among parks. On a daily scale, males exhibit earlier and more flexible activity patterns, whereas females demonstrate significantly lower presence during evening hours, indicating a "nocturnal poverty" phenomenon. Spatially, community parks display the greatest gender disparity, whereas comprehensive parks show relative gender balance. Although both genders value barrier-free facilities, females place additional emphasis on service facilities, while males are more influenced by mixed land-use functions surrounding the parks. This study demonstrates that high-precision, large-coverage multi-source data can accurately and dynamically identify gender-based differences in green space usage and their influencing factors, providing valuable insights for inclusive urban planning.

Keywords: urban green spaces; spatial vitality; gender differences; spatial equity

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1. Background

Urban Green Spaces (UGS) play a crucial role in mitigating pollution and urban heat, alleviating physical and psychological stress [1], supporting attention restoration [2], enhancing residents' interaction and well-being, and strengthening community cohesion [3]. A vibrant UGS system intuitively reflects the alignment between human needs and the built environment, providing a new perspective for urban land equity and inclusive spatial planning. Gender differences are also critical in studies of UGS vitality [4]. Existing research has indicated that men generally have more leisure time to participate in green space activities, and the frequency of UGS use among men is approximately four times higher than among women [5]. However, lower use frequency among women [6] does not necessarily imply lower demand. Women tend to be more sensitive to perceived benefits

but are often constrained by safety concerns, time limitations, and their household roles [7]. Studies have shown that women's perceived insecurity in public spaces can be up to ten times greater than that of men [5].

At a deeper level, urban planning has long suffered from gender-blindness, with many urban designs implicitly based on male-centered standards [8]. Such patterns further exacerbate gender disparities in UGS use. For example, urban layouts often prioritize private car travel and functional zoning while neglecting walking and public transport systems that women rely on more frequently [9,10]. Consequently, women experience longer commuting times and higher exposure to air pollution [11], thereby limiting their opportunities to access and use UGS.

However, not all studies support the "male-dominant" conclusion, some studies contradict this pattern. For instance, Chen and Marzabali found that although women expressed safety concerns, their duration of stay in some Malaysian community parks exceeded that of men [12]. Similarly, Zhao et al. reported no significant gender differences in park usage where lighting and safety management were well maintained [13]. Moreover, women are often the main users of public spaces [14], and Núñez highlighted that the health and well-being benefits of urban greening are often more pronounced among women [15].

Therefore, identifying gender disparities in urban green space use and elucidating their interactions with spatial factors—while integrating women's perspectives and needs—has become a critical issue in promoting urban environmental equity and inclusive design [16]. Some studies have found that in cities with high female public participation and good nighttime safety, gender differences in public space use are substantially reduced. However, in developing urban contexts, it remains necessary to examine whether gender continues to serve as a key determinant of UGS use and to explore the spatial and temporal characteristics of such disparities using high-resolution data.

With advances in information technology, traditional survey methods are no longer adequate for studying long-term, large-scale, and high-resolution spatiotemporal behaviors. Emerging tools such as Geographic Information Systems (GIS) [17], Global Positioning Systems (GPS), and mobile sensing technologies [18] enable the collection and analysis of activity and environmental data at unprecedented spatiotemporal resolutions [19], providing strong technical support for understanding gender differences in UGS [20]. The proliferation of smartphones has further facilitated the use of mobile positioning data, which offer advantages such as convenience, high penetration, fine spatiotemporal granularity, and continuous tracking [21–23]. These data have been widely used in behavioral research. However, mobile data studies have also shown that differences in park types, scales, and identification thresholds can yield inconsistent findings regarding gender gaps—in some cases, variations due to park typology or scale even outweigh the effects of gender itself.

Collectively, these findings suggest that the influence of gender on UGS use is highly context-dependent, shaped by cultural background, spatial environment, and methodological choices. Existing studies still exhibit significant divergence, primarily due to three limitations: (1) most research focuses on specific cities or samples, limiting cross-regional and cross-cultural comparability; (2) traditional surveys and field observations cannot capture long-term or high-resolution spatiotemporal behavioral patterns; and (3) there remains a lack of systematic quantitative analysis of the spatiotemporal mechanisms underlying gender differences.

2. Introduction

As a key component of environmental justice and health equity, urban green spaces can substantially alleviate the burdens caused by health inequalities [24,25]. However, under the rapid pace of urbanization, financial bias, gentrification [26,27], and the lack of

gender-sensitive perspectives in urban planning [28] have resulted in inequities in not only the distribution but also the use of green space resources. Given differences in gender roles and built-environment design, men and women may exhibit systematic variations in their spatiotemporal behaviors within UGS.

This study addresses the issue of urban green space equity from a gender-differentiated perspective. Using large-scale mobile phone positioning data, we examine the spatiotemporal behaviors of men and women in urban green spaces. Through correlation analysis and principal component regression (PCR), we explore the relationships between gender-specific user groups and built environment factors. Furthermore, drawing from urban sociology and environmental behavior research, we control for macro-level demographic variations to isolate the micro-level gender effects.

Our results show that gender differences in green space activity are primarily reflected in temporal flexibility and spatial aggregation. Both men and women tend to visit parks between 9:00 and 10:00 a.m., but compared to women, men visit earlier and display greater flexibility in evening and nighttime activities. This indicates a "nighttime poverty" phenomenon among women. Spatially, male users generally outnumber females, but women dominate in community parks on weekdays.

Further analysis reveals that accessibility facilities and service amenities are key determinants of spatial preferences for both genders. In temporal patterns, the land-use functions surrounding parks, as well as the number and configuration of entrances and public spaces, emerge as influential factors—highlighting the role of convenience and accessibility. These findings deepen our understanding of gendered differences in UGS use and suggest that improvements in facility layout, perceived safety, and lighting design can promote more inclusive park environments.

The main contributions of this study are as follows: (1) It characterizes the spatiotemporal behavioral distribution of men and women in urban green spaces. (2) It identifies the built environment factors influencing gender-specific park activities.

The purpose of this study is to reveal gender-based spatiotemporal disparities in urban park usage and to identify the underlying spatial and environmental factors that contribute to such differences, with the ultimate goal of supporting gender-sensitive and equitable urban green space planning.

Overall, by analyzing urban green space vitality through the lens of gender differences across time and space, this study provides actionable insights for inclusive urban design and spatial equity in urban environments.

3. Materials and Methods

3.1. Materials

3.1.1. Study Area

Dalian (Figure 1), as a National Garden City, it has a long history of urban green space development, and many of its parks are renowned scenic spots that serve as important venues for recreation, exercise, and social interaction. According to the Dalian Municipal Bureau of Statistics, the city's permanent population reached approximately 7.54 million by the end of 2024. The large user base and abundance of parks make central Dalian (Figure 1) an ideal area for studying gender-based differences in park usage and related influencing factors.

Data were collected on three representative days in spring 2018. A typical spring month (May) was selected to capture urban park use under moderate climatic conditions. The focus on spring was guided by the coastal climate characteristics of Dalian. During winter, strong winds and low temperatures substantially limit outdoor recreation, whereas spring provides favorable and stable weather conditions for park activities. To capture

temporal variations in park use, three typical days were chosen to represent the full range of social time contexts in China: a weekday, a weekend, and a public holiday.

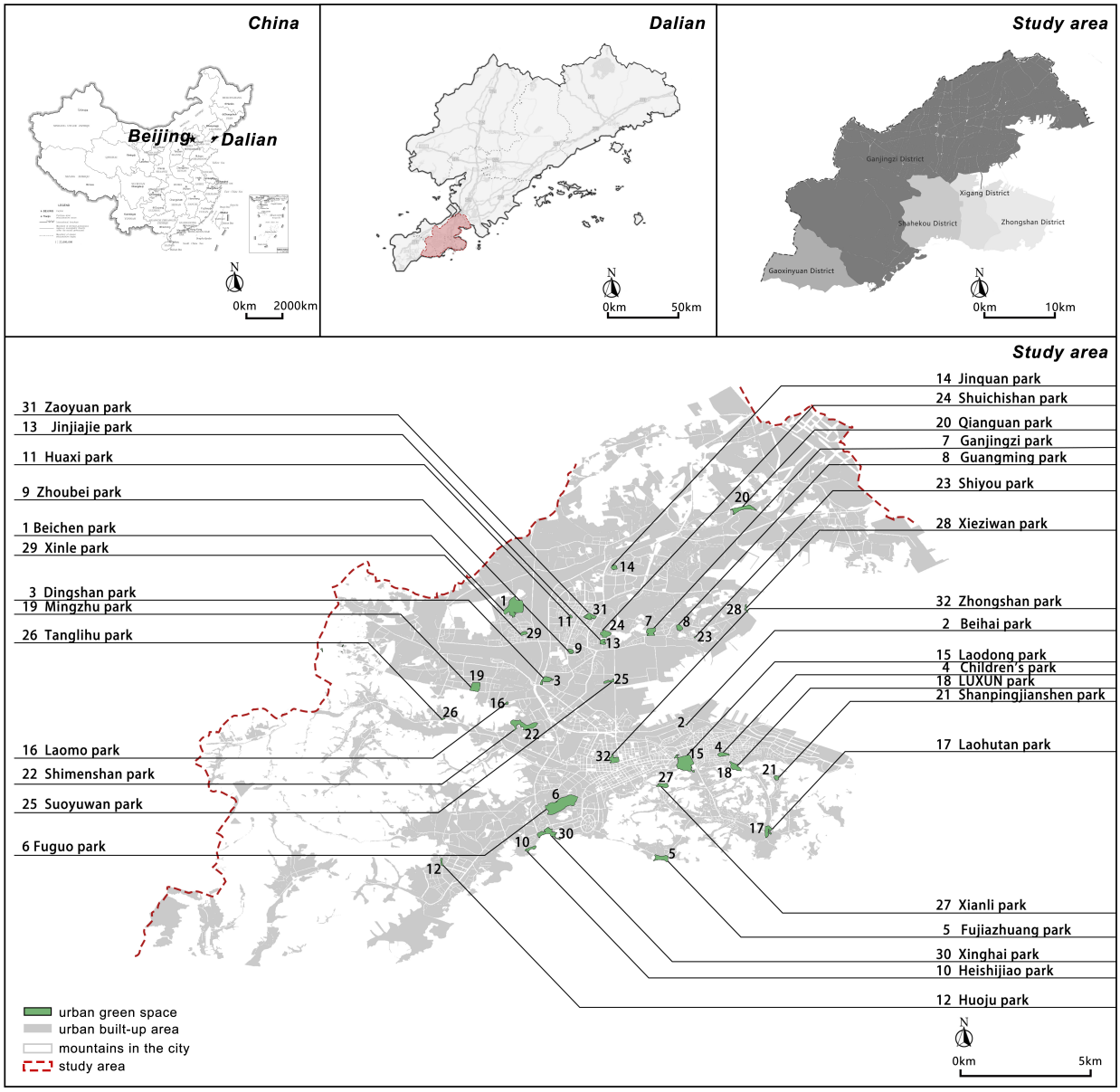


Figure 1. Distribution of Case Study Parks.

Previous studies have shown that under mild weather and balanced daylight duration, behavioral patterns in spring in northern coastal cities can approximate the overall annual trends in gendered park use [29]. While we acknowledge that seasonal differences may influence the intensity of park visitation, our focus lies in relative gender disparities, which tend to remain stable across seasons [30]. Future research could extend this analysis to multi-season datasets to further validate these findings.

3.1.2. Park Typology and Spatial Distribution

Using Landsat TM/ETM/OLI remote sensing imagery as the primary data source, and incorporating the Dalian Land Use Master Plan (2006–2020) publicly available from the Liaoning Provincial Government, we initially identified 48 parks and plazas. Scenic areas and building-adjacent squares were excluded. Map base layers were obtained from the National Administration of Surveying, Mapping and Geographic Information (standard

basemap of China) and the Amap Open Platform (Liaoning Province map). Based on criteria including ease of access, free admission, and clear boundaries, 16 green spaces were removed after field verification (Appendix A.1), resulting in 32 final parks (Figure 1).

Park classification followed the Chinese industry standard Standard for Classification of Urban Green Space, supplemented by study-specific attributes including location, presence of iconic facilities, and primary spatial characteristics (number, area, and distribution balance of dominant spaces). The 32 parks were categorized into five types: sports parks (n = 6), cultural parks (n = 6), community parks (n = 8), comprehensive parks (n = 7), and waterfront parks (n = 5) (Table 1).

Table 1. Park Classification and Basic Information.

Type	Defining Principle	Number and Name		Area (hm^2)
Sports Park	A type of park characterized by open and activity-oriented spaces, equipped with dedicated sports facilities (such as hiking trails, fitness paths, exercise equipment, etc.) and well-developed infrastructure.	11	Huaxi Park	0.6
		12	Huoju Park	4.1
		21	Shanping Park	5
		22	Shimenshan Park	19.8
		24	Shuichishan Park	13.3
		27	Xianli Park	11.8
Cultural Park	A type of park featuring prominent landmark facilities and comprehensive infrastructure.	19	Mingzhu Park	15.5
		3	Dingshan Park	8.4
		16	Laomo Park	3.1
		18	LUXUN Park	3.2
		32	Zhongshan Park	10.3
		31	Zaoyuan Park	10.2
Community Park	A type of park located adjacent to residential areas, easily accessible, and equipped with well-developed infrastructure.	2	Beihai Park	1.01
		4	Ertong Park	5.6
		8	Guanming Park	5.3
		13	Jinjiajie Park	4.3
		23	Shiyou Park	0.29
		29	Xinle Park	11.8
		9	Zhoubei Park	7.1
		14	Jinquan Park	4.5
Comprehensive Park	A type of park characterized by convenient transportation, diverse facilities, and a green space ratio $\geq$ 50%. It is generally recommended to have a scale larger than 10 hectares.	26	Tanglihu Park	70
		1	Beichen Park	71
		6	Fuguo Park	74
		7	Ganjingzi Park	32.4
		15	Laodong Park	38.5
		20	Qianguan Park	16
		25	Suoyuwan Park	22
Coastal Park	A type of park situated along coastal scenic belts, with main activity spaces such as bathing beaches, designed for tourism and recreational purposes.	5	Fujiazhuang Park	32.8
		28	Xieziwan Park	1.2
		10	Heishijiao Park	11.8
		17	Laohutan Park	17.6
		30	Xinghai Park	30.3

3.1.3. Crowd Activity Data

Urban residents' mobility patterns exhibit strong rhythmic and periodic characteristics [31]. Mobile positioning data and other large-scale location-based datasets enable timely and precise analyses of activity patterns among different gender groups within urban green spaces [32]. To ensure the comparability of the analysis, this study focuses exclusively on permanent urban residents. All data represent the daily mobility trajectories of local inhabitants, clearly defining the research boundary and minimizing the complexity and uncertainty introduced by transient populations.

The outbreak of COVID-19 significantly reduced the overall intensity of urban activities [33]. To avoid the pandemic's potential impact on human mobility, and considering the

pronounced monsoonal climate of Dalian, we selected three full-day datasets (24 h each) on 1 May, 18 May, and 19 May, 2018. These datasets encompass all public parks and green spaces within the central urban area of Dalian.

The data were derived from mobile base stations and include only anonymized information on users' geographic coordinates, time, gender, and age (Table 2). Due to the nature of the data, gender is categorized as male and female only. The dataset was provided by China's largest mobile information service provider, ensuring objectivity, representativeness, and comprehensive coverage, thereby offering a reliable empirical foundation for examining gender disparities in urban park use.

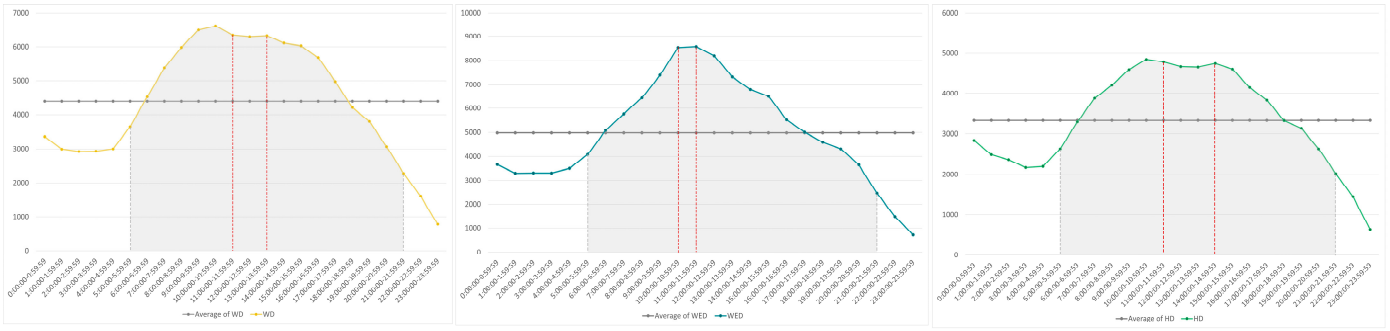
Table 2. Sample of a user's full-timeline LBS records.

SECRETIMEI	Itime	Age	Gender	Lng	Lat	TIME	
001db96defac017f417c556c227b2a8b	1525155153	16–25	M	121.500278	38.845926	2018.5.1	14:12:33

Regarding data processing, raw data was decoded and georeferenced in ArcGIS 10.6 using the WGS84 coordinate system. This process allowed for the reconstruction of individual users' park visitation trajectories across the three day types, enabling the analysis of spatiotemporal behavioral patterns. To validate data reliability, we conducted random field surveys on April 30 (Holiday), May 11 (Weekday), and May 12 (Weekend), manually verifying crowd numbers, approximate age groups, and gender ratios.

3.1.4. Definition of Study Period

The study period was determined by analyzing the 24 h activity patterns across the three day types (Figure 2). Based on diurnal rhythms of public life, the timeframe from 5:00 a.m. to 9:00 p.m. was selected for detailed analysis. To address potential data biases, spot checks were conducted within this window, confirming that actual activity periods aligned closely with the patterns shown in Figure 2, thereby supporting the data's rationality and objectivity.



(**a**) (**b**) (**c**)

Figure 2. Distribution of Total Activity Volume Over 24 h on Weekdays (**a**), Weekends (**b**), and Holidays (**c**). The red vertical lines represent the periods with the least fluctuation in population activity.

3.2. Standardized Gender Difference Index

We recognize that gender differences in overall spatial activity may be related to the gender ratio of the population in Dalian or China more broadly. Data from the National Bureau of Statistics indicate that the overall gender ratio in China in 2018 was 104.64 (males per 100 females). In contrast, Dalian's gender ratio in the same year was 99.19 (males per 100 females), as reported by the Dalian Municipal Bureau of Statistics. Therefore, it is

essential to account for macro-level demographic differences between the study area and national context. A Standardized Gender Difference Index (SDI) was introduced to correct for bias introduced by such population-level disparities and enhance the validity of the findings (Formula (1)):

$$Standardized\ Gender\ Difference\ Index\ (SDI) = \frac{Pobserved}{Pbenchmark} \times 100 \quad (1)$$

Here, *Pobserved* refers to the observed proportion of male park users, calculated as the number of male users divided by the total number of users (Formula (2)). This represents the male proportion in a specific park (or a category of parks).

Where the observed proportion of male park users *Pobserved* is calculated as:

$$Pobserved = \frac{Number\ of\ Males}{\text{Number of Males} + \text{Number of Females}} \quad (2)$$

Pbenchmark denotes the benchmark male proportion based on the general population sex ratio of Dalian City (99.19). It is derived from the calculated benchmark male share in the overall population (Formula (3)).

$$Pbenchmark = \frac{Number\ of\ Males}{Total\ Benchmark\ Population} \quad (3)$$

Using the 2018 sex ratio data (99.19), the total benchmark population is calculated as 199.19 (99.19 + 100). In this study, the benchmark male proportion *Pbenchmark* is 49.79%

3.3. Analytical Methods

3.3.1. Spatial Analysis

The capacity of a space to accommodate people reflects its vitality [34]. Intensity of green space use can indicate the environment's role in enhancing social cohesion [35] and improving public health and social well-being [36]. In spatial terms, frequency and intensity of use are fundamental to—and key determinants of—spatial vitality [34,37]. This study uses two metrics: total activity volume and spatial aggregation degree.

Total activity volume refers to the total number of park visitors of a given gender. This study focuses specifically on gender-based differences in this measure.

Spatial aggregation degree is derived from cluster and outlier analysis (Anselin Local Moran's I), calculated as follows (Formula (4) and (5)):

$$I_i = {x_i - \overline{X}} \Big/ {S_i^2 \sum_{j=1,\, j\neq i}^{n} \ w_{i,j}(x_j - \overline{X})} \quad (4)$$

$$S_i^2 = {\sum_{j=1,\, j\neq i}^{n} \ (x_j - \overline{X})^2} \Big/ {n-1} \quad (5)$$

Here, x_i and x_j are attribute values of features i and j, x^- is the mean of the attribute, $w_{i,j}$ is the spatial weight between features i and j, and n is the total number of features.

Based on the dimensions of total activity volume and spatial aggregation degree, park spaces were classified into four distinct types: High Activity Volume–High Aggregation, High Activity Volume–Low Aggregation, Low Activity Volume–High Aggregation, Low Activity Volume–Low Aggregation.

The classification threshold for each park type was defined by the average values of its respective category. For instance, within the community park category, a park was classified as "High-High" if both its total activity volume and spatial aggregation degree

exceeded the average values calculated for all community parks. Conversely, parks falling below both averages were classified as "Low-Low".

3.3.2. Temporal Analysis

In the temporal dimension, stability [38] is a key characteristic of crowd activity patterns. This study employs two metrics to capture this stability: time-slot intensity and cumulative duration.

Time-slot intensity refers to the total number of individuals of each gender present at a specific moment. This metric is used to reveal gender-based temporal preferences. In this research, time-slot intensity was tracked and aggregated at hourly intervals.

Cumulative duration denotes the total length of time a single user spent within a park, calculated from their first to last recorded location point. This duration was extracted by defining and analyzing trajectory point density, density intervals, time spans, and stop points. Using a spatial distance threshold of 100 m and a temporal threshold of 15 min, density-based calculations and stop-point identification were performed to determine the cumulative duration for each user [39].

Based on Jan Gehl's [40] classification of outdoor activities into three categories—necessary activities (e.g., passing through), optional activities (e.g., walking, exercising, parent–child interactions, dancing), and social activities (e.g., chess, card games—activities that require the participation of others)—cumulative durations were categorized accordingly. Field surveys and data analysis indicated that social activities generally required the longest time, followed by optional activities. Furthermore, in accordance with observed activity patterns (Figure 2), the maximum cumulative duration was approximately 3 h. Given the temporal resolution of the data (15 min intervals), durations were divided into 12 segments for analysis.

3.4. Impact Factors Selection and Correlation Analysis

3.4.1. Indicators of Impact Factors

Accessibility and mixed land use are widely recognized as key determinants of urban vitality [41]. Meanwhile, numerous studies have demonstrated that examining the spatiotemporal activity patterns of green space users requires simultaneous consideration of both external [42,43] and internal [44] factors, reflecting a dual influence mechanism [45]. For the sake of data accessibility and the practical applicability of design strategies, we identified eleven spatial elements that can be directly measured or calculated (Table 3), all expressed in quantitative terms.

At the same time, we incorporated the socio-cultural extensions of spatial attributes. Indicators such as park area, semi-private spaces, and basic infrastructure indirectly reflect the influence of spatial scale on visitors' perceived sense of safety [46], while the presence of entrances, exits, and accessible facilities ensures social equity and inclusiveness. Rest, fitness, and service facilities enhance residents' health, social interaction, and public order. The inclusion of landmark structures serves to capture a unique sense of place and community identity. Although these socio-cultural dimensions cannot be directly quantified, we sought to represent them through corresponding spatial elements wherever possible.

Furthermore, to comprehensively capture the temporal dynamics of park use, we simultaneously recorded climate and lighting conditions across different day types, including variables such as temperature, wind speed, and sunset time (Table 4). For each observation day, the maximum temperature (11:00–12:00 a.m.) and minimum temperatures (5:00 a.m. and 9:00 p.m.), along with wind speed and sunset time, were obtained from an open-source meteorological platform (https://zh.weatherspark.com/)

Table 3. Classification and description of impact factors.

Type	Name	Definition	Spatial Attribute	Socio-Cultural Implication
External influences	Site Functions	Number of site functions for immediately surrounding parcels centered on the park	Functional Mix and Proximity	Facilitates chance encounters and interaction among diverse social groups.
	Park entrance	Number of freely accessible exits or entrances to the park	Accessibility and Permeability	Reflects the park's openness and inclusiveness.
Internal influences	Public space	Amount of spaces used for public activities, generally open and not enclosed by vegetation	Openness and Visibility	Promotes large-scale social interaction and fosters collective identity.
	Semi-Public space	Amount of space used for semi-public activities, generally enclosed by structures or plantings	Demarcation and Sense of Territory	Ensures privacy and focus for group activities.
	Semi-Private space	Amount of space used for private activities, generally linked by garden paths and forming separate spaces	Enclosure and Tranquility	Accommodates the needs for solitude and privacy.
	Outdoor fitness equipment	Number of facilities used for sports, mostly located in public or semi-public spaces	Health Promotion and Physical Activity	Cultivates a positive community health atmosphere.
	Outdoor resting facilities	Number of rest facilities used for stopovers	Stay and Sojourn	Increases the potential for social interaction.
	Barrier-free elevator	Number of outdoor accessible elevators, generally located in areas with significant elevation differences	Equal Access and Universal Design	Symbolizes the "equal right for everyone to enjoy public space."
	Accessible ramps	Number of outdoor accessible ramps, generally located in areas with partial elevation differences	Supportive Amenities and Comfort	Ensures public order and civility; Enhances the sense of safety at night.
	Service facilities	Number of outdoor seating, street lights and trash cans, with the above facilities generally having a uniform layout spacing	Legibility and Symbolism	Reinforces the sense of belonging and identity with the community.
	Landmark structures	Number of landmark structures that characterize the park, e.g., sculptures, viewing platforms, etc.	Functional Mix and Proximity	Facilitates chance encounters and interaction among diverse social groups.

Table 4. Weather, temperature, and sunset time for three typical day.

Type	Date	Temperature (°C) During the Research Period	Sunset	Wind Direction and Wind Speed
Weekday	18 May	16–25–16	7:01 p.m.	East wind force 2
Weekend	19 May	15–21–14	7:02 p.m.	North wind force 4
Holiday	1 May	10–16-14	6:45 p.m.	East wind force 3

Although these variables were not directly incorporated into the regression models, they provided crucial contextual references for descriptive analyses and result interpretation. By aligning this information with park visitation time periods, we were able to better reveal potential temporal mechanisms underlying gendered patterns of park use.

Overall, this study aims to propose strategies for inclusive urban design, following the principle that "indicators should be directly measurable, and design strategies should be practically implementable." Accordingly, eleven spatial element indicators were selected. At the same time, the selection process fully considered the socio-cultural attributes and implications of spatial indicators (such as perceived safety and sense of belonging), expanding them from purely spatial factors to representations of social and cultural dimensions embodied in space.

In addition, the study incorporated temporal factors (e.g., weather conditions, temperature, and sunset time) to capture time-based variations. Finally, in the discussion section, we introduced explanatory variables related to temporal characteristics and socio-cultural perceptions, seeking to compensate for the limitations inherent in spatial indicators alone.

3.4.2. Correlation Analysis

Analysis revealed that service facilities and barrier-free elevators—representing park accessibility and convenience—were the most influential factors. The presence of outdoor fitness equipment and outdoor resting facilities indicated that the availability of adequate outdoor leisure amenities was a secondary influencing factor. Semi-public and semi-private spaces reflected the role of spatial privacy within parks, also emerging as a major factor. The number of park entrances and adjacent public spaces indicated that the availability of gathering spaces near entrances was another contributor.

Normality tests conducted on the study data showed that only the variable service facilities followed a normal distribution. Therefore, Spearman's rank correlation coefficient was selected to analyze the relationship between gender-specific green space vitality and park impact factors. Subsequently, Principal Component Analysis was applied to reduce the dimensionality of the 11 impact factors, extracting 4 principal components (Table 5). We found that the primary influencing dimensions encompassed: Park accessibility and convenience, Availability of outdoor recreational facilities, Spatial privacy within the park, Presence of public spaces at park entrances.

Table 5. Rotated Component Matrix of impact factors.

Name	Component 1	Component 2	Component 3	Component 4
Site functions	−0.072174448	0.284202179	0.662204119	0.23114219
Park entrances	0.093620551	0.019733505	0.113311984	0.812252238
Public space	0.230431985	0.69150562	−0.253958268	0.090889379
Semi-Public space	0.73605918	0.253075151	−0.000155638	−0.132543776
Semi-Private space	0.739810686	0.101080014	−0.000332423	0.189374756
Outdoor fitness equipment	0.671867593	−0.339022941	0.301784471	−0.261815792
Outdoor resting facilities	0.49073561	0.171992997	−0.458783666	−0.30076432
Barrier-free elevators	0.229765547	−0.066340374	0.852656338	−0.285898467
Accessible ramps	−0.128874443	0.800867702	0.236796349	−0.318537513
Service facilities	0.299614678	0.701539166	0.332901493	0.300597939
Landmark structures	−0.147330886	0.003032808	−0.072008379	0.567180379

Finally, significance testing was performed to validate the results, ensuring objectivity and accuracy.

4. Results

4.1. Spatial Variations

Across all three types of days, the proportion of male park users was systematically and significantly higher than expected based on the macro-level gender ratio of Dalian's population (the median values of all three boxplots are noticeably above the benchmark line of 100). This indicates a widespread and significant masculinization tendency in the gender composition of park users in Dalian, which contrasts with the baseline city-wide gender ratio (where females slightly outnumber males). This suggests that the park environment, facilities, or offered activities are generally more attractive to men (Figure 3a).

During holidays (likely statutory public holidays), the male-oriented usage pattern was most pronounced and consistent. All parks exhibited highly uniform behavior with the least dispersion. On weekdays, although male users still predominated overall, the strength of this tendency weakened, and variation among parks became substantially larger. Some parks showed a relatively balanced gender ratio on weekdays, while others maintained a highly skewed male-dominated usage, resulting in high data variability. The highly consistent behavior across parks during holidays implies that external factors (e.g., time off work) played a dominant role, overshadowing the influence of individual park

characteristics. In contrast, substantial differences among parks on weekdays suggest that intrinsic attributes—such as park type, location, and primary function—may be important influencing factors (Figure 3b). For example, significant differences in gender composition may exist on weekdays across various park types, such as sports parks, cultural parks, and coastal parks.

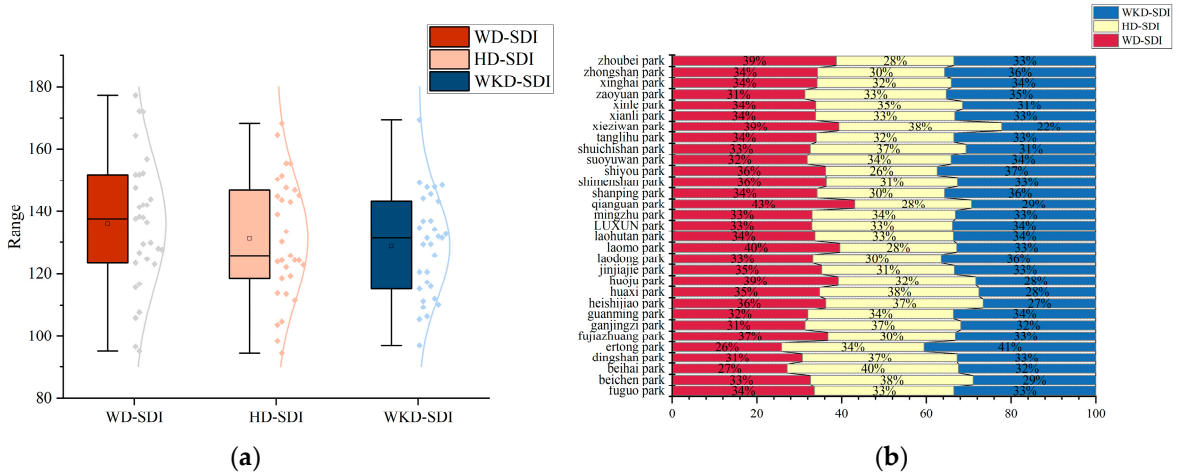


Figure 3. Distribution of gender ratios across case study parks for the three day types. (**a**) The range of Social Vitality Index (SDI) under different day types, showing the numerical distribution and differences of SDI under the three day types. (**b**) The percentage of social vitality for each park under the three day types.

Community parks emerged as one of the park types with the most significant disparities in gender distribution. Within this category, some parks exhibited a strong masculinization tendency, while others presented a critical counterexample—most notably, Ertong Park, where the proportion of female users reached as high as 41% on weekends (Figure 3b). It also ranked among the parks most favored by women on weekdays (Figure 4). Through field investigation, we found that Ertong Park is surrounded predominantly by residential areas and is well-equipped with quality amenities, attractive natural scenery, and child-friendly facilities. These features directly cater to the needs of child caregivers—who, within the current social structure, are most often mothers or grandmothers. This case demonstrates that when park facilities are intentionally designed to address women's needs, it is possible to mitigate the overall masculinization trend and advance spatial equality in urban renewal processes.

As shown in Figure 5, in terms of spatial density, visitors across different types of days showed a preference for comprehensive parks. Gender differences were minimal in parks characterized by either high visitor numbers and high density or low visitor numbers and high density. However, significant gender differences emerged in parks with high visitor numbers but low spatial density. On weekdays, women showed stronger attraction to cultural parks (e.g., Zaoyuan Park), while men were more frequently observed in comprehensive parks (e.g., Suoyuwan Park). During holidays, women preferred comprehensive and sports parks (e.g., Laodong Park, Shanping Park, and Qianguan Park), whereas men showed higher use of cultural parks (e.g., Dingshan Park). Additionally, parks with both low visitor numbers and low spatial density accounted for a considerable proportion (approximately 50–60%) of all parks. These green spaces represent key targets for future design and optimization.

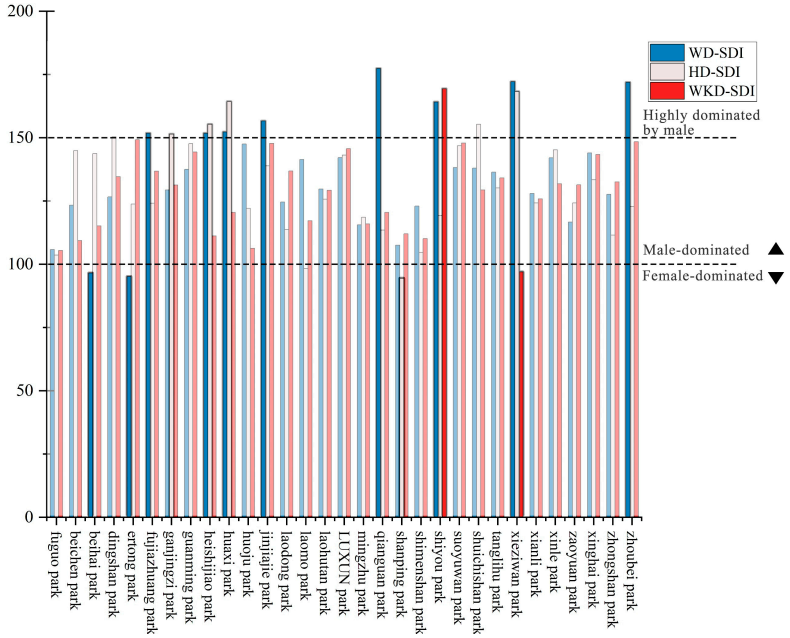


Figure 4. Distribution of gender ratios across the 32 parks for the three day types.

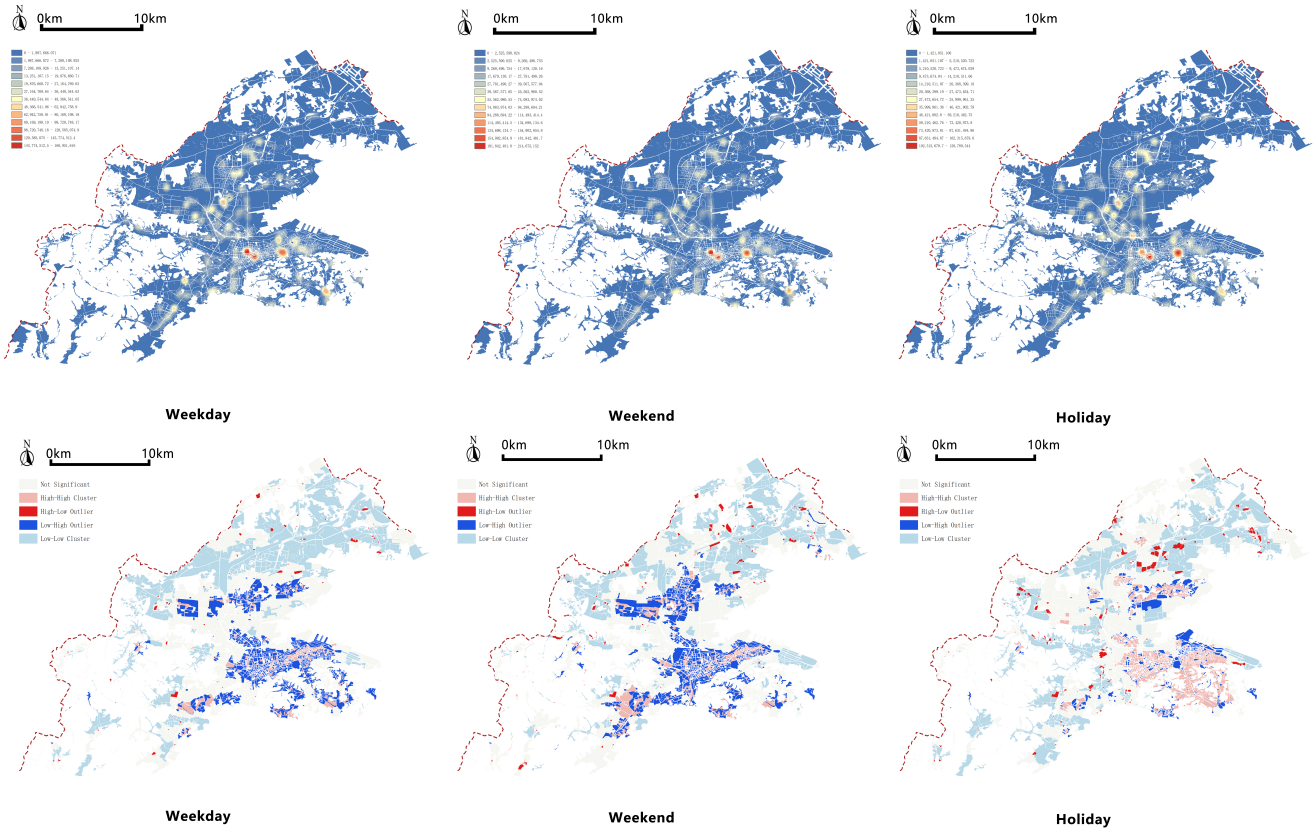


Figure 5. Analysis of the spatial density (top three images) and spatial aggregation (bottom three images) of 32 park green spaces.

4.2. Temporal Variation

Across different types of days, both males and females exhibited a tendency to visit parks in the morning (Figure 6). On weekdays, males tended to arrive earlier than females (at 7:00 and 9:00 a.m.). Male visitors were present in large and steady numbers between 9:00 a.m. and 3:00 p.m., with another peak around the evening (5:00 and 7:00 p.m.). In contrast, female visitors primarily arrived between 10:00 a.m. and 4:00 p.m. On weekends, both

genders showed similar patterns with most visits occurring between 10:00 and 12:00 a.m. On public holidays, males were more likely to visit around 10:00 a.m., while females peaked around 11:00 a.m. Overall, distinct gender-based temporal patterns were observed: males visited both earlier (7:00 a.m.) and later (7:00p.m.), whereas female visitation declined noticeably after 3:00 p.m., with very few visits in the evening.

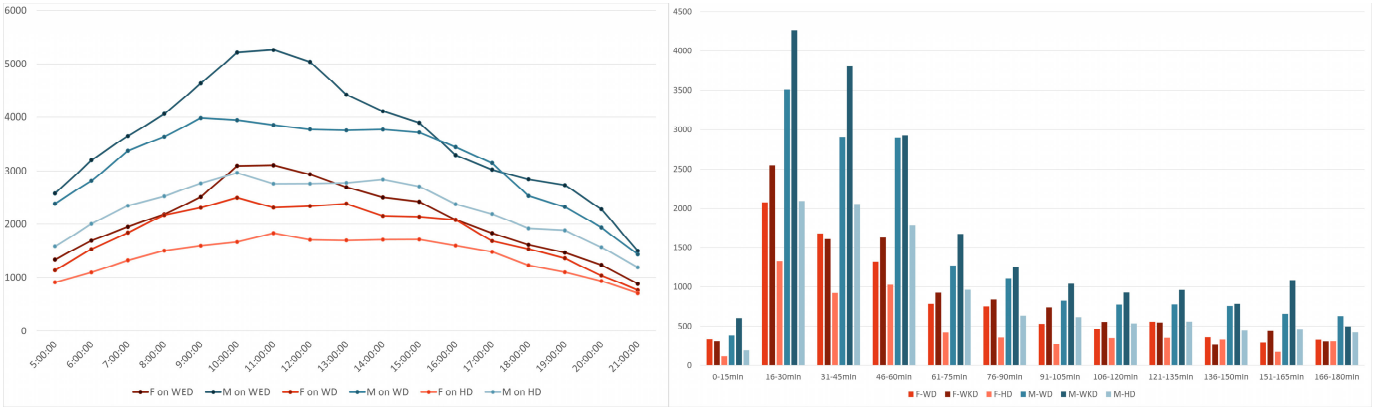


Figure 6. Temporal vitality distribution of male and female users in the 32 parks across three day types (**left**) visit intensity by time of day for both genders over three days; (**right**) duration of stay in green spaces by gender and day type.

In terms of duration of stay, visits lasting 16–30 min were the most common across all day types (Figure 6), significantly outnumbering other duration categories. Gender-based differences were also evident: on weekdays, both males and females tended to stay for 30–60 min, likely influenced by daily work routines. On weekends, males typically stayed for 16–45 min, while females stayed mainly for 16–30 min. During public holidays, females largely stayed for 16–30 min, and males for approximately 16–45 min.

In summary, males demonstrated both a greater willingness to use park spaces and more flexibility in the timing of their visits—spanning morning, afternoon, and evening periods. They also tended to stay longer than females. Females, on the other hand, preferred visiting in the morning and generally stayed for about 45 min.

4.3. Influencing Factors Show Gender Differences

4.3.1. Spatial Dimension

Spatial density was strongly correlated with total activity volume across all three day types and exhibited consistency between genders (Figure 7). Gender differences, however, emerged through the varying influence of park features. Across all day types, females were most concerned with the presence of barrier-free ramps (weekdays: 0.43, weekends: 0.51, holidays: 0.42), reflecting the importance of accessibility and safety. During holidays (Figure 7), surrounding land-use functions (0.42) also ranked among the most influential factors for women, which may be related to travel patterns—such as family-oriented trips where considerations for child and elderly accessibility and safety come into play. In contrast, males attached the greatest importance to surrounding land-use functions (weekdays: 0.52, weekends: 0.51, holidays: 0.45), indicating a prioritization of convenience around the park. It is also noteworthy that barrier-free ramps consistently mattered across all day types for both genders (e.g., males: 0.46 on weekdays, 0.53 on weekends, 0.42 on holidays), especially on weekends (Figure 7), underscoring their role in park accessibility and inclusive design.

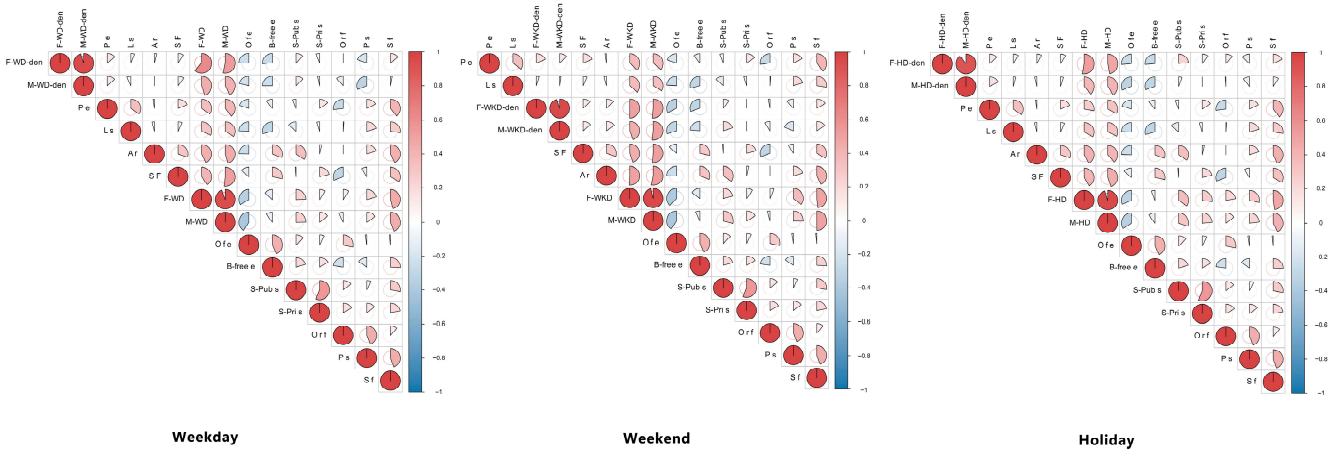


Figure 7. Correlation analysis between gender and park influencing factors (spatial dimension).

The spatial scale of green spaces also influences activity patterns. Correlation analysis between total activity volume, activity density, and park area across different day types and genders (Table 6) revealed that, in terms of total activity, female users were significantly affected on weekends, with notable gender differences. During holidays, both genders were influenced, showing relatively high correlations. In terms of spatial density, significant gender differences remained on weekends, with female activity density more susceptible to park size compared to males. On other days, gender consistency was observed.

Table 6. Correlation analysis between spatial characteristics of males/females and park area across different day types.

Total Vitality	ρ	Spatial Density	ρ
F-WD	0.335	F-WD-den	−0.462 **
F-WKD	0.470 **	F-WKD-den	−0.576 **
F-HD	0.503 **	F-HD-den	−0.480 **
M-WD	0.387 *	M-WD-den	−0.465 **
M-WKD	0.424 *	M-WKD-den	−0.414 *
M-HD	0.510 **	M-HD-den	−0.509 **

Note: * and ** represent the statistical significance level, which is the significance of the correlation coefficient (ρ).

4.3.2. Temporal Dimension

Gender differences were most pronounced on weekdays (Table 7, Appendix A.2). During the morning (5:00–12:00 a.m.), female visitors were influenced primarily by the availability of service facilities (0.511) and outdoor fitness equipment (0.484), while male visitors were more affected by surrounding land-use functions (0.634) and outdoor fitness equipment (0.496). In the afternoon (1:00–5:00 p.m.), women showed stronger correlations with service facilities (0.592) and barrier-free ramps (0.516), whereas men remained influenced by surrounding land-use functions (0.588) and outdoor fitness equipment (0.551), with the added factor of barrier-free ramps (0.507). During the evening (6:00–9:00 p.m), the primary factor affecting female visits was the number of service facilities (0.639), while males were influenced by surrounding land-use functions (0.490), barrier-free ramps (0.507), and service facilities (0.559).

On weekends (Table 7), both genders were influenced by the presence of barrier-free ramps throughout various time periods: males from 6:00 a.m. to 8:00 p.m., and females from 7:00a.m. to 3:00 p.m. During holidays, both male and female visitors were significantly affected by barrier-free ramps and service facilities. Additionally, males were influenced by surrounding

land-use functions (0.521) and number of park entrances (0.461), while females were affected by surrounding land-use functions (0.498) and the amount of public space (0.466).

Table 7. The Association Between Daily Temporal Characteristics of Men and Women and Influencing Factors.

Impact Factors	F-WD	M-WD	F-WED	M-WKD	F-HD	M-HD
Site Functions	0.33~0.57	0.35~0.60	0.53~0.61	0.45~0.62	0.53~0.61	0.45~0.62
Park entrance	0.38~0.51	0.38~0.57	0.52~0.63	0.44~0.64	0.52~0.63	0.44~0.64
Public space	0.38~0.51	0.38~0.57	0.51~0.65	0.43~0.65	0.51~0.65	0.43~0.65
Semi-Public space	0.29~0.45	0.29~0.45	0.50~0.64	0.42~0.64	0.50~0.64	0.42~0.64
Semi-Private space	0.15~0.43	0.19~0.43	0.49~0.63	0.41~0.63	0.49~0.63	0.41~0.63
Outdoor fitness equipment	0.02~0.37	0.02~0.37	0.43~0.57	0.35~0.57	0.43~0.57	0.35~0.57
Outdoor resting facilities	0.09~0.26	0.09~0.26	0.42~0.56	0.34~0.56	0.42~0.56	0.34~0.56
Barrier-free elevator	−0.03~0.02	0.00~0.02	0.41~0.55	0.33~0.55	0.41~0.55	0.33~0.55
Accessible ramps	−0.13~−0.06	−0.06~0.03	0.40~0.54	0.32~0.54	0.40~0.54	0.32~0.54
Service facilities	−0.43~−0.27	−0.43~−0.27	−0.04~0.20	−0.10~0.30	−0.04~0.20	−0.10~0.30
Landmark structures	−0.42	−0.43	−0.14~0.11	−0.20~0.20	−0.14~0.11	−0.20~0.20

Note: This study examines how the daily patterns of men and women are linked to various influencing factors. The analysis simplifies complex data by focusing on the correlation (from minimum to maximum values) and trends between gender-specific behaviors and particular spatial elements across different times of the day. For detailed data, please refer to the Appendix A.2.

Overall, females placed greater emphasis on the presence of barrier-free ramps, while males were more influenced by the variety of surrounding land-use functions, reflecting concerns related to accessibility, safety, and convenience. People generally preferred visiting parks with high land-use mix and well-designed accessible facilities, showing consistent behavioral patterns on both weekdays and weekends. For instance, Laodong Park recorded the highest number of visits on both types of days. Additionally, both genders showed interest in outdoor fitness facilities in the morning on weekdays and weekends, while their attention shifted to barrier-free ramps in the afternoon, suggesting changes in activity types and user composition throughout the day. During holidays, both men and women were also affected by surrounding land-use functions. Compared to males, females were more sensitive to the influence of spatial scale.

5. Discussion

5.1. Research Limitations

Regarding the influence of variables, this study primarily relied on mobile positioning big data for analysis. Due to the structural limitations of such datasets, it was not possible to directly control for individual-level confounding variables such as occupation or travel mode. To minimize potential bias, we selected samples from the same city, season, and time period, ensuring comparable environmental and meteorological conditions. This strategy indirectly controlled for external disturbances and enhanced the internal validity of the analysis. Future studies could integrate survey-based data or individual attributes to further improve model interpretability and robustness.

In terms of data limitations, although the data were collected in 2018, this temporal choice ensured that the observed gendered behavioral patterns were not affected by COVID-19-related restrictions or behavioral transformations, providing a stable pre-pandemic baseline for understanding the long-term spatial equity of park use. Future research could employ post-pandemic datasets to conduct comparative analyses and explore how the pandemic may have reshaped gender-differentiated outdoor behaviors.

When constructing the Standardized Difference Index (SDI), we used Dalian's overall gender ratio as the reference baseline to control for the demographic composition of the urban population. This approach follows precedents in urban sociology and environmental

behavior research, which adopt city-level demographic baselines to examine spatial disparities at the micro scale. Although gender ratios may vary across districts or occupations, employing citywide reference data minimizes local demographic noise and facilitates comparison among multiple parks within the same urban system. We acknowledge that this method may slightly overestimate male predominance; however, it provides a standardized analytical framework capable of capturing consistent gendered patterns across diverse park types. Future studies could refine this framework by incorporating multi-scale or demographically adjusted baselines.

In terms of gender classification, this study only considered the conventional binary categories of male and female, primarily due to data preprocessing requirements. While binary gender remains the dominant classification in China, inclusive urban design should ultimately address the diverse needs of non-binary and gender-diverse users. This dimension will be explicitly integrated and validated in our future research to strengthen the inclusiveness of gender-sensitive urban studies.

Finally, the coherence between conclusions and methodology should also be interpreted in light of the data type used. Studies employing mixed methods—such as questionnaires or field observations—often emphasize activity types rather than duration-based indicators, leading to differences in conclusions. In this research, our goal was to reveal how spatial elements influence gender disparities in park use and to derive spatial optimization strategies. Therefore, our indicator system incorporated spatial factors reflecting perceived experiences, such as park area (as a proxy for perceived safety) and number of entrances (as an indicator of accessibility), enabling partial overlap between usage intensity and perceptual experience. Nonetheless, future studies should refine these metrics through multi-dimensional perception data and mixed-method verification to achieve a more comprehensive understanding of gendered spatial behavior.

5.2. Spatial Patterns of Gender Differences

The results of this study demonstrate that significant gender differences exist in the use of urban parks in developing countries, generally exhibiting a "male-dominated" pattern of park utilization, consistent with the findings of Peter Odhengo et al. [4]. However, several parks—particularly Children's Park and Beihai Park—presented an opposite trend, where the proportion of female visitors exceeded that of males on weekends (reaching up to 41%) and remained relatively high on weekdays. This pattern aligns with the findings of Chen and Marzabali, and stands in contrast to the dominant "male-oriented" usage model. These cases reveal the importance of the interaction between specific spatial configurations and socio-cultural attributes in shaping gendered park use.

Field investigations further revealed that Children's Park and Beihai Park share several common spatial features: both are smaller in size (below the average of 15.5 hectares), have a higher number of entrances and exits, and are surrounded by diverse land-use types, including schools, hospitals, and commercial facilities. These characteristics collectively enhance functional connectivity and perceived safety within the parks [47]. Previous studies have noted that proximity to mixed-use zones can increase women's comfort and willingness to engage in public spaces. Our results extend this understanding by identifying a positive relationship between spatial scale and perceived safety—women tend to prefer smaller, more enclosed spaces [48]. Accordingly, the inclusion of indicators such as "semi-public spaces" and "semi-private spaces" in this study provides a clearer explanation of gendered behavioral patterns. In summary, women are more likely to engage in spaces that balance visibility and enclosure, offering both a sense of safety and social comfort, whereas men more frequently occupy open activity zones and fitness areas, reflecting greater tolerance for exposure and flexibility in spatial use.

Moreover, "accessible facilities" (e.g., ramps and elevators) were found to have a significant impact on both genders across different day types, underscoring their central role in promoting inclusivity and equity. The indicator of "landmark structures" further reveals the socio-cultural distinctions among parks. Cultural parks (e.g., Dingshan Park) attracted more male visitors during holidays, reflecting men's tendency toward exploration and symbolic identification. In contrast, community parks featuring neighborhood landmarks were more conducive to female social interaction and a sense of belonging.

In summary, the observed gender differences in urban green space use result from the interaction between physical spatial characteristics and socio-cultural meanings. Future research should aim to develop a quantifiable socio-cultural indicator framework to deepen the understanding of the mechanisms underlying gender disparities and to provide more targeted strategies for advancing inclusive urban design.

5.3. Temporal Patterns of Gender Differences

The temporal dimension further reveals the dynamic characteristics of gender differences. Men demonstrate greater temporal flexibility and longer durations of stay, whereas women's activities are concentrated from the morning to early afternoon. The absence of women in the evening and nighttime—referred to as the "nighttime poverty" phenomenon—reflects the combined influence of perceived safety, social norms, and spatial design [49]. Women tend to be more sensitive to potential risks such as sexual harassment and theft; even when the objective risk is low, their subjective perception substantially constrains nighttime mobility [50]. In addition, family roles and social responsibilities [51] further reduce women's discretionary leisure time during evening hours.

By aligning climatic and lighting data (including temperature, wind speed, and sunset time) with park visitation periods, this study finds that daylight duration and ambient brightness are closely associated with women's park activities. Insufficient lighting, lack of surveillance facilities, and the closure of functional areas at night exacerbate women's nocturnal poverty. In contrast, parks with adequate illumination and visible landmarks maintain moderate levels of female visitation during the evening, suggesting that spatial interventions can partially mitigate gender inequality along the temporal dimension.

Further regression analysis indicates that both men and women exhibit significant sensitivity to accessibility facilities across all day types, though their temporal patterns differ: women's responses are concentrated during daytime hours (7:00–15:00), while men's responses extend into the evening. This reflects differing degrees of mobility freedom and safety confidence between genders. Therefore, the design of accessible facilities from a female-centered perspective deserves greater attention in future research.

Moreover, due to variations in socio-cultural roles and social status, gender disparities are continuously reproduced through differentiated spatial belonging, social behaviors, and daily practices within modern urban environments [52]. Hence, expanding subsequent studies toward a broader social and cultural dimension will be essential for deepening the understanding of these inequalities.

Additionally, for both men and women, the majority of park visits last between 16 and 60 min, which may be associated with their outdoor activity habits. Group-based activities such as aerobic exercise, martial arts, or dancing typically last between 0.5 and 1.5 h [53]. Multiple regression analyses on physical health reveal a positive correlation between park-use duration per visit and users' physical health scores [54]. Although the contribution of park visitation to emotional health is relatively limited ($\Delta r^2 = 2.25\%$), its broad and sustained influence across diverse populations underscores the long-term public health value of urban green spaces [55].

6. Conclusions

This study leveraged mobile positioning big data to analyze the spatiotemporal characteristics of green space usage across genders, enabling precise quantification of gender-based differences in both time and space. The findings offer actionable insights for promoting equitable park planning and inclusive urban design. Conducted in Dalian, China, this research comprehensively reveals gender-specific spatiotemporal patterns and their influencing factors in urban green spaces. Key results include the following:

First, among all park types across the three day types, community parks exhibited the largest disparity in usage volume, with male users outnumbering females by approximately five times. In contrast, comprehensive parks showed the smallest gender difference in user numbers. Second, among the three day types, holidays demonstrated the smallest gender disparity. On a daily scale, males tended to visit parks earlier than females and generally stayed for longer durations. Third, female visitors displayed more regular activity rhythms, primarily using parks from morning to afternoon, whereas male visits were more temporally flexible, spanning early morning, evening, and night. Finally, females prioritized the presence of barrier-free ramps, reflecting concerns over accessibility and safety, while males placed greater importance on surrounding land-use functions, emphasizing convenience. Notably, on weekends, both genders valued barrier-free ramps.

Based on these results, this study proposes gender-sensitive design strategies to promote inclusive urban green spaces. For male users, design should prioritize functional connectivity and accessibility, integrate mixed land uses and improve entrance layouts. For female users, the focus should be on safety, visibility, and organized activities, by enhancing lighting, surveillance, and spatial openness to increase perceived safety and willingness to stay. For all users, balanced distribution of service and barrier-free facilities should follow the principles of equity, safety, and inclusiveness, creating comfortable and user-friendly environments. Moreover, involving women and minority groups in park planning and decision-making can effectively reduce gender disparities and enhance the collective sense of belonging.

Despite these insightful findings, this study has several limitations that warrant further investigation. First, the selected impact factors did not incorporate social determinants affecting gender-specific usage. Second, as the study focused exclusively on parks in Dalian, the generalizability of the results to other regions remains uncertain. Thus, future studies across diverse urban contexts are needed to validate or refute the key findings presented here.

Author Contributions: Conceptualization, Z.Z. (Zhihan Zhang), Y.T. and B.S.; methodology, Z.Z. (Zhihan Zhang) and Y.S.; software, S.L. and X.Z.; validation, Z.Z. (Zhihan Zhang), C.Z. and Z.Z. (Zhonghu Zhang); formal analysis, G.X.; investigation, Z.Z.; (Zhihan Zhang) resources, S.L.; data curation, D.C.; writing—original draft preparation, Z.Z. (Zhihan Zhang); writing—review and editing, Z.Z. (Zhihan Zhang) and Y.T.; visualization, Z.Z. (Zhonghu Zhang); supervision, Y.T., B.S. and Y.S. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The data presented in this study are available on request from the first author.

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Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

UGS	Urban Green Spaces
GIS	Geographic Information Systems
GPS	Real-Time Global Positioning Systems Standardized Difference Index
SDI	Standardized Gender Difference Index
WD	Weekdays
HD	Holidays
WKD	Weekends Three Letter Acronym

Appendix A

Appendix A.1

Table A1. 16 ineffective green spaces and the reasons for their selection.

Name of Green Space	Survey Feedback	Number of Weekdays	Number of Weekends	Number of Holidays
Bangchui Island Park	Tourist attraction, located on the hill, not having complete boundary	356	1549	895
Dongzaiyuan Park	Small hill inside the East Finance School, does not have complete boundaries and is not easily accessible by direct access	524	671	488
Huananjin Park	No such park	87	155	100
Triumph Plaza	Traffic distribution square, no activity space, incomplete boundary	705	1430	720
Tiger Beach Park	Surrounded by scenic spots, belongs to a park in a tourist attraction, does not have complete boundary	3511	4587	556
Nanshan Park	Large hill, low accessibility	605	621	883
Tongli Lake Park	Recreation area, incomplete boundary	34	31	3406
Wuyi Square	No such park	39	34	75
Xiangfujiao Park	No such park	128	236	262
Silver Beach Park	By the sea and beach, no activity space, no complete boundary	167	238	149
Friendship Square	Just a place name, no activity space, no complete boundary	143	85	145
Zaofangshang Park	Located on the hill, low accessibility	114	178	164
Zhoushuizi Park	No such park	300	315	268
Dalian Botanical Garden	Specialized park with entrance fee	128	104	100
Jinquan park	No such park	74	89	102
Olympic Square	Blurred boundaries do not accurately define the use of the population	3546	3046	4546

Number: total number of people visiting the green space on a given type of day.

Appendix A.2

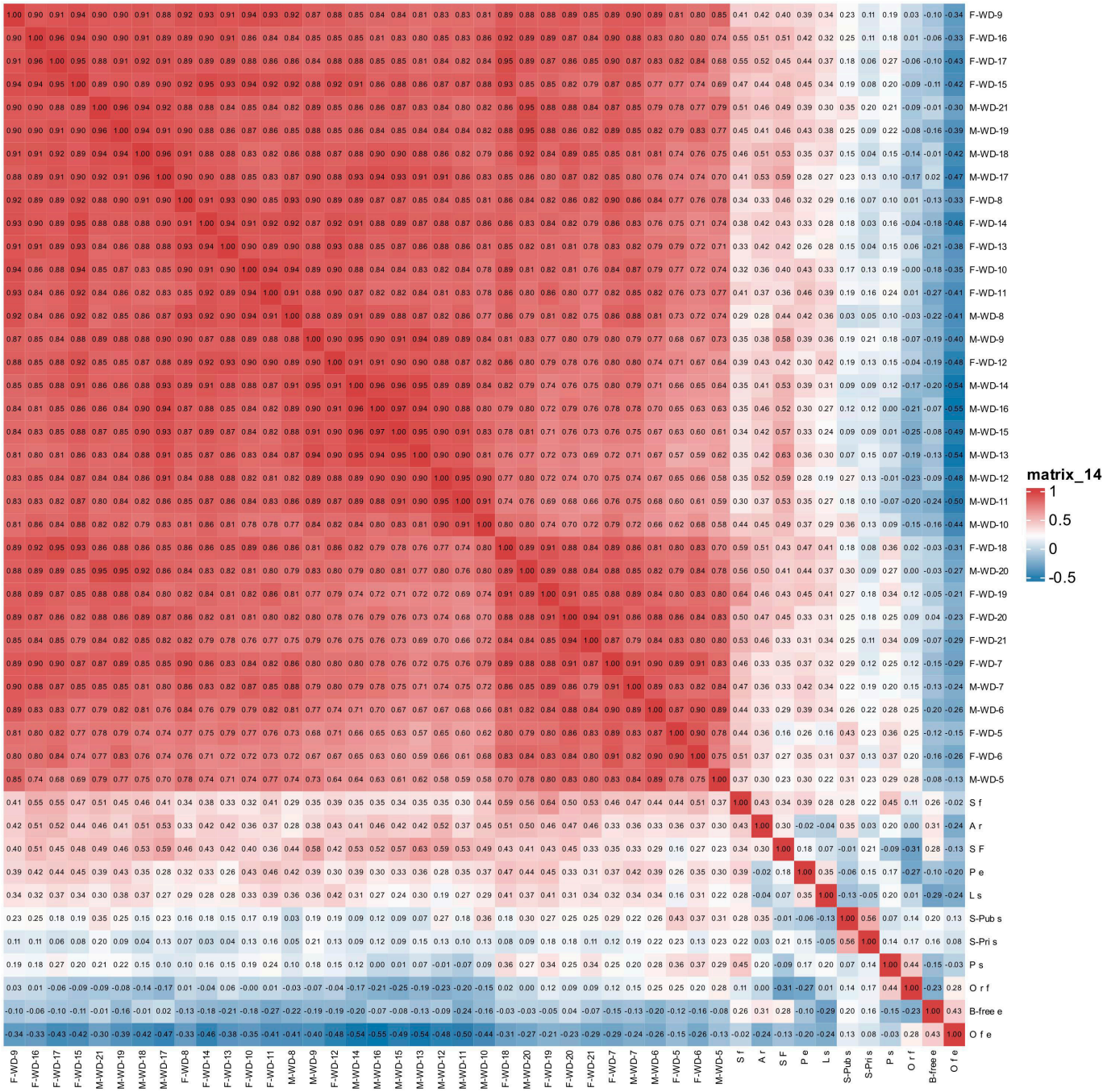

Figure A1. Correlation analysis between male and female activity time periods on **weekdays** and spatial elements.

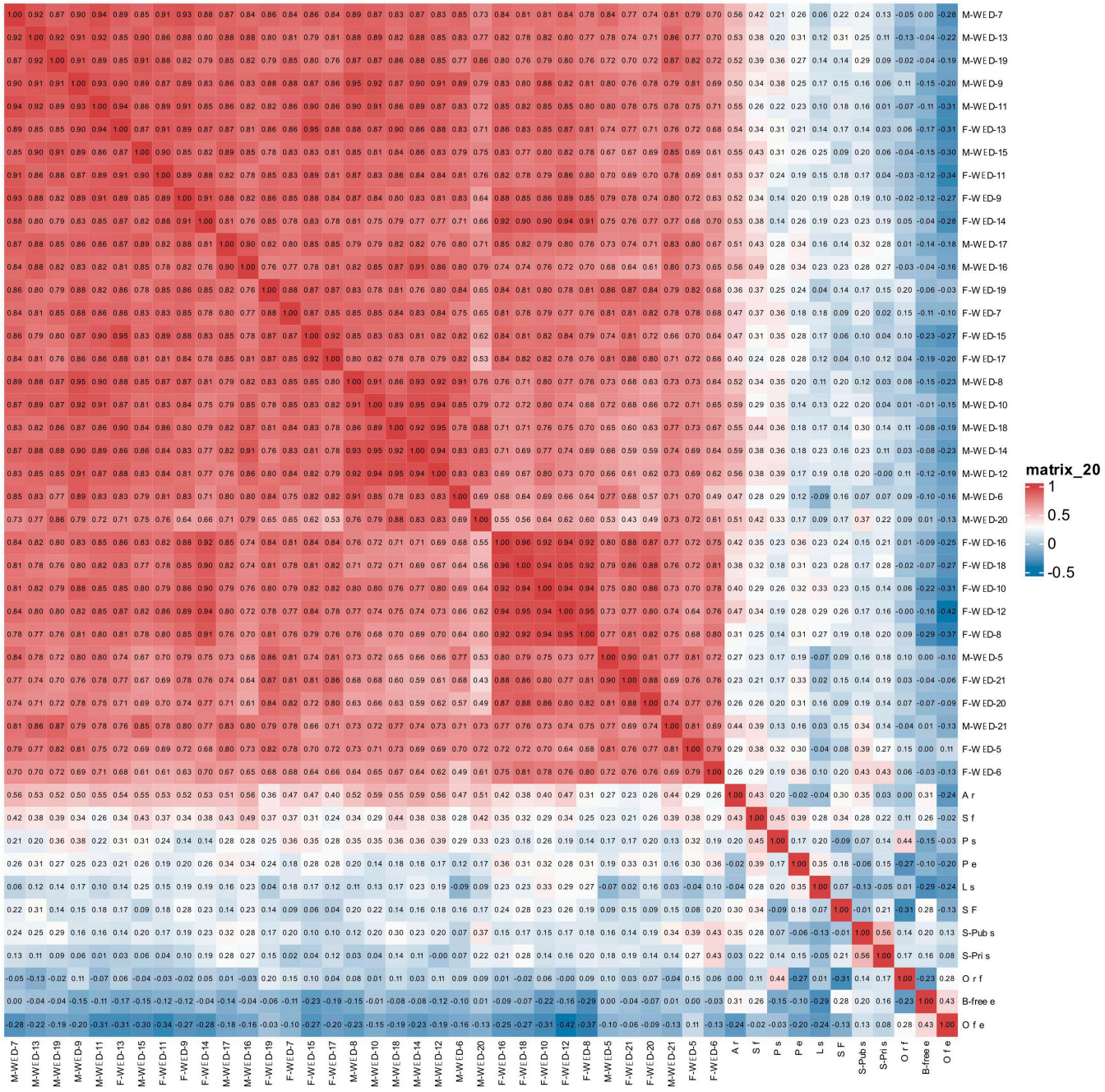

Figure A2. Correlation analysis between male and female activity time periods on **weekends** and spatial elements.

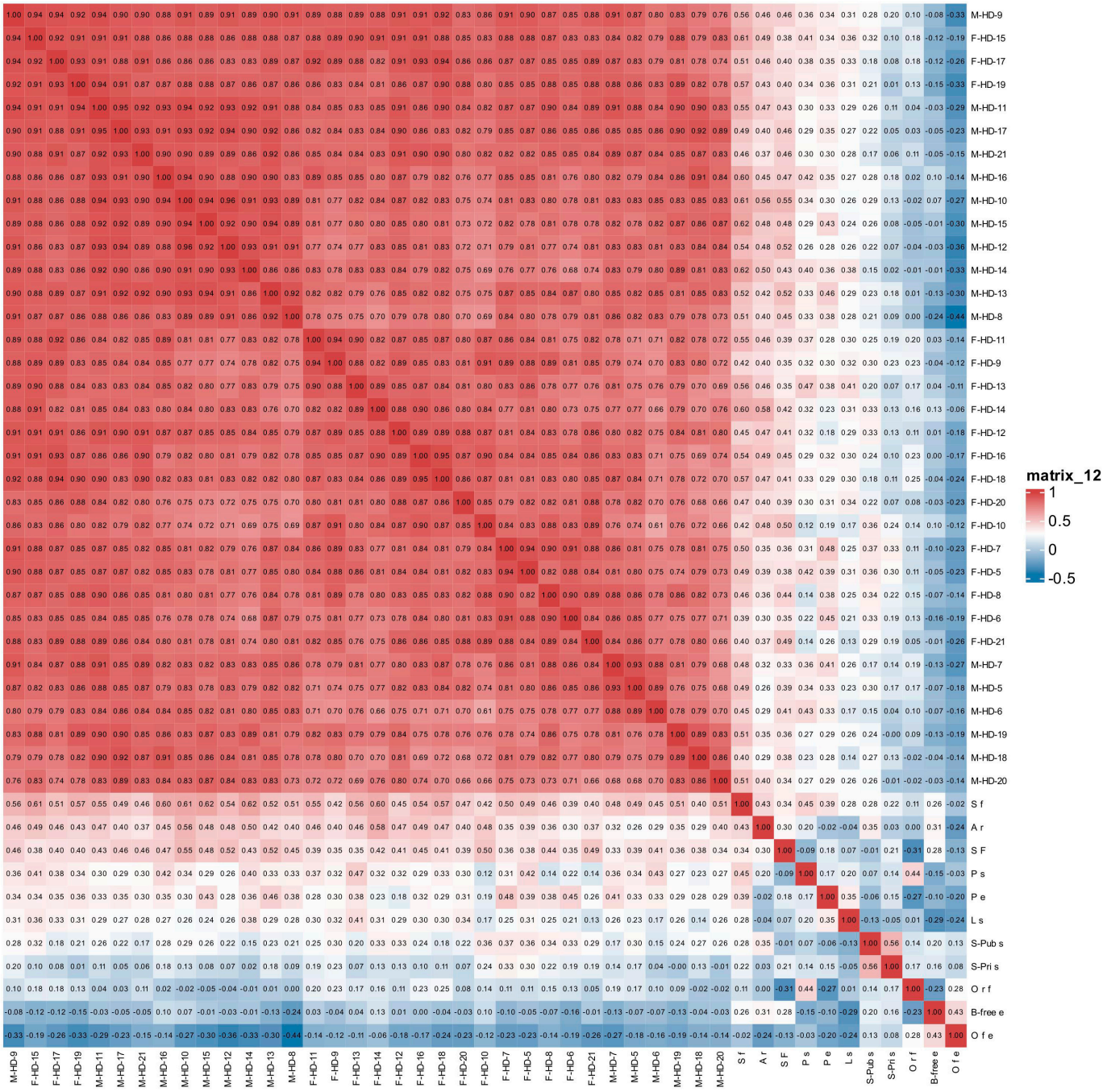

Figure A3. Correlation analysis between male and female activity time periods on **holidays** and spatial elements.

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