

Article

Quantifying Older Adults' Spatial Perceptions of Outdoor Activity Areas for Embedded Retirement Facilities

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Abstract: Outdoor activity areas for embedded retirement facilities (ERFs) are essential for providing older adults with access to outdoor environments within communities. However, there is limited evidence on how these areas influence older adults' spatial perceptions. This study investigated the impact of ERFs' spatial characteristics on older adults' physiological and psychological perceptions. Three kinds of outdoor activity areas in a coastal city in eastern China were investigated, and older adults' physiological data were collected through real environments from wearable sensors. Their subjective perception data were collected through subjective satisfaction questionnaires. By combining them, the authors identified correlations between older adults' spatial perceptions and the characteristics of outdoor activity areas, quantifying the impact of various spatial features on their satisfaction. The results showed that areas with high subjective satisfaction were linked to strong emotional arousal and increased visual comfort. Spaces with favourable sky view factors and spatial openness significantly enhanced spatial perception satisfaction. Key design elements can shape older adults' spatial perceptions. This study highlights the positive relationship between outdoor activity areas for ERFs and older adults' spatial experiences, offering insights for age-friendly renovations and site selection to create supportive environments for ageing populations.



Academic Editor: Yung Yau

Received: 12 December 2024

Revised: 15 January 2025

Accepted: 15 January 2025

Published: 18 January 2025

Citation: Fu, G.; Gai, Y.; Xiang, L.; Lin, L. Quantifying Older Adults' Spatial Perceptions of Outdoor Activity Areas for Embedded Retirement Facilities. *Buildings* **2025**, *15*, 271. <https://doi.org/10.3390/buildings15020271>

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Keywords: embedded retirement facilities (ERFs); outdoor activity areas; emotional arousal; spatial perceptions

1. Introduction

The global population is rapidly ageing. The proportion of individuals aged 60 and older is projected to increase from 9.3% in 2020 to 16.0% by 2050 [1]. In China, 21.1% of the population has become 60 years old, with 15.4% aged over 65 by the end of 2023 [2]. This demographic shift presents significant challenges to the existing social support structures. Since a large proportion of older adults live in urban areas, it is critical for communities to provide supportive environments that can enhance older adults' functional abilities [3].

The Chinese government has begun promoting embedded retirement facilities (ERFs) since 2017 to extend care services in communities and address the needs of older adults [4]. An ERF is defined as a small-scale, multifunctional community-based care facility offering daycare services, long-term residence, or both [5,6]. In November 2023, the General Office of the State Council of the People's Republic of China released the *Implementation Plan for*

the Construction Project of Community-Level Embedded Service Facilities in Urban Areas. This plan outlined key principles for facility planning, functional configuration, and operational modes related to ERFs [7]. Subsequently, in January 2024, the Chinese government introduced construction guidelines [8]. By September 2024, further efforts to advance the development of ERFs were mandated [9]. Studies have shown that older adults' satisfaction with outdoor environments in retirement facilities is significantly influenced by their exposure to nature, the spatial layout, greenery, and air quality [10]. Additionally, environmental features that support physical activity, such as exercise facilities, are associated with increased activity levels and reduced sedentary behaviour [11].

As mobility declines with age, outdoor activity areas become essential spaces for older adults to engage with the natural environment and participate in daily activities [12]. Given the importance of exercise and access to fresh air for their overall health, these outdoor spaces should be designed to support their needs [13,14]. Despite the growing recognition of the importance of these spaces, there is a lack of quantitative research on the factors influencing older adults' satisfaction with outdoor activity areas in ERFs. Previous research has employed surveys, interviews, and focus group discussions to examine the impact of outdoor spaces on older adults [15–17]. Satisfaction with outdoor space is primarily assessed through subjective questionnaires. These studies have demonstrated that the spatial aspect ratio and the average height of the surrounding buildings significantly affect the frequency with which older adults use outdoor spaces [18]. Additionally, the enclosure and transparency of outdoor spaces are closely related to older adults' emotional responses [19], while sky visibility has been shown to affect their health positively [20]. Furthermore, behavioural observation methods have been used to explore how factors such as safety and the availability of rest facilities influence older adults' willingness to engage in physical activities [21,22]. The design of outdoor environments significantly affects older adults' use and satisfaction with these areas, contributing to their physical and mental health by encouraging interaction with nature [23,24]. Although traditional subjective satisfaction survey methods are effective in evaluating the impact of outdoor space characteristics on older adults' spatial perceptions, they are prone to retrospective bias and can be influenced by the participants' personal judgment and cognitive differences. Recent advancements in wearable sensors have enabled researchers to capture real-time physiological data from people in real-world outdoor spaces. These technologies combine measurements such as electrodermal activity (EDA), heart rate variability (HRV), eye movement, and electroencephalograms to assess spatial perceptions or emotional arousal [25–27]. Studies have applied these methods in a variety of outdoor settings, including historic neighbourhoods, campuses, green spaces, and residential areas [28–31]. However, most of these studies focus on young people or specific populations [31,32]. Although some studies have explored the impact of outdoor space characteristics on older adults' spatial perceptions using wearable sensors, they tend to focus on factors like walking ability and stress detection [33,34]. Wearable sensors can objectively capture older adults' environmental responses, providing valuable data to support subjective findings. Despite this potential, there is still a lack of studies that explore the impact of outdoor activity areas for ERFs on older adults' spatial perceptions by integrating subjective satisfaction surveys with objective physiological data.

This study aimed to explore older adults' spatial perceptions of outdoor activity areas for ERFs and to assess how the characteristics of these areas influence older adults' spatial perception satisfaction. By integrating physiological responses with subjective satisfaction assessments, the authors correlated older adults' spatial perceptions with the characteristics of the outdoor activity areas. In addition, key elements of outdoor activity areas that influence older adults' spatial perceptions were identified. The findings will provide

references for promoting age-friendly spaces and offer guidance on the optimal selection and renovation of ERF sites to create supportive environments for older adults.

2. Materials and Methods

2.1. The Study Area and Related Characteristics

The experiment was conducted in Qingdao, a city with a temperate monsoon climate that exhibits distinct maritime climatic characteristics. By the end of 2023, the population of older adults in this city became 2.15 million, representing an ageing rate of 25.17% [35]. In 2022, Qingdao was selected as a pilot city for China's initiative to enhance essential care services in both home and community settings for older adults.

Following a comprehensive field study, three ERFs were selected on the basis of their size, functional configuration, and the ageing rate of the surrounding communities (Table 1). These criteria were chosen to ensure that the selected facilities represented typical operational models of ERFs. The three facilities provide daycare, short-term care, and meal assistance services. Each bed shall have an allocated area of no less than 35 m², and the total floor area is no less than 350 m², which aligns with the policy's requirements [8]. The outdoor activity spaces adjacent to the main entrances of these ERFs were chosen for the experiment. The outdoor activity area for ERF A is an open and spacious space located at a road intersection, offering a broad view of the sky. A fountain is situated on-site, and street trees line both sides. The outdoor activity area for ERF B is situated within the interior of the settlement and features a high degree of enclosure. The site includes a basketball court, a fitness area, and a landscaped pavilion, with limited greenery. The outdoor activity area for ERF C is surrounded by two high-rise buildings, creating an enclosed environment with limited sky visibility. On one side, an urban expressway runs nearby, and the site features a high level of greenery. Figure 1 illustrates the locations and field photos of the three experimental sites.



Figure 1. Locations and field photos of the experimental sites (Site A, B and C).

Table 1. Characteristics of the neighbourhood of the ERFs.

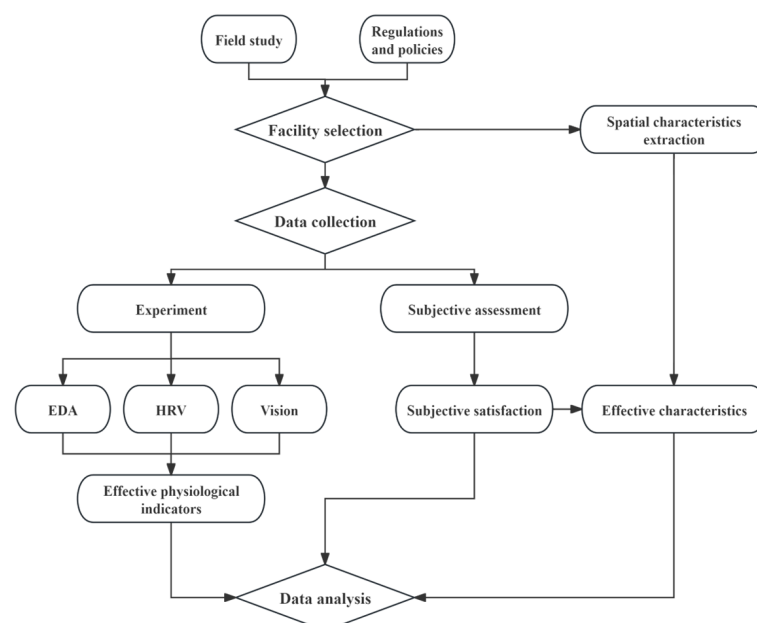
	A	B	C
The year of completion	2014	2000	2018
Properties	Resettlement and commercial housing	Resettlement housing	Resettlement and commercial housing
Plot ratio	1.48	1.19	1.20
Greening rate	20%	35%	30%
Proportion of older adults	20%	22%	17%

2.2. The Characteristics of the Participants

The required number of participants for this experiment was determined to be 10, considering the duration of each experiment, the data requirements, and previous studies on measuring spatial perceptions [36–38]. The participants had a mean age of 64 years with a standard deviation (SD) of 3.5 years, and the majority were young old (60–74 years old, 90.0%) and female (60.0%). They were all healthy older adults capable of understanding the experiment’s purpose. During the experiment, the participants were not undergoing any medical treatment or taking medications. They were required to abstain from alcohol, caffeine, and smoking throughout the study period. Before the experiment began, all participants were informed of the procedures, and written informed consent was obtained. The study was conducted in compliance with the ethical principles outlined in the Declaration of Helsinki [39].

2.3. Study Procedure and Measurements

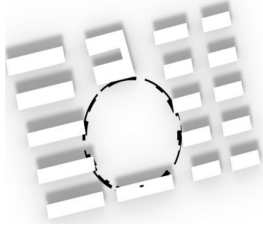
Figure 2 indicates the research process: First, the spatial characteristics of the three outdoor activity areas were quantified. Next, differences in the older adults’ physiological perceptions during the environmental exposure phase were analysed to identify key physiological indicators. Then, subjective evaluations were examined to determine which spatial characteristics influenced older adults’ overall satisfaction. Finally, the impact of ERFs’ outdoor activity areas on older adults’ spatial perceptions was quantified by performing a correlation analysis between the physiological indicators and spatial characteristics.

**Figure 2.** Research process.

The data collection process is outlined as follows.

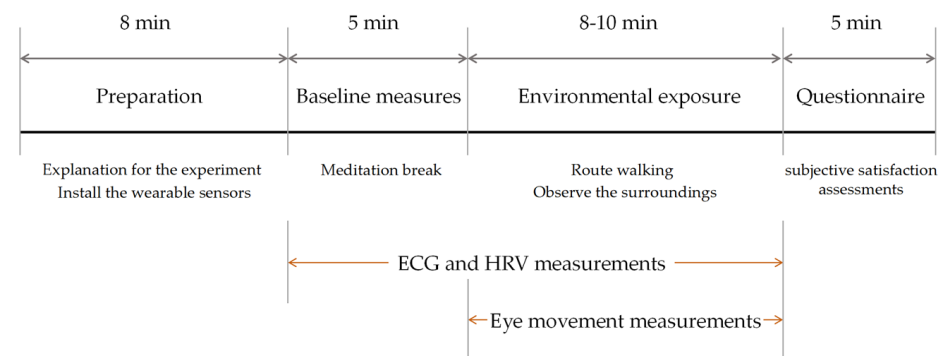
- (1) **Spatial characteristics:** The sky view factor (SVF) is a geometric measure of the sky's visibility and serves as a standard metric for describing urban geometry [40,41]. Access to natural light and an expansive sky view can reduce stress, alleviate anxiety, and enhance mental well-being. To explore the impact of sky visibility on older adults' spatial perceptions, SVF was calculated by Rhinoceros 7.0. The degree of spatial openness (D/H) was used to quantify the spatial openness of outdoor activity areas for ERFs, aiming to investigate its effect on older adults' spatial perceptions. When $D/H < 1$, the space evokes a sense of urgency. Conversely, the space is perceived as more pleasant and comfortable [42]. The first-floor interface enclosure was used to quantify the spatial enclosure of outdoor activity areas for ERFs. It refers to the ratio of the total length of the surrounding building enclosures to the perimeter of the site itself. A longer perimeter of the surrounding building interfaces enhances the sense of spatial enclosure [43]. Table 2 presents the spatial characteristics of the three selected areas.
- (2) **Physiological data:** The participants' EDA and HRV data were collected using wristbands with Ergo Sensing multimodal sensors produced by PsychTech Ergosensing. The wristband recorded EDA signals at a sampling rate of 4 Hz and HRV signals at 100 Hz [44]. EDA, which reflects emotional arousal, includes two components: skin conductance level (SCL) and skin conductance response (SCR) [45]. SCL, which increases emotional arousal and sweating, was selected in this study due to its suitability for long-term recordings and continuous environmental stimuli [46,47]. HRV, the variation in time between consecutive heartbeats, reflects the balance between the sympathetic and parasympathetic nervous systems and is commonly used to assess cardiac autonomic regulation [48]. The root mean square of the successive differences (RMSSD) and the percentage of successive normal cardiac interbeat intervals greater than 50 ms (pNN50) indices were used in the HRV analysis. RMSSD is the root mean square of the difference between consecutive heartbeats, decreasing with increased sympathetic activity due to emotional or nervous stimulation. pNN50 is the proportion of intervals greater than 50 ms between consecutive heartbeats, which increases with parasympathetic activity during relaxation.
- (3) **Visual data:** Eye movements and gaze behaviour influence visual perceptions of objects and scenes [49]. These data were captured using wearable eye trackers produced by ASee Glasses, operating at a sampling rate of 120 Hz [50]. In this study, average pupil diameter and blink count were used as indicators of visual perception. Pupil diameter predicts emotional arousal and autonomic activation, with cognitive stress, emotional arousal, and light intensity all causing changes in pupil size [51–53]. Smaller pupil diameters are linked to greater visual relaxation [54]. Blink count, influenced by dopamine secretion, serves as an indicator of emotional pleasure [55].
- (4) **Subjective data:** At the end of the environmental exposure phase, the participants completed a subjective satisfaction questionnaire to assess their psychological perception of the spatial characteristics. The questionnaire included an overall satisfaction rating for the outdoor activity areas of the ERFs, along with 10 sub-items rated on a five-point Likert scale (1 = very dissatisfied, 5 = very satisfied). Higher scores indicated greater satisfaction.

Table 2. Quantified spatial elements of outdoor activity areas for the ERFs.

Item	Area A	Area B	Area C
Site area (m ²)	998	2115	1612
SVF (%)	 63.00	 69.20	 26.50
D/H	1.467	2.52	0.453
The first-floor interface enclosure	0.323	0.526	0.692
Rate of the green space (%)	21.50	13.80	34.10
Absolute green space area (m ²)	214.57	291.87	549.69

2.4. Experimental Design

The experiment was conducted over 27–29 June 2024, between 14:30 and 17:30. The weather remained mild throughout the duration, with minimal fluctuations. The average temperature was 24.5 ± 0.4 °C, and the average relative humidity was $86.9 \pm 3.1\%$. Each session lasted approximately 30 min and consisted of four phases: preparation, baseline measurement, environmental exposure, and subjective assessment (Figure 3). Given the duration of each experiment, 10 participants completed it at one area per day to ensure relatively consistent weather conditions. In the preparation phase, the researcher explained the procedures to the participants, who then donned wearable sensors, including wrist-band physiological sensors and an eye tracker, to monitor EDA, HRV, and eye movement. During the baseline measurement phase, the participants were asked to sit still for five minutes to allow the researchers to record baseline physiological data. In the environmental exposure phase, the participants were escorted to the main entrance of the ERF, where they were instructed to walk along a predetermined path at their preferred moderate pace while observing their surroundings. Two researchers accompanied the participant during this phase: one monitored the participant's real-time physiological responses, and the other guided the participant's movement, ensured that no special conditions affected the experiment, and recorded a video of the process. In the final subjective assessment phase, the wearable sensors were removed, and the participants were invited to complete a questionnaire survey regarding their satisfaction with the spatial characteristics.

**Figure 3.** Experimental process.

3. Results

The experimental data were organised, cleaned, and analysed using SPSS 26.0. Descriptive statistics and paired sample tests were performed. The paired Wilcoxon signed-rank test was used for physiological data without a normal distribution to compare physiological indicators between the environmental exposure and baseline phases. The Kruskal–Wallis test examined differences in physiological responses across outdoor activity areas for the ERFs, while Spearman’s correlation analysis assessed the relationships between spatial characteristics and older adults’ physiological responses.

3.1. Objective Data Analysis

A paired Wilcoxon signed-rank test was conducted on the baseline and environmental exposure data to assess whether outdoor activity areas for ERFs influence the physiological responses of older adults. As shown in Table 3, all three outdoor activity areas showed increased SCL during environmental exposure, with significant elevations in Areas A, B, and C. Heart rate (HR) also increased significantly, while RMSSD decreased significantly in Areas A and B. Additionally, pNN50 values increased, with that of Area A significantly rising. These results suggest that the spatial characteristics of outdoor activity areas for ERFs affect the physiological responses of older adults, with variations observed across different areas.

Table 3. Differences regarding older adults’ physiological responses between the baseline and environmental exposure phases.

Physiological Indicator	Area	Baseline Phase (Mean $\pm$ SD)	Environmental Exposure Phase (Mean $\pm$ SD)	<i>p</i>
SCR	A	0.017 $\pm$ 0.022	0.030 $\pm$ 0.055	0.386
	B	0.051 $\pm$ 0.097	0.060 $\pm$ 0.079	0.074
	C	0.012 $\pm$ 0.024	0.006 $\pm$ 0.012	0.445
SCL	A	1.362 $\pm$ 1.077	1.430 $\pm$ 1.138	0.005 **
	B	1.376 $\pm$ 0.807	1.709 $\pm$ 1.009	0.005 **
	C	1.283 $\pm$ 0.993	1.321 $\pm$ 1.068	0.047 *
SDNN	A	40.678 $\pm$ 21.125	35.262 $\pm$ 12.443	0.169
	B	55.643 $\pm$ 29.387	40.384 $\pm$ 13.056	0.028 *
	C	32.831 $\pm$ 9.722	34.035 $\pm$ 12.606	0.575
HR	A	72.974 $\pm$ 8.377	80.186 $\pm$ 10.069	0.005 **
	B	73.466 $\pm$ 6.882	82.967 $\pm$ 7.186	0.005 **
	C	77.658 $\pm$ 9.916	87.055 $\pm$ 7.175	0.005 **
RMSSD	A	48.075 $\pm$ 14.751	44.154 $\pm$ 13.899	0.047 *
	B	62.623 $\pm$ 9.583	51.830 $\pm$ 8.327	0.005 **
	C	45.503 $\pm$ 13.269	45.320 $\pm$ 14.143	0.959
pNN20	A	0.404 $\pm$ 0.174	0.479 $\pm$ 0.136	0.139
	B	0.491 $\pm$ 0.104	0.517 $\pm$ 0.113	0.878
	C	0.423 $\pm$ 0.137	0.459 $\pm$ 0.175	0.285
pNN50	A	0.170 $\pm$ 0.068	0.224 $\pm$ 0.094	0.007 **
	B	0.220 $\pm$ 0.095	0.268 $\pm$ 0.084	0.059
	C	0.197 $\pm$ 0.087	0.212 $\pm$ 0.108	0.721

* $p < 0.05$, ** $p < 0.01$.

To assess older adults' physiological perceptions, changes in several physiological indicators were measured, accounting for individual differences and daily variations. Specifically, the indicators used were SCL, HR, and HRV, with HRV further analysed through the parameters of RMSSD and pNN50. The changes in these indicators during the exposure phase were compared with the baseline values and were recorded as Δ SCL, Δ HR, Δ RMSSD, and Δ pNN50. As shown in Figure 4, the results obtained from the Kruskal–Wallis test revealed significant differences in Δ SCL and Δ RMSSD among the three areas. Bonferroni-corrected pairwise comparisons showed that Δ SCL was significantly higher in Area B (0.333 ± 0.077) than in Areas A (0.067 ± 0.027) and C (0.038 ± 0.028), the Δ RMSSD in Area B (-10.793 ± 1.103) was significantly lower than in Areas A (-3.920 ± 1.601) and C (-0.184 ± 2.271). There were no significant differences in Δ HR and Δ pNN50 among the three areas. Higher Δ SCL values and lower Δ RMSSD indicate greater emotional arousal, suggesting that the emotional arousal levels induced by the spatial characteristics of outdoor activity areas follow the order Area B > Area A > Area C.

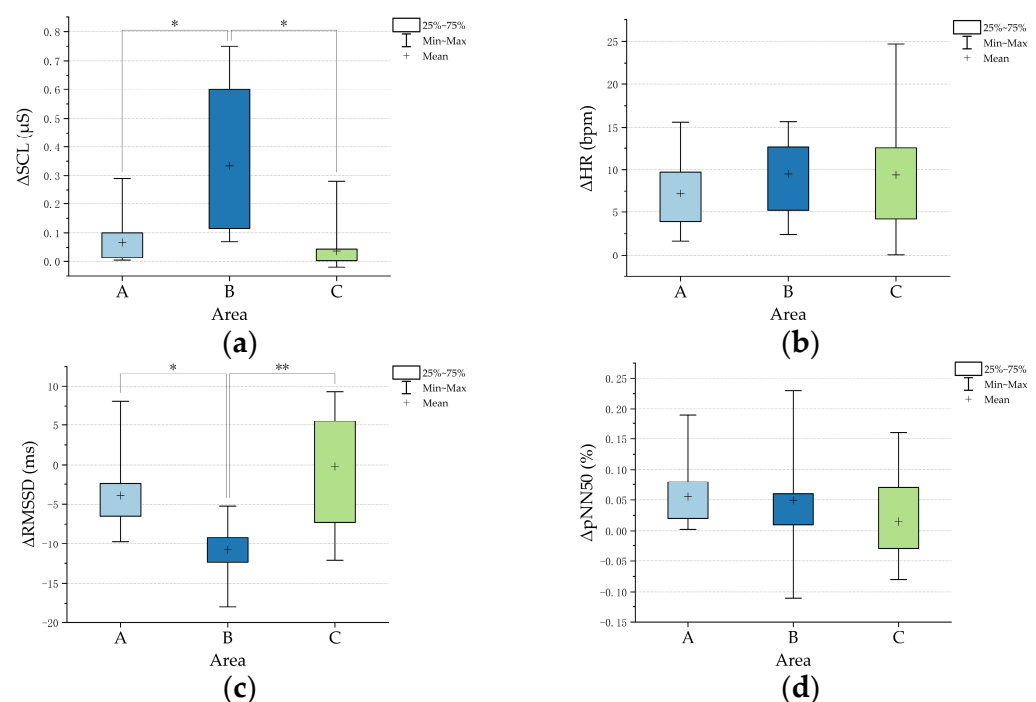


Figure 4. Indicators of older adults' physiological perceptions of the three outdoor activity areas: (a) Δ SCL; (b) Δ HR; (c) Δ RMSSD; (d) Δ pNN50. * $p < 0.05$, ** $p < 0.01$.

Older adults' visual perceptions and attention were measured by average pupil diameter, blink count, and gaze patterns. As shown in Figure 5, significant differences in average pupil diameter were found among the three areas, with Area B (3.267 ± 0.294) showing a smaller pupil diameter than Area C (4.497 ± 0.302), and Area A (3.595 ± 0.298) showing no significant difference from Area B. Smaller pupil diameter values indicate greater visual relaxation, suggesting that older adults experienced more relaxation in Area B compared with Area C. No significant differences were observed in average blink count across the areas.

Gaze patterns, assessed using a gaze heatmap (Figure 6), provided further insight into older adults' visual attention. The concentration and prominence of red areas indicate that older adults pay more attention to and show greater interest in these spaces. In Area A, older adults concentrated their gaze on the small landscape fountain in the centre of the plaza. In Area B, their gaze was primarily focused on the resting seats and the cobblestone ground, with some attention directed towards the sky. While in Area C, their gaze was

more dispersed, with a particular focus on the height differences in the road surface. These findings highlight how the spatial features of each area shaped both visual attention and relaxation. Specifically, Area B appeared to foster greater visual engagement and relaxation compared with Areas A and C.

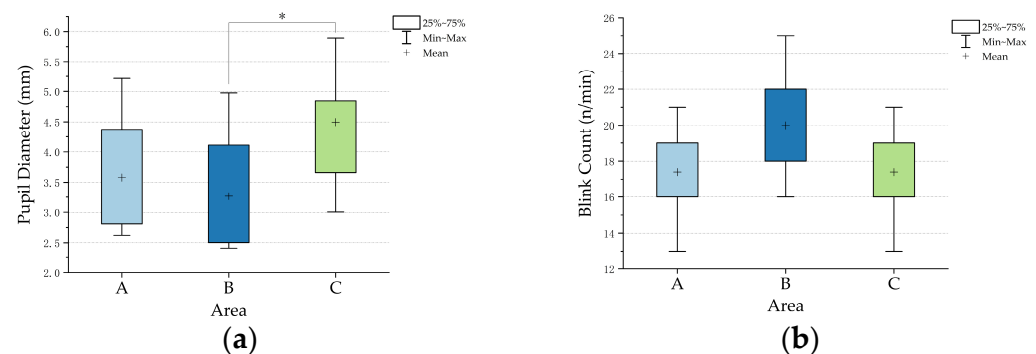


Figure 5. Indicators of older adults' visual perceptions of the three outdoor activity areas: (a) pupil diameter; (b) blink count. * $p < 0.05$.

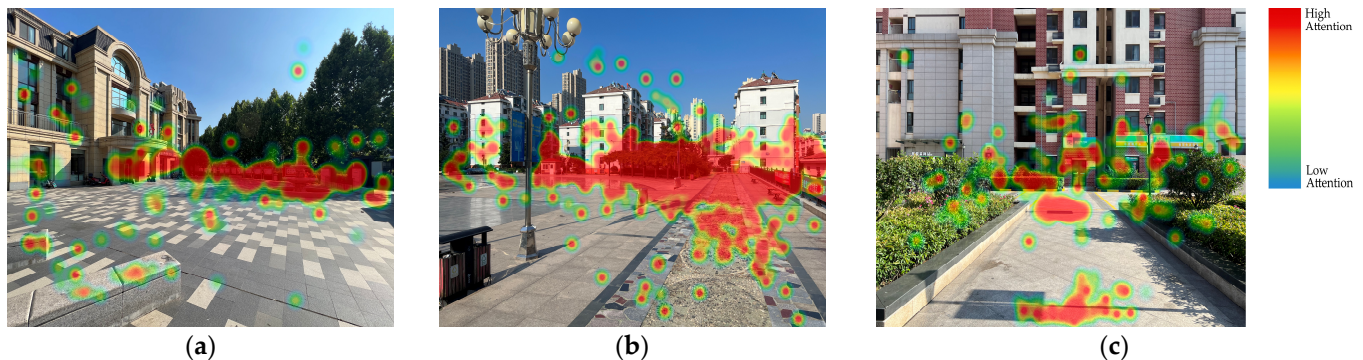


Figure 6. Gaze heatmap of older adults' visual attention: (a) Area A, (b) Area B, and (c) Area C.

3.2. Subjective Data Analysis

Older adults' subjective perceptions were assessed on the basis of their satisfaction with the items listed in Table 4. Participants rated their satisfaction using a five-point Likert scale, ranging from 1 (very dissatisfied) to 5 (very satisfied). The internal consistency of the questionnaire was evaluated using Cronbach's α coefficient, which is generally considered vital if $\alpha > 0.7$. The questionnaire demonstrated good internal consistency after each environmental exposure phase, with α values of 0.74 for Area A, 0.86 for Area B, and 0.75 for Area C.

Table 4. Pearson's correlation coefficients between older adults' overall satisfaction and their subjective assessment items.

Green Space	Rest Facility	Exercise Equipment	Sky Visibility	Shade	Spatial Enclosure	Noise	Spatial Openness	Landscape
−0.219	0.536 **	0.654 **	0.534 **	0.126	0.570 **	0.268	0.630 **	0.269

** $p < 0.01$.

As shown in Figure 7, the Kruskal–Wallis test revealed significant differences across eight items among the three areas. Bonferroni-corrected pairwise comparisons indicated the following.

- (1) Overall satisfaction and rest facilities were significantly higher in Area B than in Area C, and in Area A than in Area C.

- (2) Spatial openness, spatial enclosure, sky visibility, and noise were significantly higher in Area B than in Area C.
- (3) Exercise equipment was significantly higher in Area B than in both Area A and Area C.
- (4) Green space was significantly higher in Area C than in Area B.

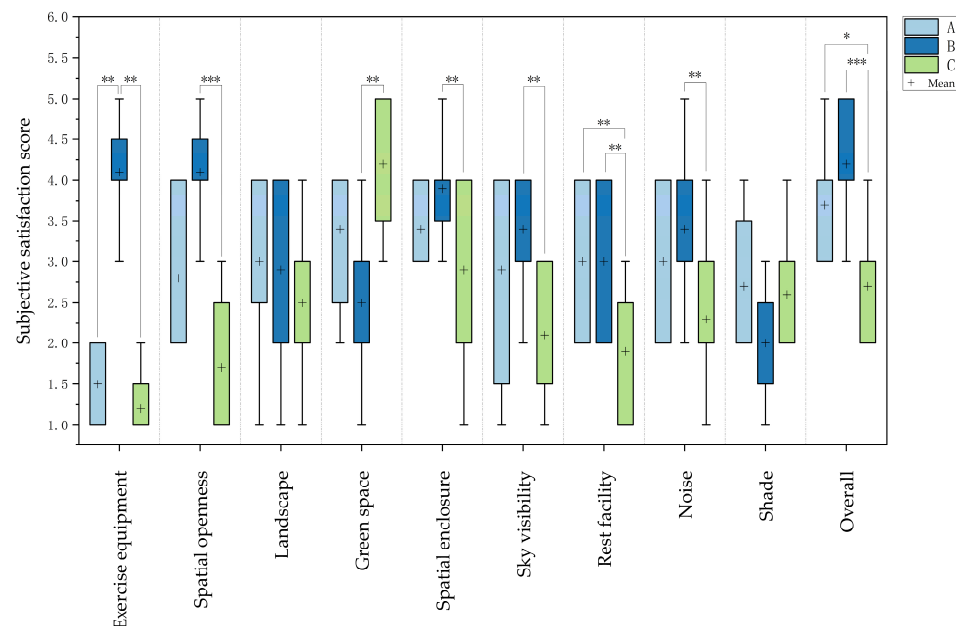


Figure 7. Older adults' subjective satisfaction with the spatial characteristics of the three areas. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

No significant differences were observed for landscape and shade among the three areas.

As shown in Table 4, Spearman's correlation analysis was conducted to identify the factors influencing overall satisfaction with outdoor activity areas for ERFs. The analysis revealed significant positive correlations ($p < 0.01$) between older adults' overall satisfactions and their assessments of rest facilities, exercise equipment, sky visibility, spatial openness, and spatial enclosure.

3.3. The Impact of ERFs' Outdoor Activity Areas on Older Adults' Spatial Perceptions

Physiological indicators were analysed alongside quantified spatial elements to further explore the relationship between older adults' emotional arousal and spatial characteristics. The physiological indicators included ΔSCL , $\Delta RMSSD$, average blink count, and average pupil diameter. The quantified spatial elements were SVF, D/H, first-floor interface enclosure, green space ratio, and site area.

As shown in Table 5, Pearson's correlation analysis revealed the following significant relationships.

- (1) SVF was positively correlated with ΔSCL and negatively correlated with $\Delta RMSSD$ and average pupil diameter.
- (2) D/H was positively correlated with ΔSCL and average blink count and negatively correlated with $\Delta RMSSD$ and average pupil diameter.
- (3) Site area was positively correlated with ΔSCL and average blink count and negatively correlated with $\Delta RMSSD$.
- (4) The rate of green space was positively correlated with $\Delta RMSSD$ and average pupil diameter and negatively correlated with ΔSCL and average blink count.

No significant correlations were found between first-floor interface enclosure and the physiological indicators.

Table 5. Pearson’s correlation coefficients between spatial characteristics and physiological indicators.

Spatial Characteristic Physiological Indicator	SVF	D/H	First-Floor Interface Enclosure	Rate of Green Space	Site Area
Δ SCL	0.449 *	0.601 ***	−0.021	−0.554 **	0.517 **
Δ RMSSD	−0.549 **	−0.639 ***	0.189	0.617 ***	−0.384 *
Average blink count	0.282	0.402 *	0.027	−0.364 *	0.386 *
Average pupil diameter	−0.499 **	−0.482 **	0.340	0.498 **	−0.094

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

To quantify the impact of spatial characteristics on older adults’ spatial perceptions, optimal scale regression analyses were conducted using physiological indicators as dependent variables and spatial characteristics as independent variables. Specifically, the dependent variables were Δ SCL and Δ RMSSD, while the independent variables were SVF and D/H.

As shown in Table 6, the results indicated that the regression model for Δ SCL was statistically significant, with an adjusted R^2 of 0.385. However, the regression model for Δ RMSSD did not show statistical significance. These findings suggest that emotional arousal levels induced by the spatial characteristics of outdoor activity areas follow the influence hierarchy: D/H > SVF.

Table 6. Optimal scale regression analysis of spatial characteristics and physiological responses.

Dependent Variable	Independent Variable	β	Standard Error	df	F	p
Δ SCL	SVF	0.204	0.341	1	0.359	0.554
	D/H	0.48	0.218	2	4.83	0.016
Δ RMSSD	SVF	−1.223	0.145	3	70.769	0.000
	D/H	0.632	0.1	3	40.075	0.000

4. Discussion

4.1. The Relationship Between Physiological Indicators and Older Adults’ Subjective Spatial Satisfaction

Objective experimental methods using physiological indicators are widely employed to examine the relationship between the environment and older adults’ spatial perceptions [56]. The experiments conducted on the three outdoor activity areas of ERFs revealed that several spatial characteristics, including SVF, D/H, site area, spatial enclosure, and the presence of functional amenities, significantly influence older adults’ spatial perceptions and satisfaction.

SCL and HRV are effective parameters for evaluating spatial perceptions [57]. The findings reveal that exposure to these outdoor areas led to varying levels of emotional arousal among older adults. Areas with high SVF, D/H, and a large site area induced greater increases in SCL, decreases in RMSSD, and smaller average pupil diameter, all of which reflect higher emotional arousal [20]. The subjective satisfaction assessments also showed higher satisfaction scores. The findings suggest that these spatial characteristics should be prioritised in the planning and design of ERFs’ outdoor activity areas. In contrast, areas with low satisfaction showed smaller changes in physiological indicators, which may indicate lower emotional arousal or the influence of exercise, requiring further investigation. It is worth noting that while Δ RMSSD is significantly correlated with spatial characteristics, its regression model is not statistically significant. This may be due to the fixed nature of the spatial characteristics in the areas studied, suggesting that greater diversity in the

spatial features should be considered in future research. Wearable sensors have proven effective in studying older adults' stress-related visual perceptions in urban spaces [58]. The results from the experiments conducted in this study suggest that areas with high spatial satisfaction promote visual relaxation and reduce stress, likely due to better landscapes and fewer vehicles, consistent with prior studies [59]. The findings below may provide deeper insights for both researchers and practitioners related to this field.

- (1) SVF: Prior research highlights the positive effects of outdoor spaces in ERFs on the health of older adults [60,61]. The experiments conducted by the authors confirmed the strong correlation between SVF and older adults' spatial satisfaction, aligning with existing findings that SVF enhances emotional health [62]. High SVF areas promote better sky visibility, emotional arousal, and higher spatial satisfaction. The comparison between Area A and Area B—with a similar SVF—revealed that the tall trees in Area A reduced the sky visibility benefits, affecting older adults' spatial perceptions. For Area C, the high-rise buildings on both the north and south sides exert a significant blocking effect on sky visibility, thereby diminishing the satisfaction of older adults' spatial perceptions.
- (2) D/H: Higher D/H ratios significantly improved older adults' emotional arousal and satisfaction. Area B, with a D/H ratio reflecting surrounding buildings of 15–20 m, was rated as the most open and satisfying by older adults, consistent with prior research [18,63]. Conversely, Area C's taller buildings diminished spatial openness, leading to lower emotional arousal and increased feelings of enclosure. Area A is situated at a road intersection, with the site positioned near the buildings' interface. Due to the proximity of the more open side of the space to the urban road, older adults often gravitate toward the side near the building for safety. This behaviour may reduce the perceived spatial openness and lower satisfaction levels among older adults.
- (3) Site area and interaction effects: Site area is also positively correlated with emotional arousal. However, the interaction among site area, SVF, and D/H likely moderates this effect, warranting further exploration. For instance, spatial enclosure—a factor previously shown to enhance perceptions [19,63]—had no significant physiological effects in this study. Area B had a higher D/H ratio and a lower first-floor interface enclosure compared with Area C, indicating that it was more open than Area C. From the perspective of spatial enclosure satisfaction, Area B was higher than Area C, which indicated that a certain degree of spatial enclosure could improve older adults' satisfaction. If the degree were too high, it would cause a sense of oppression [64]. The dense enclosure of Area C, with a prominent first-floor interface, may have overshadowed its benefits. Although Area A had the lowest first-floor interface enclosure, older adults thought that the tall trees surrounding the area blocked their visual connection to the urban roads, and this may contribute to an increased sense of spatial enclosure.
- (4) Facilities and green space: Outdoor features such as rest facilities and exercise equipment significantly enhanced spatial perceptions, aligning with prior research on the appeal of functional amenities like benches, fitness areas, and anti-slip measures [65,66]. Gaze heatmaps showed that older adults were visually drawn to the cobblestone paths, seating, and exercise equipment in Area B, which provided the most visual relaxation. Conversely, Area C's uneven surfaces posed obstacles, echoing earlier findings [67]. Interestingly, the relationship between green space and spatial satisfaction was non-linear [68]. Although Area C had the highest green space rate and total green space area, it received the lowest subjective overall satisfaction scores, which may explain the negative correlation between green space and emotional arousal. Interviews revealed that the integration of greenery with walking

paths for older adults, as well as the types of tree species, had a notable impact on their satisfaction. This suggests that green space's effectiveness depends not only on its quantity but also on its quality.

4.2. Potential Applications of Spatial Characteristics in Designing ERFs

Creating supportive environments in outdoor activity areas for ERFs is crucial for older adults. The physiological measurement approach used in this study provides an objective reflection of older adults' spatial perceptions, reducing the subjectivity bias of self-reported surveys and field observations. This method enables designers and policymakers to evaluate whether the outdoor activity areas meet older adults' preferences and identify places needing improvement. The potential applications of spatial characteristics are summarised below.

- (1) **Site selection:** The Chinese government is currently engaged in comprehensive planning for ERFs. This study offers guidance on site selection and age-friendly renovations. Key spatial characteristics such as SVF, D/H, and the height of surrounding buildings should be prioritised. SVF significantly influences emotional arousal, emphasising the importance of sky visibility for perceived satisfaction. When the site's SVF is low, the obstructive effects of tall trees on sky visibility should be minimised. Conversely, when SVF is high, the shading effects of vegetation and facilities should be carefully balanced. Similarly, D/H affects emotional arousal, with open spaces enhancing satisfaction. When D/H is low, it is important to avoid overly tall surrounding buildings. However, when D/H is high, incorporating a certain degree of enclosure should be considered.
- (2) **Site design:** The spatial layout and facility configuration of outdoor activity areas are crucial in making ERFs age-friendly. When designing these areas, improvements can be identified using physiological data such as SCL and RMSSD, which can also be used to verify the effectiveness of the transformations. In cases where older adults' emotional arousal and spatial satisfaction are low, the positive effects of spatial openness and sky visibility on emotional arousal can be enhanced by adjusting the spatial layout, facility configuration, and greening elements of the area. Essential features such as rest facilities and exercise equipment can enhance older adults' satisfaction with these spaces, promote healthy ageing, and support the maintenance and recovery of physical functions [67,69]. Incorporating accessible facilities further ensures a safe and comfortable walking environment, reducing physical strain on older adults. The arrangement of green plants should also be carefully considered, with attention to their quality and quantity, to maximise their health benefits. Furthermore, the spatial scale and characteristics of these areas should be evaluated comprehensively to ensure the design accommodates varying population densities and enhances usability [70].
- (3) **Transition between indoor and outdoor spaces:** Strengthening the visual connection between the lobbies and outdoor activity areas of ERFs is crucial. Facade colours and landmark designs of the surrounding buildings significantly impact older adults' visual perceptions and should be optimised to enhance spatial satisfaction. Additionally, the proximity to surrounding roads is critical. Outdoor activity areas within communities foster a sense of security and encourage participation. In contrast, interviews revealed that areas near urban roads may cause stress and expose older adults to noise and air pollution. While weather conditions limited the ability to quantify the impact of noise on older adults' spatial perceptions, the participants generally reported that the noise level in Area B, located within the community, was low, and it received high satisfaction scores related to noise.

4.3. Limitations and Future Research Directions

This study has several limitations that are worth further investigation, primarily due to resource and time constraints during the experiment.

First, it is important to acknowledge that the sample size was small due to challenges in recruiting older adults who were willing to participate. Even though previous studies on similar topics have also used small sample sizes, this limitation may affect the generalisability of the results. Additionally, the health of the experimental participants was relatively good, and due to the limitations of the current experimental equipment, the results may not fully represent the spatial perceptions of the broader older adult population. Future research should consider increasing both the diversity and the number of participants, including those with varying health conditions and age groups, to enhance the robustness and generalisability of the findings.

Second, to minimise the effects of daily fluctuations in circadian rhythms, efforts were made to maintain consistent weather conditions (e.g., temperature, wind speed, and humidity) by scheduling all sessions in the afternoon over three days. This scheduling inadvertently limited the study's ability to explore the effects of shade and noise on older adults' spatial perceptions, as well as the applicability of the findings across different weather conditions and seasons. Although no significant changes in weather were observed during the experiment, the influence of weather conditions on the data cannot be entirely ruled out. Future research should evaluate these characteristics at various times of the day, incorporate the impact of seasonal factors on spatial perceptions, and analyse the dynamic influence of spatial characteristics on older adults' perceptions under the combined effects of time and weather conditions.

Third, the three areas selected for this study cannot fully represent the diverse range of outdoor activity areas for ERFs. Future research should consider classifying these areas into distinct categories to enhance the generalisability of the findings. To more objectively quantify the relationship between spatial characteristics and older adults' spatial perceptions, and to minimise the influence of subjective factors, the selected participants had lived in the area for an extended period, shared the same regional lifestyle and culture, and were relatively healthy. In addition, socio-cultural and psychological factors may mediate the relationship between spatial characteristics and older adults' spatial perceptions [71]. Since the main goal of the study was to quantify the direct impact of spatial characteristics on spatial perception satisfaction, the questionnaire did not fully address the moderating effects of factors such as education level, economic status, and familiarity with the areas. Future research should consider the impact of community belonging and cultural background on spatial perceptions.

5. Conclusions

Through experiments conducted in three types of outdoor activity spaces and the integration of older adults' physiological responses with subjective satisfaction assessments, this study established correlations between older adults' spatial perceptions and the attributes of outdoor activity areas, shedding light on how different spatial characteristics influence their satisfaction. The findings highlight that while all three outdoor activity areas of ERFs positively impact older adults' health, the magnitude of these benefits depends on specific spatial characteristics.

Well-designed spatial characteristics of outdoor activity areas can address older adults' physiological and psychological needs, helping to maintain their physical functions by encouraging participation in social activities and physical exercise, and creating a supportive outdoor environment. Areas with high subjective satisfaction were associated with stronger emotional arousal and enhanced visual comfort. Notably, spaces offering favourable sky

view factors and greater spatial openness contributed to increased emotional arousal, visual relaxation, and higher spatial perception satisfaction. Key elements such as the height of surrounding buildings, the availability of rest facilities, exercise equipment, barrier-free facilities, and the quality of green spaces were identified as significant factors influencing older adults' spatial perceptions. Efforts were made to maintain consistent weather conditions during the experiment, but only the short-term effects of spatial characteristics on older adults' spatial perceptions were examined. Future studies should extend the duration of the experiment to assess the long-term effects.

For site selection of ERFs, priority should be given to locations with high sky visibility, open spaces, and distances from urban roads, while avoiding the negative impacts of surrounding tall buildings on older adults' spatial perceptions. In terms of age-friendly renovations for outdoor activity areas in ERFs, the focus should be on aligning the spatial layout of key elements with older adults' behavioural characteristics, while also prioritising the quality of green space. This study provides valuable insights for planners and designers, offering guidance on optimising the spatial characteristics of outdoor activity areas for ERFs.

Author Contributions: Conceptualisation, G.F., L.X. and L.L.; methodology, G.F. and L.X.; validation, G.F. and Y.G.; formal analysis, G.F., Y.G. and L.L.; investigation, G.F. and Y.G.; resources, L.X. and G.F.; data curation, L.X.; writing—original draft preparation, G.F. and Y.G.; writing—review and editing, G.F., L.X., L.L. and Y.G.; visualisation, Y.G.; supervision, G.F. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the Natural Science Foundation of Xiamen, China (grant number: 3502ZZ20227025), and the Urban Renewal and Rural Revitalization Innovation Team, College of Civil Engineering and Architecture, Shandong University of Science and Technology.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of the College of Civil Engineering and Architecture, Shandong University of Science and Technology (date of approval: 22 June 2024).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors upon request.

Acknowledgments: The authors would like to thank the Urban Renewal and Rural Revitalization Innovation Team, College of Civil Engineering and Architecture, Shandong University of Science and Technology.

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

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