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Community Environment-Health Pathways from a Behavioural Perspective: A Study of Preschool Visual Acuity Using Digital Environmental Representation

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Abstract

Health and wellbeing form a core dimension of urban resilience. Addressing this dimension requires attention to the everyday environments that support healthy living. To explore how daily activity may connect community environments with health, this study uses preschool visual acuity as a specific health outcome. A cross-sectional analysis examined environment-activity-visual acuity associations among 195 children aged 3–6 years in Shanghai. Path analysis used a structured digital representation comprising 13 parent-perceived indicators and five mapped measures in the contextual model. The clearest pattern centred on perceived greenery, which was consistently associated with longer outdoor duration in the primary and contextual models. Both associations met the pointwise and hypothesis-specific Holm criteria, although neither met the main analysis-based criterion. Other environmental attributes showed weaker, activity-specific associations. Outdoor-acuity and corresponding greenery-outdoor activity-visual acuity indirect estimates were positive, but their confidence intervals included zero, and neither met the Holm-adjusted criterion. The findings suggest outdoor activity as a potential behavioural link between perceived neighbourhood greenery and reported visual acuity. The digital representation brings parental assessments and physical conditions into a common framework for examining how community environments relate to activity and health. This approach can inform the health and wellbeing priorities of urban resilience planning and their application in child-friendly communities.

Keywords: urban resilience; outdoor activity; community environment; perceived environment; visual acuity; digital environmental assessment

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1. Introduction

Protecting residents' health and wellbeing is a core concern of urban resilience. The City Resilience Framework 2024 recognises health and wellbeing as one of its four dimensions [1]. The World Health Organization (WHO) likewise identifies urban health as essential to resilience, and advocates coordinated action across sectors [2]. This perspective brings the health-supporting role of environments into urban resilience research.

Understanding this role requires examining how environmental conditions support daily activities and how these activities relate to health. Residents encounter and use

community environments through daily activities. The updated resilience framework highlights neighbourhood design as a means of keeping residents active [1]. Activity reflects both the opportunities that local spaces offer and residents' decisions about whether and how to use them. These activity patterns also have relevance to health and wellbeing, particularly through physical activity. For example, a meta-analysis of prospective studies linked higher physical activity to a lower risk of depression in adults [3]. This behavioural perspective provides a basis for examining environment-activity-health relationships.

Children's visual health provides a specific case for examining these environment-activity-health relationships. Young children's outdoor activity depends partly on nearby community spaces and parental decisions about their use [4–6]. Outdoor activity also warrants attention for its potential role in preventing myopia, an important concern for children's visual health [7]. A global synthesis estimated a pooled myopia prevalence of 35.8% among children and adolescents aged 5–19 years for 2020–2023 [8]. This health burden has prompted research into modifiable behaviours in children's daily lives. Time spent outdoors is an important measure of outdoor exposure in myopia prevention research [7]. Randomised trials in primary-school children show that increasing outdoor time during the school day can reduce myopia incidence over subsequent years [7,9]. These findings support examining outdoor activity as a potential link between community environments and children's visual health.

The preschool years offer a complementary perspective in terms of age and activity context. Neighbourhood public open spaces and community greenspace provide important opportunities for young children's outdoor play and exploration [10]. Longitudinal evidence links greater outdoor time from age three onwards to a lower risk of incident myopia between ages 10 and 15 [11]. Research has also examined residential environments in relation to preschool visual outcomes [12]. Examining children's current community environments, daily activities and visual health indicators before school entry can therefore complement the contexts covered by school interventions and early-exposure studies. This study accordingly focuses on preschool children to examine environment-activity-health associations at this stage.

Existing research includes separate strands on the environmental correlates of children's health and activity [12–14]. Studies of environment-health associations use objective measures such as greenness and building density to identify environmental features associated with children's visual outcomes [12,13]. For example, lower building density around schools remained associated with lower odds of screening-defined myopia [13]. These associations help identify spatial conditions that warrant attention. However, environment-vision associations alone may obscure the role of activity in preschool children's interactions with community environments, limiting interpretation. There is therefore a need to include activity in the same analytical framework to examine indirect associations between the environment and visual health.

Research on environment-activity relationships has also examined objectively measured neighbourhood features. For example, greater neighbourhood greenness, measured using satellite imagery, was associated with more parent-reported outdoor play time among preschool children [14]. These measures describe the physical setting in which outdoor activity takes place. Meanwhile, parental assessments of safety, accessibility and comfort complement this information by reflecting families' experiences of using that setting [4,5]. Parent-perceived neighbourhood activity opportunities were positively associated with preschool physical activity when parents also perceived neighbourhood safety favourably [5]. This finding indicates that the provision of space needs to be interpreted alongside parental judgements. These perceptions can be represented as structured survey indicators alongside digitally mapped physical conditions. Together, the two sets of indicators provide

complementary components of a digital representation of the neighbourhood environment. This representation allows families' assessments and physical conditions to be examined in relation to children's activities and health.

Although community environments are closely linked to outdoor activity, indoor behaviours, especially screen use, also warrant significant consideration when examining visual health. Previous studies suggest that outdoor time and screen time may mediate the association between greenness and children's visual health [12,15]. The analytical framework should therefore include both behaviours. It can also test the indirect pathway through each behaviour.

This study examines the health relevance of community environments through associations among environmental conditions, daily activities and preschool children's parent-reported visual acuity. This outcome describes visual performance rather than refractive status or hyperopic reserve. The study integrates parental ratings and mapped physical conditions within a digital environmental representation. The study addresses three questions:

(1) Which parent-perceived and mapped environmental indicators are associated with children's outdoor-duration and recreational screen-time scores?
(2) Are outdoor-duration and recreational screen-time scores each associated with children's reported visual acuity?
(3) Are environmental features indirectly associated with reported visual acuity through either behaviour?

To address these questions, the study applies path analysis to exploratory cross-sectional data from 195 children aged 3–6 years in Shanghai. The primary model includes 13 parent-perceived environmental indicators, outdoor-duration and recreational screen-time scores, and parent-reported recent visual acuity. An extended model adds five mapped environmental indicators to characterise the subdistrict or town context. Both models adjust for child and family characteristics and estimate direct and indirect associations. The study contributes a behavioural perspective to digital environmental assessment by examining activity as a potential link between community environments and health. This focus on everyday environment-health associations provides evidence relevant to the health and wellbeing dimension of urban resilience.

2. Literature Review and Hypothesis Development

This chapter first situates community health within urban resilience, then reviews evidence guiding the environmental indicators, behaviours, and visual outcomes. It also considers child and family factors that inform covariate selection. This evidence supports seven hypotheses about environment-activity-visual acuity associations.

2.1. Health and Wellbeing in Urban Resilience

Community environments support urban resilience by providing spaces and resources that help communities cope with acute shocks and chronic stresses [1,16]. Beyond maintaining infrastructure and services, urban resilience also concerns protecting residents' health. The City Resilience Framework reflects this broader scope by recognising health and wellbeing as one of its four dimensions [1]. This dimension warrants particular attention as urban development and changing lifestyles reshape everyday health risks. Car-dependent development, limited space for active living, and sedentary routines can contribute to persistent health burdens [17]. Addressing these pressures requires attention to the environments in which daily life takes place. WHO identifies urban planning and design as tools for reducing vulnerability and protecting health through local resilience strategies [18].

Supporting daily activity is one way in which community environments can contribute to this health dimension. Walkable streets and green spaces can support health through

activity and social interaction [16]. Recognising these health-supporting functions, Manafa et al. [19] included green spaces and activity facilities in their assessment of neighbourhood resilience. Research during Shanghai's COVID-19 lockdown linked outdoor activity to more favourable perceptions of health and community liveability, which were also associated with subjective wellbeing [20]. These studies provide a basis for examining environment-activity-health relationships within the health and wellbeing dimension of urban resilience.

2.2. Perceived Built Environment and Children's Behaviours

Parental perceptions may help explain how community environments relate to children's outdoor activity and screen use. This study proposes that more favourable perceived built-environment conditions are associated with longer outdoor duration (H1) and less recreational screen time (H2).

Parents shape young children's outdoor opportunities through supervision, daily routines and judgements about local spaces [4,21]. Perceived environmental measures capture judgements about safety, greenery, access and comfort. The Neighbourhood Environment Walkability Scale for Youth (NEWS-Y) provides established domains for examining activity-related neighbourhood conditions [22]. These domains inform questionnaire design, but their adaptation for parents of preschool children requires attention to age-specific activities and supervision [5].

Green spaces and playgrounds provide settings for outdoor play, social interaction and contact with nature. Reviews identify access to nearby outdoor spaces and their physical characteristics as relevant correlates of children's play [4,23]. Natural features can support varied play, while equipment and layout influence how children use a space [24–26]. Facility counts alone provide limited information about these qualities.

Walkability and perceived safety are established dimensions of neighbourhood assessment [27]. Pavements, crossings and separation from vehicles may support accompanied trips. Traffic and personal-safety concerns can discourage parents from using otherwise accessible destinations [28,29]. Thermal conditions also shape the experience of outdoor space. Shade and protection from wind are relevant to play-space design in climates with hot summers and cold winters [30,31].

Perceived neighbourhood conditions may also relate to children's screen use. Carson et al. [21] examined these associations among Canadian primary-school children. Children whose parents rated neighbourhood services, parks and pavements more favourably were more likely to have parent-reported screen time of two hours or less per day. Preschool evidence further indicates that these associations depend on parenting practices. Among children in Hong Kong and Houston, greater perceived neighbourhood disorder was associated with more weekend screen time when parents restricted activity for safety reasons [5]. These findings motivate H2 while indicating that associations may depend on specific neighbourhood conditions and parenting practices.

2.3. Physical Built Environment and Outdoor Activity

Geospatial measures describe the physical provision of neighbourhood environments independently of parents' ratings. Relevant measures include building density, street and path density, potential activity-facility density, vegetation cover, the normalised difference vegetation index (NDVI), and park-area share. These measures describe the balance between built form, routes, destinations and vegetation. They motivate H3, which proposes an association between the set of physical built-environment conditions and children's outdoor duration.

Building density captures the concentration of built form at ground level. Compact development can shorten distances to destinations, but it can also reduce open space and

coincide with heavier traffic. Reviews accordingly report context-dependent relationships between urban density and children's outdoor play or health [23,32]. Building density therefore warrants separate consideration without assuming a uniformly favourable or adverse association.

Street and path density represents the route network through which families reach and use neighbourhood spaces. A connected pedestrian network can improve access, whereas heavy traffic and unsafe crossings can restrict young children's outdoor play. Reviews identify engaging routes, pedestrian conditions and traffic protection as central components of neighbourhood playability [4,23]. Road provision therefore needs to be interpreted together with route quality and traffic conditions.

Potential activity-facility density describes mapped destinations such as playgrounds and sports facilities. Nearby formal and informal play spaces can support outdoor activity, although access and design influence whether children use them [4,23,33]. A natural experiment also found that upgrading childcare outdoor spaces increased preschool physical activity [34]. Facility provision therefore describes opportunity, while the quality and usability of each destination remain important.

Vegetation cover describes the proportion of vegetated land, while NDVI reflects spectral greenness. Park-area share provides a separate measure of potential park provision. Natural settings provide space and varied features for outdoor activity. Reviews associate neighbourhood greenness with more outdoor play [4,23]. Higher satellite-derived NDVI has also been associated with more outdoor play among preschool children [14]. An analysis of high-resolution PLAYCE data further linked larger yards and greater tree and shrub cover to more outdoor play among preschool children [35]. Mapped green area thus provides a physical counterpart to parents' perceptions of neighbourhood greenery.

2.4. Behavioural Pathways to Preschool Visual Health

Outdoor duration and recreational screen time provide distinct behavioural links to visual health and underpin H4 and H5. For outdoor duration, a Cochrane review of trials in primary-school children suggests that sustained increases in outdoor time may reduce myopia onset [36]. Outdoor light is a proposed biological mechanism, although reported time outdoors does not directly measure light exposure [37]. Outdoor duration therefore represents time spent outside rather than the intensity of physical activity.

Screen use provides another potential behavioural link to visual health. An earlier systematic review found mixed evidence for associations between screen time and myopia [38]. A more recent dose-response meta-analysis associated more digital screen time with higher odds of myopia across several age groups, including young children [39]. The two behaviours require separate consideration because more outdoor time does not necessarily imply less screen time. Screen time also differs from near work, which includes non-screen tasks performed at short viewing distances, such as reading, writing and drawing [40].

The evidence reviewed above mainly concerns myopia and refractive development. Unaided distance visual acuity offers a complementary measure of current visual performance in preschool children, but does not independently diagnose myopia or quantify hyperopic reserve. Paediatric guidance recommends regular monitoring of visual acuity alongside refractive status during early childhood [41], providing a rationale for using recent examination records in surveys. H4 and H5 examine whether the behavioural associations suggested by previous research extend to reported visual acuity.

2.5. Individual and Family Factors

Individual and family factors can shape both daily behaviour and visual development. Age and sex may coincide with differences in activity patterns and visual maturation,

parental myopia indicates familial susceptibility, and socioeconomic conditions influence children's opportunities and routines. These factors therefore provide essential context for interpreting environment-activity-vision associations.

Age is especially important during early childhood, when visual acuity, refractive development, mobility and reliance on caregivers change rapidly. Screening studies in Shanghai document age-related variation in visual status and refractive development [42,43]. Children of different ages may also use neighbourhood spaces differently as their mobility, routines and dependence on caregivers change [4,44]. Age can therefore account for variation in both activity and visual outcomes.

Inherited susceptibility contributes to myopia alongside environmental and behavioural exposures [40,45]. Parental myopia provides an accessible indicator of familial myopic risk, although it can also reflect shared environments and habits. This familial context is important when interpreting associations between neighbourhood conditions and children's visual outcomes.

Family socioeconomic context may also shape both daily behaviours and environmental exposure. Research with toddlers links parental and home characteristics to screen time [46], while school-age evidence relates socioeconomic conditions and green-space exposure to myopia [47]. Household income and parental education therefore help describe the family circumstances within which neighbourhood conditions are perceived and used.

2.6. Hypothesis Development and Analytical Framework

The evidence above supports seven hypotheses within the environment-activity-vision framework (Figure 1). H1–H3 concern environmental associations with activity, whereas H4 and H5 concern activity-vision associations. Combining these paths yields the indirect associations in H6 and H7. Outdoor duration and recreational screen time form parallel pathways, allowing the framework to distinguish the contribution of each behaviour.

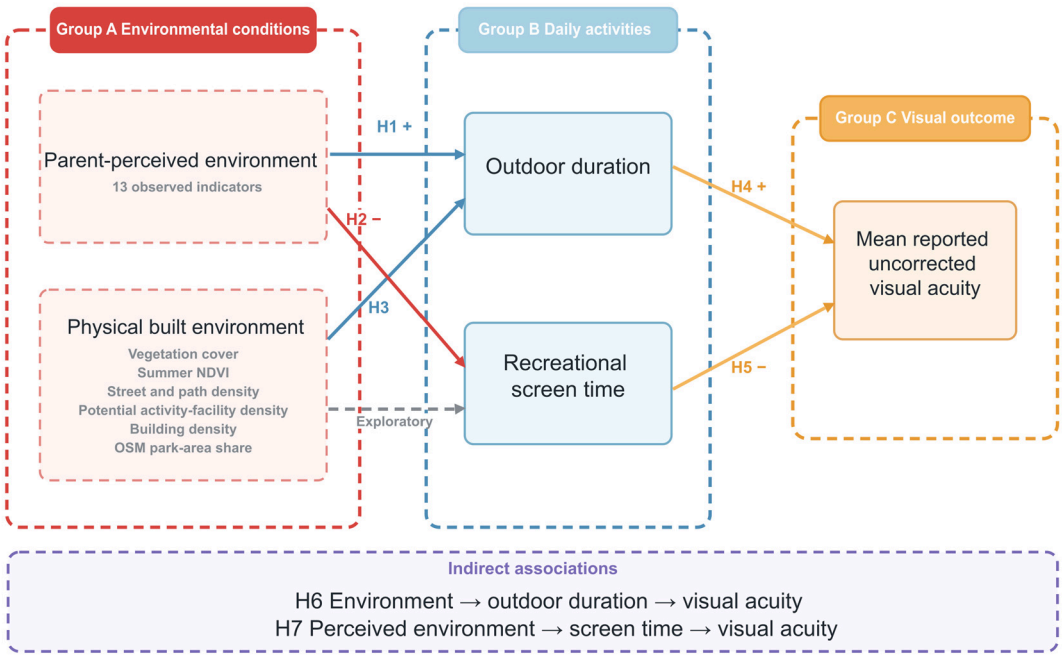


Figure 1. Literature-informed environment-activity-vision framework. Arrows indicate hypothesised associations. H6 and H7 are indirect associations.

The hypotheses concern observed environmental conditions, reported daily activities, and mean parent-reported uncorrected visual acuity. Higher scores on the Chinese five-point logarithmic acuity scale indicate better acuity. Because the proposed relationships are

assessed cross-sectionally, H6 and H7 refer to indirect statistical associations rather than causal mediation.

H1. *More favourable perceived built-environment conditions are associated with longer reported outdoor duration.*

H2. *More favourable perceived built-environment conditions are associated with less reported recreational screen time.*

H3. *Physical built-environment conditions are associated with reported outdoor duration.*

H4. *Longer reported outdoor duration is associated with higher mean uncorrected visual acuity.*

H5. *More reported recreational screen time is associated with lower mean uncorrected visual acuity.*

H6. *Perceived and physical built-environment conditions are indirectly associated with mean uncorrected visual acuity through outdoor duration.*

H7. *Perceived built-environment conditions are indirectly associated with mean uncorrected visual acuity through recreational screen time.*

3. Materials and Methods

3.1. Study Design and Participant Profile

A cross-sectional online survey examined associations between neighbourhood environmental conditions and preschool children's outdoor duration, recreational screen time and mean reported acuity in Shanghai, China. Parents of children aged 3 to 6 years who permanently resided in Shanghai were recruited online by convenience sampling. The dataset comprised 242 responses collected from 9 to 18 March 2026. Each family reported on one eligible child. The information sheet explained the study purpose, voluntary participation, and aggregate reporting of results. Parents indicated consent by proceeding with the questionnaire.

The survey recorded residential location at the district and subdistrict or town levels. Four respondents reported acuity values despite indicating no previous visual examination. Excluding these records left 238 children. Restriction to examinations within 12 months retained 204 children. Requiring both reported eye values to fall within 4.0–5.3 yielded the main sample of 195 children across 90 administrative units. Both the primary and contextual models used this sample, with complete data for all required predictors. Descriptive analyses retained all 242 respondents.

3.2. Structured Digital Representation of the Community Environment

The structured digital representation comprised two components: 13 questionnaire-based parental ratings and five indicators derived from open spatial data. The primary model used the parental ratings, and the contextual model added five mapped indicators. Each indicator retained its own definition and entered the models as a separate predictor.

3.2.1. Parent-Reported Environmental Indicators

The study-specific questionnaire assessed neighbourhood conditions relevant to children's outdoor activities, with domains informed by the Neighborhood Environment Walkability Scale for Youth (NEWS-Y) [22]. Thirteen items covered seven content domains (Table 1). All 13 items entered each equation in the primary model as separate predictors. The domain groupings were used for interpretation and supplementary joint tests. Specific

indicators represented safety and suitability, with overall safety reserved for a sensitivity check. Q39 provided a common pollution item across respondents; conditional follow-up questions identified particular sources. Supplementary File S1 provides the questionnaire and informed-consent information.

Table 1. Parent-reported environmental indicators in the primary model.

Content Domain	Item	Indicator	Higher Scores Indicate	VIF (Activity/Acuity)
Walking and traffic space	Q37.3	Perceived pedestrian crossing and sidewalk continuity	Easier crossing and more continuous sidewalks	1.80/1.90
Walking and traffic space	Q37.6	Perceived vehicle-pedestrian separation	Better separation	1.89/1.95
Greenery	Q37.4	Perceived neighbourhood greenery	More abundant greenery	1.64/1.75
Play space	Q37.5	Perceived sufficiency of children's play spaces	More adequate provision	1.66/1.67
Seasonal comfort	Q37.7	Perceived adequacy of summer shade	More adequate shade	1.50/1.54
Seasonal comfort	Q37.8	Perceived winter wind comfort	More comfortable wind conditions	1.51/1.54
Safety	Q32.2	Perceived traffic safety	Greater safety	1.46/1.48
Safety	Q32.3	Perceived facility and activity-site safety	Greater safety	1.48/1.49
Safety	Q32.4	Perceived personal security	Greater security	1.40/1.40
Walking access	Q38	Reported walking time to the nearest park or playground	Shorter reported walking time	1.39/1.45
Pollution and disturbance	Q39	Perceived air-pollution sources	Less apparent pollution from nearby sources	2.78/2.97
Pollution and disturbance	Q41	Perceived disturbing night lighting	Less disturbance	2.31/2.33
Pollution and disturbance	Q43	Perceived quietness	Greater quietness	2.64/2.65

Note: VIF = variance inflation factor. The first value applies to both activity equations, which have the same predictors. The second applies to the acuity equation, which also includes both activity scores.

Variance inflation factors (VIFs) were calculated for all predictors in each equation. In the primary model, VIFs ranged from 1.19 to 2.78 in both activity equations and from 1.23 to 2.97 in the acuity equation. Table 1 reports the values for the 13 perceived environmental items. The Pearson correlation between traffic safety and crossing/pavement continuity was 0.328. Complete VIFs, including covariates, are reported in Supplementary File S2 (Table S3B).

Environmental items were scored from 1 to 5. Q37 responses ranged from strongly disagree to strongly agree, and Q32 responses from very unsafe to very safe. Walking time (Q38) was recorded as <5, 5–10, 10–15, 15–20, or >20 min and reverse-coded as 6 minus the original category code. For Q39, scores 1–5 represented multiple obvious sources

causing discomfort, one or two fixed sources, occasional non-persistent pollution, very few visible sources, and no visible sources with fresh air. The corresponding Q41 categories were multiple glaring sources, obvious advertising screens or excessive lighting, lighting without major disturbance, soft lighting with little disturbance, and no disturbing sources. Q43 categories were severe noise affecting daily life, frequent obvious noise, continuous non-harsh background noise, occasional slight noise, and almost no noise. Higher scores therefore indicated more favourable reported conditions for all 13 indicators.

3.2.2. Mapped Environmental Indicators

The mapped indicators described the administrative context at the subdistrict or town level, the finest residential spatial resolution available in the survey. Children assigned to the same administrative unit shared the same mapped indicator values. Reported district and subdistrict or town names were matched to OpenStreetMap (OSM) administrative polygons [48], with Gumeilu and Gumei in Minhang District treated as the same unit. The 242 responses matched 103 administrative units. The main sample represented 90 of these units. Supplementary File S2 provides administrative-unit areas (Table S9).

Six candidate mapped indicators were assessed for collinearity. When vegetation cover and NDVI entered together, their VIFs ranged from 16.17 to 18.14 across the three equations. Their Pearson correlation was 0.943 across the 195 child records, matching the model weighting, and 0.958 across the 90 equally weighted units. To reduce this overlap, the contextual model retained vegetation cover, a direct measure of vegetated land-area share, and omitted NDVI. Table 2 identifies the five retained indicators and reports their VIFs.

Table 2. Definition and processing of mapped environmental indicators.

Indicator	Calculation and Transformation	VIF (Activity/Acuity)	Contextual Model
Vegetation cover share	ESA WorldCover 2021 v200 classes 10, 20, 30, 40, 90, 95 and 100 [49]. Classified vegetation area/total administrative area; z-standardisation. Includes cropland and wetland vegetation.	2.44/2.54	Retained
Summer NDVI	Selected Sentinel-2 Level-2A observations, June–August 2025 [50]. NDVI = (NIR − red)/(NIR + red). Clear-land pixel-median composite, then unit mean; z-standardisation.	16.17/16.51 *	Supplementary only
Street and path density	Eligible OSM route length/total administrative area (km/km^2); ln(1 + density), then z-standardisation.	4.94/4.97	Retained
Potential activity-facility density	Eligible mapped playground and sports feature count/total administrative area (features/km^2); ln(1 + density), then z-standardisation.	2.13/2.17	Retained
Building density	Union area of valid OSM building footprints/total administrative area; z-standardisation.	3.65/3.73	Retained
OSM park-area share	Union area of all valid leisure = park polygons/total administrative area; z-standardisation. Uses unbuffered polygon areas across all access categories to represent potential park supply.	1.51/1.52	Retained

Note: VIFs are reported for the five-indicator contextual model, except NDVI (*), whose values come from the joint six-indicator specification. Activity VIFs are identical for the outdoor and screen equations. Complete equation-specific values for all models appear in Supplementary File S2 (Table S3B).

Vegetation cover uses ESA WorldCover 2021 v200, whereas NDVI uses selected cloud-screened Sentinel-2 Level-2A observations from June-August 2025. These sources precede the March 2026 survey by different intervals. OSM data came from the archived snapshot of 11 March 2026 [48]. Vegetation area was divided by the total administrative area, including water. All 220 mapped units had complete WorldCover classification coverage. Park-area calculations retained polygons of all sizes. Facility counts covered playground and sports features, with parks represented separately by area share. Facility and route measures excluded recorded private or prohibited access. The mapped indicators describe land cover and potential resource provision; public access, maintenance, safety and preschool suitability require site-level assessment. Supplementary File S2 lists the OSM tags and processing rules (Table S8).

The z-standardisation used the means and sample standard deviations across the 195 children, thereby weighting each administrative unit in proportion to its number of sampled children. Sensitivity analyses retained these main-sample transformation constants. The contextual model entered five mapped indicators, excluding NDVI, into each equation alongside the 13 parent-reported indicators and the same covariates. The visual-acuity equation also included both activity scores. VIFs ranged from 1.23 to 4.94 in both contextual activity equations and from 1.28 to 4.97 in the acuity equation. The NDVI alternative and the joint specification were retained as supplementary comparisons.

3.3. Activity, Visual Acuity and Covariates

3.3.1. Activity Scores and Visual Acuity

Parents reported daily activities. Outdoor duration (Q21) covered the cumulative daily time spent in outdoor play, exercise and leisure. The response labels were <30, 30–60, 60–90, 90–120, 120–180 and >180 min. Recreational screen time (Q26) covered daily screen use for entertainment, with response labels of almost never, <30, 30–60, 60–90, 90–120 and >120 min. Both variables were coded from 1 to 6 in ascending order of the response categories and entered as parallel activity scores. The linear models treated successive score categories as equally spaced, while the underlying time intervals varied in width. Alternative ordinal-outcome and categorical-predictor specifications were examined in the sensitivity analyses (Section 3.5.1).

Mean reported acuity was the mean of the parent-reported left- and right-eye uncorrected visual acuity values from the most recent examination (Q18), rounded to two decimal places. Acuity was recorded on the five-point notation of the Chinese logarithmic visual-acuity scale, with higher values indicating better reported acuity. The questionnaire included a recording-scale guide (Supplementary File S1, Q18). Its stated range of 4.0–5.3 corresponds to the standard distance chart's direct measurement range [51]. Assessment of myopia and hyperopic reserve requires refractive measurements. Examination timing (Q17) and daily activity reports could refer to different periods. A 0.1-unit change corresponds to one chart line. Unstandardised activity coefficients and indirect estimates are also expressed in chart lines to show their measurement-scale magnitude.

3.3.2. Covariates

All three regression equations included six covariate terms: child age, child sex, two indicators of parental myopia, annual household income, and mean parental education score (Table 3). These variables were included to adjust for measured demographic, family-history, and socioeconomic differences. Separate indicators for one and two myopic parents allowed their associations to differ. Reported parental myopia served as a family-history proxy that may reflect both inherited susceptibility and shared family circumstances. All equations retained the full covariate set.

Table 3. Child and family covariates in both models.

Covariate	Definition and Coding
Child age	Age in completed years (3–6), entered as a linear term.
Child sex	Female = 1; male = 0 (reference).
Reported parental myopia	A parent was classified as myopic if a positive myopia magnitude was reported for either eye (Q8; no myopia = 0). Two indicators represented one and two myopic parents, with neither parent myopic as the reference.
Annual household income	Original bands scored 1–5: <CNY 100,000; CNY 100,000–200,000; CNY 200,000–300,000; CNY 300,000–500,000; >CNY 500,000 (Q11). Entered as one ordinal score term.
Mean parental education score	Mean of the father's and mother's education scores (Q9–Q10): 1, junior secondary or below; 2, senior secondary or technical secondary; 3, junior college or bachelor's; 4, master's or above. Entered as a linear score term.

3.4. Statistical Analysis

The analysis fitted three linear regression equations to estimate environmental associations with the two activity scores and mean reported acuity. All environmental indicators entered the equations jointly, so each coefficient was adjusted for the other environmental indicators and covariates.

For child i, X_{ij} denotes environmental indicator j, O_i the outdoor-duration score, S_i the recreational screen-time score, and Y_i mean reported acuity. The vector C_i contains the six covariate terms listed in Table 3. The primary model includes $p = 13$ environmental indicators, and the contextual model includes $p = 18$:

$$O_i = \alpha_O + \sum_{j=1}^{p} a_{Oj} X_{ij} + \gamma_O^T C_i + \varepsilon_{Oi} \quad (1)$$

$$S_i = \alpha_S + \sum_{j=1}^{p} a_{Sj} X_{ij} + \gamma_S^T C_i + \varepsilon_{Si} \quad (2)$$

$$Y_i = \alpha_Y + \sum_{j=1}^{p} c_j' X_{ij} + b_O O_i + b_S S_i + \gamma_Y^T C_i + \varepsilon_{Yi} \quad (3)$$

The coefficients a_{Oj} and a_{Sj} represent adjusted associations of each environmental indicator with the activity scores. In Equation (3), b_O and b_S represent the activity-acuity associations, adjusted for each other and the remaining predictors. Their unstandardised values describe the difference in mean reported acuity associated with a one-category increase in the corresponding activity score. The coefficient c_j' is the environmental-acuity association conditional on both activity scores, the other environmental indicators, and the covariates. The term "direct association" refers to this model coefficient. Each α is an intercept, each γ is a vector of covariate coefficients, T denotes transpose, and each ε is an equation-specific error term.

The equations were estimated by ordinary least squares (OLS). Standardised coefficients in the primary model and contextual model were checked against an equivalent maximum-likelihood structural equation model (SEM), allowing covariances among environmental indicators and covariates and residual covariance between the activity equations. The activities formed parallel paths. The saturated SEM had zero degrees of freedom

and served as a computational check of the OLS point estimates. Supplementary File S2 reports complete coefficients and HC3 comparisons for the primary and contextual models (Table S1). It also provides explained variance, Shapiro-Wilk and Breusch-Pagan tests, leverage and Cook's distance for each equation (Table S3).

For each environmental indicator, the linear path model decomposed its conditional total association into a direct association and two specific indirect associations:

$$\begin{aligned} IE_j^O &= a_{Oj} b_O, \quad IE_j^S = a_{Sj} b_S \\ IE_j &= IE_j^O + IE_j^S, \quad TE_j = c'_j + IE_j \end{aligned} \tag{4}$$

Here, IE_j^O and IE_j^S are the specific indirect associations through the outdoor-duration and recreational screen-time scores, IE_j is their sum, and TE_j is the total association conditional on the other environmental indicators and covariates. TE_j was checked against the coefficient for the same environmental indicator in a regression of mean reported acuity that used the same sample, environmental indicators and covariates but omitted both activity scores. This check assessed the algebraic consistency of the linear decomposition. The estimates were interpreted as conditional cross-sectional associations [52,53].

The analysis reports unstandardised coefficients B and fully standardised coefficients $\beta_{U \to V} = B_{U \to V} \frac{s_U}{s_V}$, where s is the standard deviation of predictor U or outcome V in the relevant analysis sample. Each indirect estimate was standardised by multiplying it by the environmental indicator's standard deviation and dividing by the standard deviation of mean reported acuity. Unstandardised parental-myopia coefficients compare one or two myopic parents with neither parent myopic.

Linear-regression covariance estimates used the subdistrict- or town-level cluster-robust CRV1 estimator with the finite-sample multiplier $\frac{G}{G-1} \cdot \frac{n-1}{n-k}$, where n is the analysis sample size, G the number of administrative units, and k the number of regression parameters including the intercept. Coefficient tests used a t distribution with $G - 1$ degrees of freedom. G was 90 in both the primary model and the contextual model. For each linear path specification, 5000 bootstrap samples were generated by drawing G whole units with replacement (seed 20260908). Each selection retained all children in that unit, including repeated copies when a unit was drawn more than once. All three equations were refitted, and fully standardised coefficients and indirect estimates were recomputed using each bootstrap sample's standard deviations. All 19 linear specifications completed 5000 successful replicates: the primary and contextual models, 12 sensitivity specifications, two alternative greenness specifications, two single-record exclusion checks and the separate 204-record boundary audit. Percentile-based 95% bootstrap confidence intervals were the primary intervals for indirect associations. Bias-corrected and accelerated (BCa) intervals were a sensitivity check, with acceleration estimated by leaving out one unit at a time.

Individual regression coefficients were tested using two-sided tests. Holm's step-down procedure controlled the family-wise error rate at 0.05 within each specified test family.

Specific indirect associations were tested using $p_{\text{joint}} = \max(p_a, p_b)$, where p_a and p_b are the unadjusted cluster-robust p values for their component coefficients. The null hypothesis was that at least one component coefficient was zero. Two grouping schemes were used: analysis-based Holm adjustment and hypothesis-specific Holm adjustment. Both schemes used the same unadjusted coefficient and joint-significance p values.

Analysis-based Holm adjustment grouped tests into four families within each model: activity-path coefficients ($2p + 2$ tests: 28 in the primary model and 38 in the contextual model), direct environmental-acuity coefficients (p tests: 13 and 18), domain-level joint tests (14 in each model), and specific indirect associations ($2p$ tests: 26 and 36). The activity-path family included all environmental associations with the two activity scores and both activity-acuity associations. Domain-level F tests assessed whether all coefficients within a given

parent-reported environmental domain were zero, yielding 14 nondirectional tests across the two activity equations. Single-item domains used the corresponding coefficient tests.

Hypothesis-specific Holm adjustment assessed evidence within each of H1–H7 separately in each of the two 195-child models. All tests assigned to each hypothesis were retained. H1 and H2 concerned perceived environmental associations with outdoor duration and screen time, respectively. H3 concerned mapped environmental associations with outdoor duration and applied only to the contextual model. H4 and H5 each contained one activity-acuity test per model, so their adjusted p values equalled their unadjusted p values. H6 and H7 concerned the specified indirect associations. Complete family definitions and both sets of results are provided in Supplementary File S2 (Table S16).

Both sets of adjusted p values are reported, with analysis-based adjustment retained as the main statistical standard. Unless otherwise stated, reported Holm-adjusted p values refer to this scheme. Evidence consistent with a directional hypothesis required both the expected sign and an adjusted p value below 0.05. Mapped indirect associations through screen time were exploratory. Error control was applied separately to each family within each model, and bootstrap confidence intervals described pointwise uncertainty. Holm adjustment remains valid for dependent tests, including indirect tests sharing an activity-acuity coefficient. Analysis-based family sizes were updated when sensitivity specifications changed the included indicators. Statistical analyses were conducted in Python 3.12.14.

3.5. Sensitivity and Additional Analyses

3.5.1. Sensitivity Analyses

Sensitivity analyses changed one aspect of each model specification at a time. Table 4 summarises the sensitivity and additional analyses. Removing the examination-recency restriction while retaining the acuity range yielded 226 children. Further checks substituted the lower of the two reported eye values, entered age categorically, or added three near-work groups. Each of these four changes was fitted in the primary and contextual models. A separate 204-record boundary audit retained all recent examinations before range screening to assess sensitivity to acuity-range screening. Sample restrictions were applied to all three equations. Changing the acuity definition affected only the visual-acuity equation. For the linear path sensitivity models, changes to environmental indicators or covariates were applied consistently to all three equations. Two additional contextual specifications replaced vegetation cover with NDVI or included both measures jointly, retaining the same sample and other predictors. Complete coefficients and diagnostics for these comparisons are reported in Supplementary File S2 (Table S10).

Environmental checks in the primary model added perceived population and building density as covariates or replaced the three specific safety indicators with overall safety. In addition, a sensitivity check in the primary model entered reported walking time as three groups based on the original, unreversed Q38 category codes: 1–2, 3, and 4–5. The last group, representing the longest reported walking times, was the reference.

The age-category check used age 3 as the reference. An additional sensitivity check in the primary model grouped household income into original bands 1–2, 3, and 4–5, with the first group as the reference. All other child and family covariates retained their original definitions.

Near work (Q27: reading, drawing, puzzles and similar activities) was added as indicators for three groups: original category 1 (<1 h), category 2 (1–2 h) and categories 3–5 (≥2 h), with category 1 as the reference.

Table 4. Overview of sensitivity and additional analyses.

Category	Analyses	Purpose
1. Sample selection and influential observations	Remove the 12-month restriction (n = 226, both models). Retain all recent examinations before acuity-range screening (n = 204, primary model). Exclude the highest outdoor-duration record (n = 194, both linear models and the Firth model).	Assess sensitivity to eligibility criteria and the influence of a single observation.
2. Variable definitions and coding	Use lower-eye acuity (both models). Enter age categorically (both models). Group income or walking time into three categories (primary model).	Assess dependence on the outcome definition and predictor coding.
3. Environmental measures and covariate specifications	Add near-work groups (both models). Add perceived population and building density (primary model). Replace three safety items with overall safety (primary model). Compare NDVI-only and joint greenness specifications (contextual models). Compare individual greenery ratings with other parents' mean ratings within the same unit (n = 149, matched sample).	Assess changes associated with additional adjustment, environmental measures and the source of greenery ratings.
4. Model form and statistical inference	Fit ordered-logit activity models. Enter both activities categorically in the acuity equation. Compare HC3 with cluster-robust inference. Compare percentile and BCa bootstrap intervals.	Assess dependence on linear score specifications and methods for estimating uncertainty.
5. Additional outcomes and cross-measure comparisons	Fit an age-referenced Firth regression. Compare mapped indicators with unit-mean parental ratings.	Examine a complementary visual outcome and correspondence between physical and perceived environmental measures.
6. Joint tests and multiple comparisons	Jointly test indicators within each perceived environmental domain. Apply analysis-based and hypothesis-specific Holm adjustments.	Assess evidence at the item, domain and hypothesis levels, with explicit multiplicity families.

Note. "Both models" refers to the primary and five-indicator contextual models. Categories 1–4 cover sensitivity or robustness checks; categories 5–6 cover additional analyses and assessment of statistical evidence.

Proportional-odds logistic models assessed each activity score as an ordered outcome using the same 13 environmental indicators and six covariate terms. Predictors were standardised, and environmental coefficients were reported as odds ratios per standard-deviation increase with cluster-robust intervals. These models assumed a common slope across outcome thresholds. Holm adjustment covered the 26 environmental coefficients across both activity models. A separate OLS visual-acuity model entered both activities categorically alongside the same 13 environmental indicators and six covariate terms, using the lowest observed category as the reference for each activity. Joint F tests assessed each activity's category coefficients, with Holm adjustment across the two tests. These models checked component associations. The product decomposition in Equation (4) was applied only to linear path models. HC3 heteroskedasticity-robust intervals were calculated under an independence assumption for comparison only. Cluster-robust intervals remained the primary intervals for linear-regression coefficients.

An additional influence analysis examined the single child in the highest outdoor-duration category (>180 min). The original questionnaire export and processed records were checked for agreement. Cook's distance and the outdoor-duration coefficient's DFBETA and standardised DFBETAS were calculated in both 195-child acuity equations. Both linear path models and the age-referenced Firth model were then refitted without this record (n = 194), retaining all other specifications and inference procedures. The 195-child analyses remained primary.

3.5.2. Cross-Measure and Age-Referenced Supplementary Analyses

Cross-measure comparisons paired vegetation cover share and summer NDVI separately with perceived neighbourhood greenery, street and path density with perceived pedestrian crossing and sidewalk continuity, and potential activity-facility density with perceived sufficiency of children's play spaces. Parent-reported indicators were averaged within the 90 administrative units using the 195 children in the main sample. Spearman correlations gave each unit equal weight, with Holm adjustment across the four comparisons. These correlations described area-level correspondence between parental ratings and mapped physical attributes.

An age-referenced binary indicator identified children with either eye below the reference values in Shanghai's 2019 technical specifications for eye care and visual health in children aged 0–6 years [54]: <4.7 at age 3, <4.8 at ages 4–5, or <4.9 at age 6. Survey age served as a proxy for age at examination when applying these age-specific reference values. Continuous mean acuity remained the primary outcome.

The supplementary binary regression included both activity scores, age in completed years as a linear term, sex, two parental-myopia indicators, income and mean parental education. With 21 children below the reference, the model used this reduced predictor set to limit complexity. Firth's penalised logistic likelihood reduced separation-related estimation problems [55]. Activity odds ratios were reported per one-category increase, with pointwise percentile intervals from 5000 whole-unit bootstrap draws. In the 195-child analysis, seventy draws required an alternative optimiser for the same penalised likelihood and the same resampled data. All original draws were retained.

4. Results

4.1. Sample and Baseline Measurement Characteristics

The primary analysis included 195 children from 90 subdistrict or town units. Of the 242 records, 38 were excluded because no previous examination was reported (n = 4), the latest examination was more than 12 months earlier (n = 20), or examination timing could not be recalled (n = 14). Excluding a further nine records with acuity outside 4.0–5.3 in either eye yielded a primary sample of 195 children. The number of children per unit ranged from 1 to 9 (mean 2.17; median 1). Forty-six units contained one child, and 23 contained two. All predictors were complete in the primary sample. Table 5 summarises the sample characteristics, including household income and parental education, alongside the core activity and acuity measures.

The activity responses concentrated in the middle categories. In the primary sample, 77 children (39.5%) reported 60–90 min of outdoor activity per day, and 53 (27.2%) reported 30–60 min. Recreational screen time was below 30 min for 93 children (47.7%) and 30–60 min for 71 (36.4%). Seven children occupied the lowest outdoor category and one the highest. The corresponding screen-time counts were ten and two.

Reported acuity averaged 5.02 (SD 0.21) in the primary sample and ranged from 4.00 to 5.30. Mean reported acuity at ages 3, 4, 5 and 6 was 4.85, 5.01, 5.03 and 5.11, respectively. Among the 238 records reporting a previous examination, nine children had

at least one eye value above 5.3, and three had a value below 4.0. Nine of these 12 records concerned examinations within the previous 12 months. Supplementary File S2 reports age-specific acuity distributions before and after screening (Table S7).

Table 5. Sample characteristics and core measures.

Characteristic	All Records, N = 242	Primary Sample, N = 195
Age 3 years	26 (10.7%)	18 (9.2%)
Age 4 years	83 (34.3%)	68 (34.9%)
Age 5 years	86 (35.5%)	68 (34.9%)
Age 6 years	47 (19.4%)	41 (21.0%)
Male	126 (52.1%)	109 (55.9%)
Female	116 (47.9%)	86 (44.1%)
0 parents reporting myopia	121 (50.0%)	101 (51.8%)
1 parent reporting myopia	66 (27.3%)	48 (24.6%)
2 parents reporting myopia	55 (22.7%)	46 (23.6%)
Annual household income: <CNY 100,000	7 (2.9%)	6 (3.1%)
CNY 100,000–200,000	25 (10.3%)	24 (12.3%)
CNY 200,000–300,000	108 (44.6%)	87 (44.6%)
CNY 300,000–500,000	57 (23.6%)	48 (24.6%)
>CNY 500,000	45 (18.6%)	30 (15.4%)
Father's education: Junior secondary or below	0 (0.0%)	0 (0.0%)
Senior secondary or technical secondary	16 (6.6%)	14 (7.2%)
Junior college or bachelor's degree	195 (80.6%)	155 (79.5%)
Master's degree or above	31 (12.8%)	26 (13.3%)
Mother's education: Junior secondary or below	1 (0.4%)	1 (0.5%)
Senior secondary or technical secondary	35 (14.5%)	22 (11.3%)
Junior college or bachelor's degree	180 (74.4%)	159 (81.5%)
Master's degree or above	26 (10.7%)	13 (6.7%)
Outdoor-duration category score	3.02 (1.07)	3.09 (1.06)
Recreational screen-time category score	2.55 (0.87)	2.56 (0.84)
Mean reported visual acuity	5.02 (0.24)	5.02 (0.21)

Note: Values are n (%) or mean (SD). Education is presented separately for each parent; the models use the mean parental education score. Acuity uses the Chinese five-point logarithmic scale. The all-record acuity summary includes reports excluded from the primary analysis. Outdoor and screen scores represent ordered duration categories rather than measured hours.

Parents generally rated the community environment favourably, although the 13 items captured distinct conditions rather than a single combined score. Table 6 therefore reports each indicator separately. Personal security and reduced night-light disturbance received the highest mean ratings, while walking access received the lowest.

The five objective indicators described the wider administrative context. For the primary sample, the median vegetation cover share was 18.46% (IQR 14.06–31.54%). Median OSM park-area share was 1.94% (0.78–4.28%). Street and path density was 11.89 km/km^2 (7.89–14.48), potential activity-facility density was 2.79 features/km^2 (0.84–6.38), and mapped building density was 13.95% (3.68–21.25%). Figure 2 displays all five indicators across the same 220 administrative units.

The physical indicators and matched parental ratings showed limited correspondence at the administrative-unit level. With equal weight for 90 units, Spearman correlations were −0.158 between vegetation cover and perceived greenery, 0.127 between street density and crossing/pavement continuity, and 0.170 between facility density and play-space sufficiency. The respective Holm-adjusted p values were 0.4401, 0.4569, and 0.4401. These findings support treating objective context and parental perception as complementary rather than interchangeable measures.

Table 6. Distribution of parent-perceived environmental indicators in the primary sample.

Indicator	Mean (SD)	Median [Q1,Q3]	Rating 4–5, n (%)
Crossing and pavement continuity	3.88 (0.75)	4 [3,4]	134 (68.7%)
Vehicle-pedestrian separation	3.79 (0.77)	4 [3,4]	130 (66.7%)
Perceived greenery	4.04 (0.79)	4 [4,5]	149 (76.4%)
Play-space sufficiency	4.02 (0.81)	4 [4,5]	147 (75.4%)
Summer shade	4.04 (0.81)	4 [3,5]	145 (74.4%)
Winter wind comfort	3.91 (0.72)	4 [3,4]	141 (72.3%)
Traffic safety	3.94 (0.85)	4 [3,5]	133 (68.2%)
Facility safety	4.05 (0.69)	4 [4,4.5]	158 (81.0%)
Personal security	4.17 (0.68)	4 [4,5]	176 (90.3%)
Walking access	3.13 (0.95)	3 [3,4]	83 (42.6%)
Fewer air-pollution sources	4.05 (0.87)	4 [4,5]	159 (81.5%)
Less disturbing night light	4.14 (0.83)	4 [4,5]	163 (83.6%)
Quietness	3.93 (0.85)	4 [4,4]	149 (76.4%)

Note: n = 195. Each item uses a five-point scale; higher scores indicate more favourable perceived conditions. Q1 and Q3 denote the 25th and 75th percentiles, respectively.

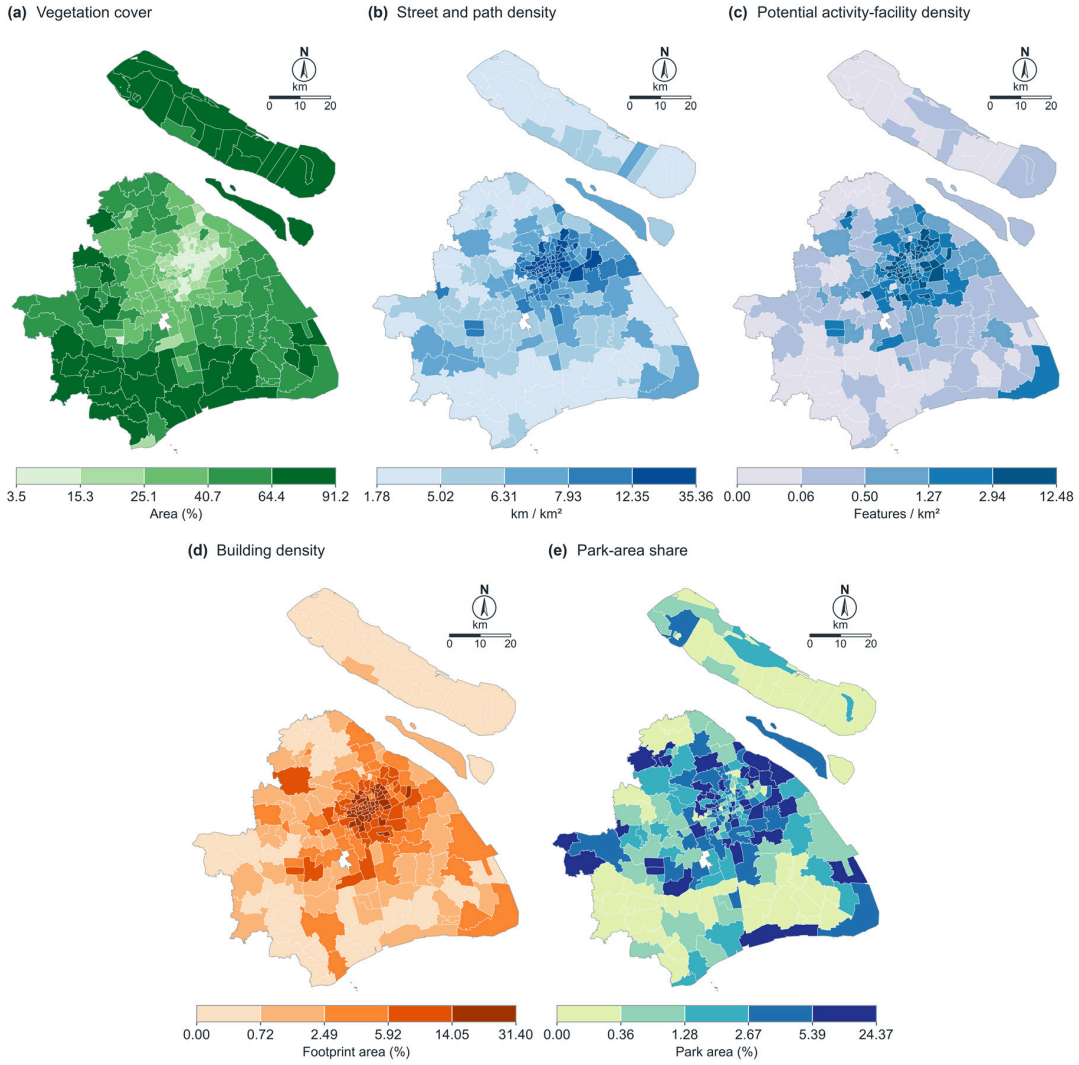


Figure 2. Physical environmental context across 220 subdistrict or town units in Shanghai. Panels show (**a**) vegetation cover share, (**b**) street and path density, (**c**) potential activity-facility density, (**d**) mapped building density measured as building-footprint coverage, and (**e**) OSM park-area share. Colours indicate five quantile classes for each indicator. The maps describe administrative context, not individual exposure.

4.2. Environmental Associations with Daily Activity (H1–H3)

Perceived greenery showed the clearest association with reported outdoor duration. In the primary model, a one-SD higher greenery rating corresponded to a 0.286-SD higher outdoor-duration score (95% CI 0.096 to 0.476; unadjusted $p = 0.0037$, analysis-based Holm $p = 0.0950$). The five-indicator contextual model produced a similar estimate ($\beta = 0.281$, 95% CI 0.100 to 0.463; unadjusted $p = 0.0027$, analysis-based Holm $p = 0.1010$). These positive pointwise associations followed the direction proposed in H1. Both greenery-outdoor associations met the hypothesis-specific Holm criterion for H1 (adjusted $p = 0.0475$ and 0.0355 for the primary and contextual models, respectively). Perceived summer shade also showed a positive but imprecise association with outdoor duration in the primary model ($\beta = 0.162$, 95% CI −0.013 to 0.337).

For recreational screen time, several perceived environmental attributes showed pointwise associations. In the primary model, better walking access ($\beta = -0.192$, 95% CI −0.369 to −0.014) and fewer perceived air-pollution sources ($\beta = -0.367$, 95% CI −0.595 to −0.138) showed pointwise associations with less recreational screen time. Better crossing and pavement continuity also showed a negative pointwise association with recreational screen time ($\beta = -0.219$, 95% CI −0.363 to −0.075). The walking-access, crossing/pavement, and air-pollution associations remained pointwise significant in the contextual model. Vehicle-pedestrian separation showed positive pointwise associations with screen time in both models ($\beta = 0.198$ and 0.189, respectively), opposite to the direction proposed in H2. None of these screen-time associations met the analysis-based Holm criterion in the 195-child models. Under hypothesis-specific Holm adjustment for H2, fewer perceived air-pollution sources met the criterion in both models (adjusted $p = 0.0260$ and 0.0191). Crossing and pavement continuity met this criterion in the primary model (0.0400), but not in the contextual model (0.0508; Supplementary File S2, Table S16).

Among the mapped indicators in the contextual model, vegetation cover had a positive estimate for recreational screen time, with an interval spanning zero ($\beta = 0.209$, 95% CI −0.021 to 0.439). For outdoor duration, mapped building density showed a negative pointwise association ($\beta = -0.238$, 95% CI −0.472 to −0.004), while activity-facility density showed a positive estimate ($\beta = 0.134$, 95% CI −0.036 to 0.305). The facility-density interval included zero. None of the mapped outdoor-duration associations met either the analysis-based or the hypothesis-specific Holm criterion for H3. Figure 3 and Supplementary File S2 (Table S1) present the full environment-to-activity coefficient set.

Domain-level tests assessed the joint associations of related perceived environmental indicators with each activity outcome. No primary-model test met the Holm-adjusted criterion. In the contextual model, the greenery domain was associated with outdoor duration ($F(1, 89) = 9.50$, Holm $p = 0.0382$), while the pollution and disturbance domain did not meet the adjusted criterion for screen time ($F(3, 89) = 4.72$, Holm $p = 0.0545$). These supplementary results describe domain-level associations and remain distinct from the item-level hypothesis tests.

4.3. Activity Associations with Reported Visual Acuity (H4–H5)

Outdoor-duration estimates were positive in both models, following the direction proposed in H4. The primary estimate was $\beta = 0.127$ (95% CI −0.071 to 0.325), and the five-indicator contextual estimate was $\beta = 0.141$ (95% CI −0.060 to 0.342). On the reported acuity scale, a one-category increase in outdoor duration corresponded to an estimated difference of 0.25 chart lines in the primary model (95% CI −0.14 to 0.64). The contextual estimate was 0.28 lines (95% CI −0.12 to 0.68). One chart line represents 0.1 units on the reported acuity scale. Recreational screen-time estimates were close to zero in both models. All activity-acuity confidence intervals included zero, and neither activity met the analysis-

based or the hypothesis-specific Holm criterion (Supplementary File S2, Table S16). These estimates quantify the magnitude and uncertainty of the proposed activity-acuity links, providing a basis for further longitudinal investigation.

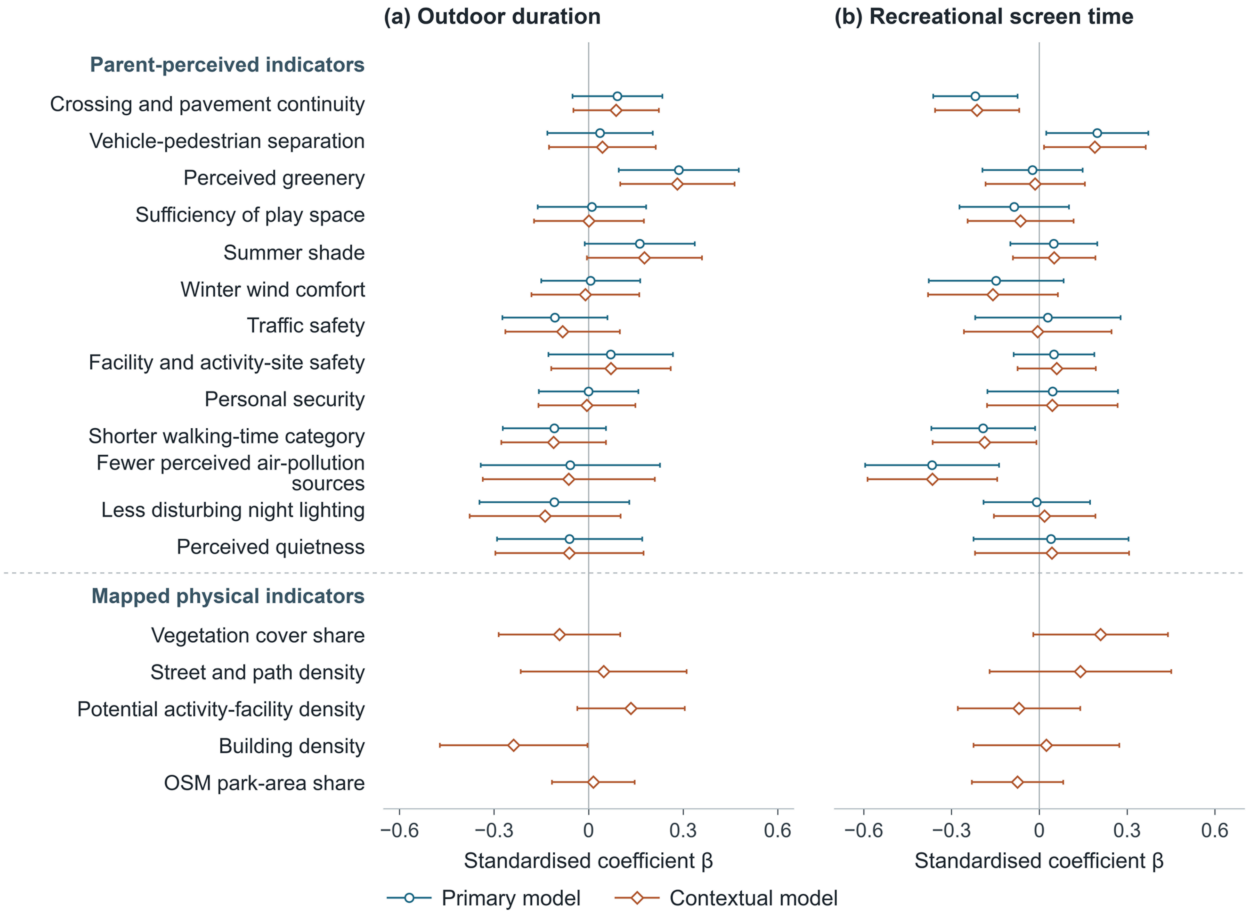


Figure 3. Environmental associations with (**a**) outdoor duration and (**b**) recreational screen time. Lines show pointwise cluster-robust 95% confidence intervals. The horizontal dashed line separates parent-perceived and mapped indicators.

The supplementary analysis classified children according to whether reported acuity in at least one eye fell below the reference for their age. Among the same 195 children, 21 (10.8%) met this criterion. Firth logistic regression included both activity scores and adjusted for child and family characteristics. For each one-category increase in outdoor duration, the estimated odds ratio for below-reference acuity was 0.683 (95% cluster-bootstrap CI 0.307 to 1.184). This estimate pointed towards lower odds with longer outdoor duration, consistent in direction with the continuous-acuity results. The confidence interval included one, highlighting the need for further clarification of this potential association. Recreational screen time showed no clear association with this age-referenced outcome. Complete coefficients, including child and family covariates, are provided in Supplementary File S2 (Table S2).

4.4. Environment-Activity-Visual Acuity Associations (H6–H7)

The greenery-outdoor pathway produced a positive standardised indirect estimate in both models. The primary estimate was 0.0362 (percentile 95% CI −0.0206 to 0.1193), and the contextual estimate was 0.0396 (percentile 95% CI −0.0164 to 0.1256). On the original acuity scale, these estimates corresponded to 0.10 and 0.11 chart lines per one-point increase

in the perceived-greenery rating, respectively. The indirect estimates were positive in both models but did not meet the family-wise criterion for H6.

Several pathways through outdoor duration also showed positive point estimates, including perceived summer shade and potential activity-facility density in the five-indicator contextual model. The mapped building-density estimate through outdoor duration was negative. Across both models, all specific indirect estimates had pointwise percentile intervals spanning zero, and none of the hypothesised indirect associations met the analysis-based or the hypothesis-specific Holm criterion for H6 or H7 (Supplementary File S2, Table S16). Figure 4 shows all specific indirect estimates.

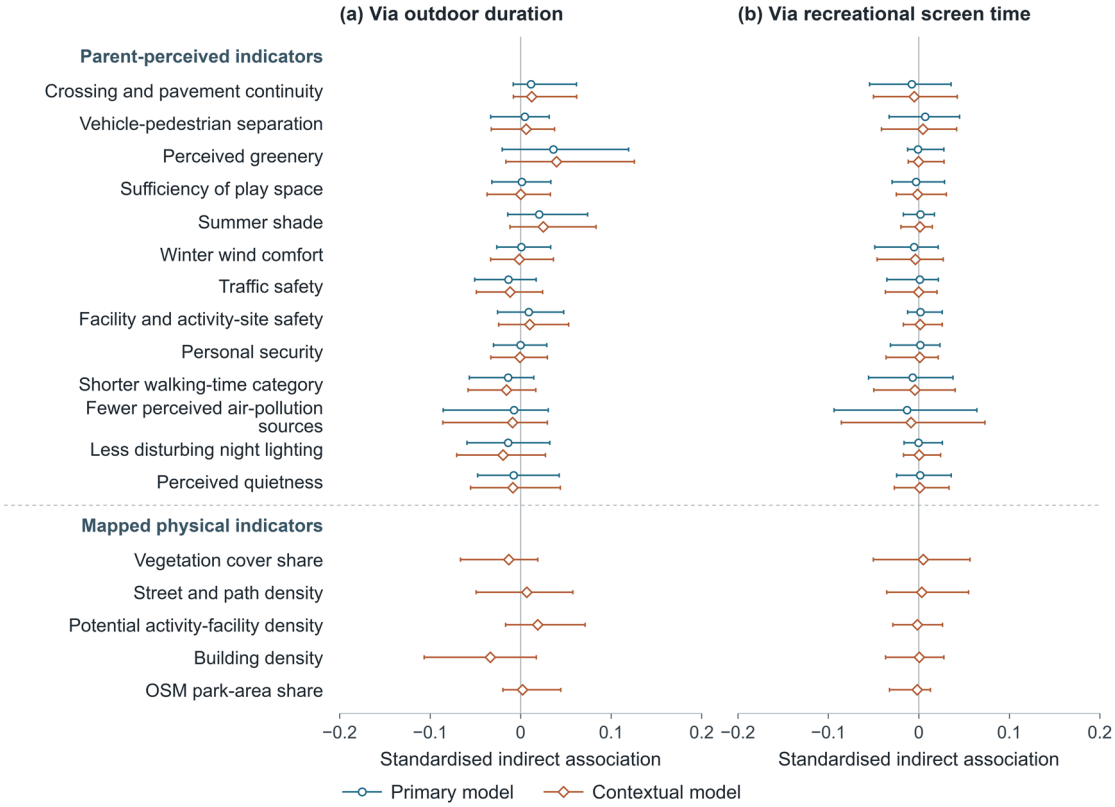


Figure 4. Specific indirect environmental associations with reported visual acuity through (**a**) outdoor duration and (**b**) recreational screen time. Lines show pointwise percentile-based 95% bootstrap confidence intervals from 5000 whole-cluster bootstrap draws per model. The horizontal dashed line separates parent-perceived and mapped indicators.

The analysis combined the direct and indirect estimates to assess the overall association between perceived greenery and reported visual acuity. In both models, the positive combined indirect estimate for perceived greenery mainly reflected the outdoor-duration pathway. The indirect estimate through recreational screen time was close to zero. After accounting for both activity scores and the other covariates, the direct greenery-acuity estimates were slightly negative. Adding these to the positive combined indirect estimates yielded small positive total estimates. The standardised total estimate was 0.0129 (percentile 95% CI −0.1406 to 0.1933) in the primary model. The contextual model yielded a similar estimate of 0.0195 (percentile 95% CI −0.1390 to 0.2123).

4.5. Sensitivity and Supplementary Analyses

The greenery-outdoor association remained positive across the two main models and 12 retained linear sensitivity specifications. The standardised coefficient ranged from 0.217 to 0.286, and every pointwise 95% confidence interval remained above zero. None of these

associations met the corresponding analysis-based Holm criterion. The smallest coefficient occurred when overall safety replaced the three specific safety items (β = 0.217). Adjustment for near work retained similar greenery-outdoor estimates in the primary and contextual models (β = 0.286 and 0.281, respectively). The corresponding greenery-outdoor-acuity indirect estimates remained positive (0.023–0.040), with all pointwise percentile intervals including zero. Figure 5 separates the two main specifications from changes to the sample, outcome definition, or covariate coding. Replacing mean acuity with the lower-eye value changed only the acuity equation and left the greenery-outdoor estimates unchanged. Supplementary File S2 (Table S4) summarises these estimates, including percentile and BCa intervals for the greenery-outdoor-acuity indirect association. The 204-record analysis before acuity-range screening is reported separately in the same table. In that 204-child analysis, the greenery-outdoor estimate was 0.281 (95% CI 0.102 to 0.461). Its analysis-based item-level Holm p value was 0.0700, whereas the greenery-domain test met its separate criterion (Holm $p = 0.0350$; Table S13). The greenery-domain tests also met this criterion in both 226-child analyses (Holm $p = 0.0289$ and 0.0220; Table S15B).

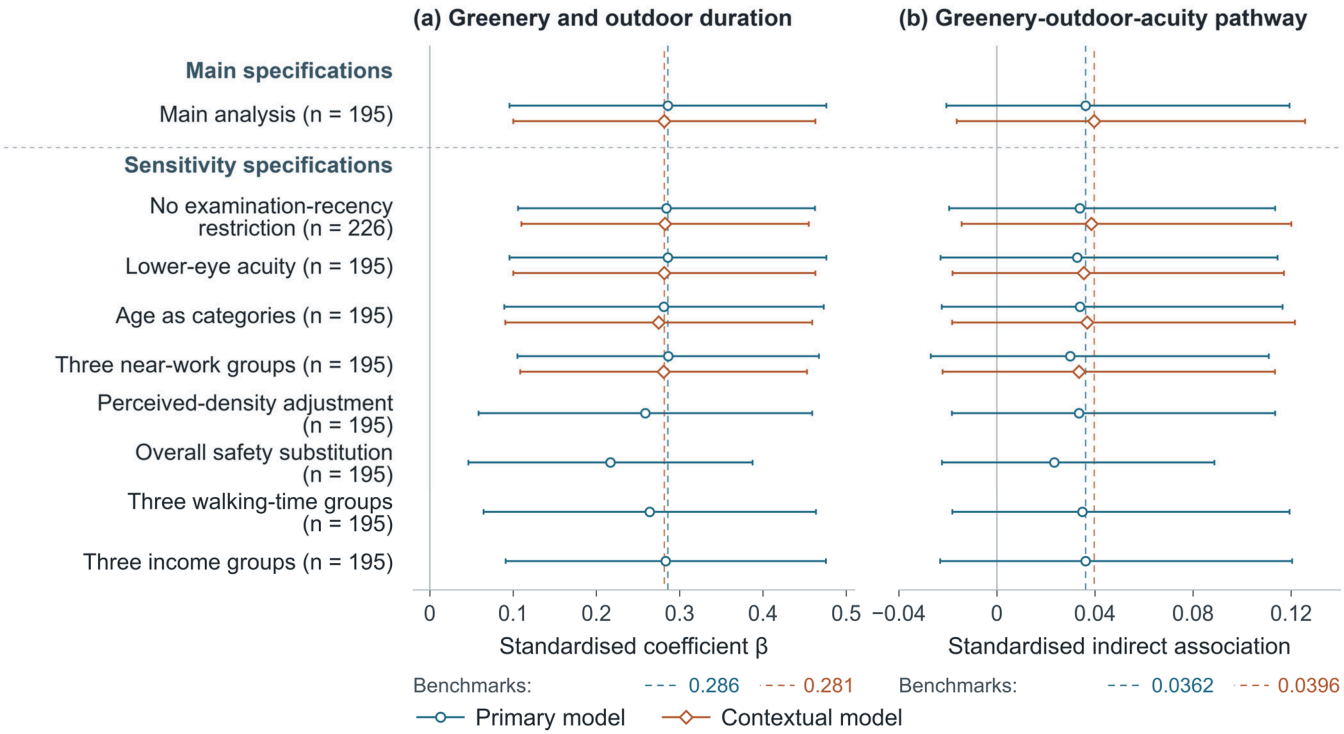


Figure 5. Perceived greenery and the outdoor pathway across two main models and 12 sensitivity specifications. Panel (**a**) shows greenery-outdoor coefficients with pointwise cluster-robust 95% confidence intervals. Panel (**b**) shows the corresponding indirect estimates with pointwise percentile 95% bootstrap intervals. The horizontal dashed line separates the two main models from the sensitivity specifications. Coloured vertical dashed lines mark the corresponding primary- and contextual-model estimates as benchmarks.

Several screen-time associations met the analysis-based Holm criterion for H2 in sensitivity analyses. Fewer perceived air-pollution sources were associated with less screen time in both age-category and near-work-adjusted models, and in the primary-model checks using overall safety or grouped walking time. Across these six 195-child specifications, coefficients ranged from −0.375 to −0.317, and Holm p values from 0.0208 to 0.0474. Crossing and pavement continuity also met the criterion after adjustment for perceived population and building density (β = −0.229, 95% CI −0.366 to −0.092; Holm $p = 0.0368$). Table S15A reports both indicators across all linear specifications. Domain tests identi-

fied pollution/disturbance-screen associations in several sensitivity specifications and a walking/traffic-space-screen association with perceived-density adjustment (Table S15B).

The ordinal sensitivity model retained the positive greenery-outdoor association. A one-SD increase in perceived greenery corresponded to higher odds of reporting a longer outdoor-duration category (OR = 1.926, 95% CI 1.232–3.010, Holm $p = 0.1162$). Crossing and pavement continuity and fewer perceived air-pollution sources were associated with lower screen-time categories at the pointwise level (OR = 0.633, 95% CI 0.445 to 0.901; OR = 0.434, 0.202 to 0.932, respectively). Neither screen-time association met its Holm criterion. Sparse extreme categories limited assessment of the proportional-odds assumption. In the separate acuity model treating both activities categorically, the highest outdoor-duration category contained only one child, producing leverage of 1 and unstable inference. Supplementary File S2 reports the ordinal and categorical results (Tables S5, S6A and S6B).

Checking the highest outdoor-duration record against the original export found no transcription or processing discrepancy. Excluding this record increased the outdoor-acuity coefficients to $\beta = 0.194$ (95% CI 0.020 to 0.369) in the primary model and 0.205 (0.025 to 0.386) in the contextual model. The corresponding standardised indirect estimates were 0.0587 (95% CI 0.0021 to 0.1324) and 0.0611 (0.0034 to 0.1381). Neither H4 nor H6 met its analysis-based Holm criterion. The greenery-outdoor estimates remained positive and met the corresponding analysis-based Holm criteria in this sensitivity analysis (adjusted $p = 0.0417$ and 0.0427). Fewer perceived air-pollution sources were also associated with less screen time in both 194-child models ($\beta = -0.407$ in each; Holm $p = 0.0210$ and 0.0176), meeting the H2 criterion for this indicator (Table S15A). The age-referenced outdoor OR was 0.554 (95% cluster-bootstrap CI 0.249 to 0.901). Full comparisons and influence diagnostics are reported in Supplementary File S2 (Table S11).

The NDVI-only and joint greenness specifications yielded similar perceived greenery-outdoor coefficients ($\beta = 0.283$ and 0.281) and greenery-outdoor-acuity indirect estimates (0.0387 and 0.0416), with both indirect intervals spanning zero (Supplementary File S2). Vegetation cover and NDVI had opposite-signed coefficients when entered jointly, but their separate models gave the same direction of association for each outcome (Table S10). Other sensitivity checks showed a positive pointwise association between summer shade and outdoor duration when overall safety replaced the specific safety items ($\beta = 0.174$). Facility density also showed a positive pointwise association with outdoor duration in the contextual model additionally adjusted for near-work duration ($\beta = 0.157$). Neither association met the analysis-based Holm criterion. Table S14 summarises the evidence for H1–H7 across specifications.

The primary equations explained 21.5% of outdoor-score variance, 30.5% of screen-score variance and 31.3% of acuity variance. The corresponding contextual-model values were 24.2%, 33.5% and 32.3%. Residual diagnostics indicate departures from normality in the screen-time and acuity equations and from constant variance in the screen-time equations. The analysis retained cluster-robust inference, bootstrap intervals and HC3 checks. Supplementary File S2 summarises the numerical residual and influence diagnostics for the primary and contextual models (Table S3). Equivalent OLS and saturated SEM calculations agreed to within 6.18×10^{-7}. This comparison checked numerical consistency, not global model fit.

5. Discussion

5.1. Key Findings

The findings were clearest for the environment-activity component of the proposed framework (Table 7). Perceived greenery was consistently associated with longer reported outdoor duration across the main and retained sensitivity specifications. In the 195-child

models, these associations met the pointwise and hypothesis-specific Holm criteria for H1. The greenery-domain tests met their separate Holm criterion in the contextual model and in the 204- and 226-child analyses. In the 194-child sensitivity analysis excluding the single child in the highest outdoor-duration category, the greenery-outdoor association met the analysis-based Holm criterion for H1 in both models.

Table 7. Summary of evidence for H1–H7 across model specifications.

Hypothesis	Core Findings in the 195-Child Models	Evidence from Sensitivity and Domain Analyses
H1: Perceived environment-outdoor duration	Perceived greenery met the hypothesis-specific Holm criterion in both primary and contextual models.	Positive pointwise associations persisted across retained linear checks. Both 194-child models met the analysis-based Holm criterion. Greenery-domain tests met their separate criterion in selected specifications. Summer shade showed a positive pointwise association with outdoor duration when overall safety replaced the three specific safety items.
H2: Perceived environment-screen time	Fewer air-pollution sources met the hypothesis-specific Holm criterion in both models; crossing/pavement continuity met it in the primary model.	Selected air-pollution and pavement-continuity associations met the analysis-based Holm criterion. Pollution/disturbance domain tests met their separate criterion in selected specifications.
H3: Mapped environment-outdoor duration	Building density showed a negative pointwise association; no mapped indicator met either Holm criterion.	Building density remained negative at the pointwise level in selected checks. Facility density showed a positive pointwise association with additional near-work adjustment. Neither met the analysis-based Holm criterion.
H4: Outdoor duration-acuity	Estimates were positive, with confidence intervals including zero.	The 194-child analysis showed pointwise support, but did not meet the analysis-based Holm criterion. Longer outdoor duration was also associated with lower odds of below-age-reference acuity in this sample.
H5: Screen time-acuity	Estimates were small, with no clear evidence for the proposed negative association.	Continuous and age-referenced analyses provided no clear evidence of a screen-acuity association.
H6: Environment-outdoor duration-acuity	The perceived-greenery indirect estimates were positive, with confidence intervals including zero.	These estimates remained positive across specifications. The 194-child analysis showed pointwise support, but did not meet the analysis-based Holm criterion.
H7: Perceived environment-screen time-acuity	No clear indirect association through screen time was identified.	No specific screen-mediated indirect association met the analysis-based Holm criterion across the linear specifications.

Note: Analysis-based Holm results remain the main statistical standard and apply throughout the table unless otherwise specified. Hypothesis-specific Holm results group tests separately within H1–H7 in each 195-child model. Domain tests use a separate family. Sensitivity analyses use overlapping samples and are not independent replications.

Several additional environment-activity associations emerged at the pointwise level, particularly those linking walking access, crossing and pavement continuity, and fewer perceived air-pollution sources to less recreational screen time. In the 195-child models, the air-pollution association met the hypothesis-specific Holm criterion for H2 in both

models, and the continuity association met it in the primary model. The air-pollution association also met the analysis-based Holm criterion for H2 in several 195-child sensitivity specifications and both 194-child analyses. The continuity association also met this criterion with perceived-density adjustment. These results identify specific environmental attributes associated with children's reported activity patterns. The hypothesis-specific results support these environment-activity associations, while analysis-based adjustment remains the main statistical standard.

The outdoor-acuity and greenery-outdoor-acuity indirect estimates were positive in both 195-child models, with confidence intervals spanning zero. Excluding the influential record strengthened these estimates, and their pointwise intervals then excluded zero. Longer outdoor duration was also associated with lower odds of below-age-reference acuity in that sensitivity analysis. Neither H4 nor H6 met its family-wise criterion in either sample. The overall greenery-acuity estimates remained small and positive in the 195-child models, with intervals spanning zero. Outdoor activity therefore remains a potential behavioural link between perceived community greenery and preschool children's reported visual acuity. The evidence is clearer for the environment-activity association than for its extension to visual acuity.

These findings support specific environment-activity associations within the proposed framework. Perceived greenery was associated with longer reported outdoor duration, while several perceived environmental attributes were associated with less recreational screen time. These patterns are broadly consistent with existing evidence on neighbourhood environments and preschool children's activity [5,14]. The positive outdoor-acuity and greenery-outdoor-acuity estimates followed the proposed direction, although the complete sequence was not established. The framework considers direct environment-health associations alongside the component and indirect associations involving outdoor activity and recreational screen time. This allows evidence for each link to be distinguished from evidence for a complete pathway through activity. It therefore helps future studies specify the behavioural pathways to be tested and the evidence needed to evaluate them.

5.2. Activity as a Behavioural Link Between the Community Environment and Visual Acuity

The greenery-outdoor association directs attention to how families use the environmental opportunities available around them. This association is consistent with previous research linking neighbourhood greenness to children's outdoor activity [4,14,23,35]. Parents' environmental perceptions are relevant because parents help determine their children's activity opportunities [56]. Examining these perceptions alongside activity within the same family preserves this behavioural focus. An international study likewise examined parent-reported environmental conditions and outdoor play among 1855 preschool children across 19 countries [6]. In the PLAYCE study, perceptions of access and safety modified associations between objectively measured neighbourhood features and preschool children's energetic play [57]. In this context, perceived greenery may reflect not only the amount of vegetation but also its visibility, familiarity and perceived usability. These qualities may shape whether parents regard nearby spaces as suitable for their children's daily activities.

This emphasis on everyday use helps explain why mapped conditions and parental ratings need to be considered together. Vegetation cover describes conditions across administrative units, while parental ratings may reflect families' experiences of nearby spaces. Their limited correspondence may therefore reflect differences in measurement and spatial scale. The perceived pollution and disturbance items showed opposite-signed direct estimates. Access, thermal comfort and potential destinations provide further context for understanding how environmental resources become part of children's routines. Outdoor experience may also shape parents' greenery ratings, and shared reporting may contribute

to the observed greenery-outdoor association. Evidence from Chinese preschool children has similarly linked neighbourhood pavements, cycle paths, aesthetic quality and traffic conditions to outdoor play [58]. These perspectives shift attention from the presence of resources to the conditions under which families may use them.

Outdoor activity could connect these environmental opportunities with visual health through children's exposure when using local spaces. Research on childhood myopia identifies outdoor duration and light exposure as relevant to visual development [7]. This provides a rationale for examining whether community conditions that support regular outdoor activity also relate to visual outcomes. The positive outdoor-acuity and greenery-outdoor-acuity estimates followed this proposed direction, although their confidence intervals included zero. The behavioural pathway therefore remains exploratory, with the clearest observed association linking perceived greenery to outdoor activity. The direct acuity estimate for fewer perceived air-pollution sources was unexpectedly negative. Estimates for quietness and less disturbing night light were positive (Supplementary File S2, Table S1). This exploratory pattern warrants further examination of whether these associations persist across alternative measurements and model specifications.

Recreational screen time showed no clear association with reported visual acuity in this study. Inconclusive findings have also appeared in earlier research. A systematic review reported mixed evidence on screen time and myopia, with no clear pooled association across five studies [38]. A more recent meta-analysis found higher odds of myopia with greater screen exposure, although estimates varied substantially between studies [39]. In the present sample, screen use was concentrated in the lower duration categories, and the outcome was reported as visual acuity rather than myopia. These differences in exposure range and visual outcome may partly explain why a clear association was not apparent. Within the proposed framework, the screen-related pathway therefore remains unresolved. Future research should characterise screen-use habits more precisely, including device type, viewing distance and patterns of continuous use, and examine their relationships with clinical visual outcomes.

The broader implication is to examine how environmental opportunities become part of daily routines. New or improved activity spaces may encourage families to spend more time outdoors or change where children play [5,34]. Activity-based modelling could investigate these adjustments, drawing on applications to residents' time allocation during urban emergencies [59,60]. Longitudinal applications could help clarify whether changes in activity connect neighbourhood improvements with subsequent health outcomes.

5.3. Implications for the Health and Wellbeing Dimension of Urban Resilience

The findings can inform the health and wellbeing priorities of urban resilience planning by identifying environmental conditions associated with children's everyday activity. Therefore, based on the findings, this study recommends future community assessment practices combining mapped measures of greenness, park resources, facility provision, street networks and building density with parental perceptions of greenery, safety, access and environmental quality. This combined approach distinguishes resource availability from families' assessments of everyday usability.

Participatory methods can help translate families' assessments into location-specific planning priorities. Participatory mapping and neighbourhood walks with children and caregivers can identify locations where traffic, access, or comfort affects daily use. Co-design workshops and temporary full-scale prototypes can then allow families to test and refine proposals before permanent implementation. UNICEF places children's participation within child-responsive urban planning [61]. A Copenhagen project likewise showed how full-scale co-design prototypes brought children's perspectives into public-space planning

and engaged local stakeholders [62]. Such approaches may also help planners consider how children, adults and animals share public green spaces [63]. These approaches make perceived environmental quality a practical input to planning and evaluation.

In this planning context, potential visual-health benefits of community environments that support outdoor activity warrant further investigation. The clearest observed pattern links perceived greenery with reported outdoor duration, while the extension to reported visual acuity remains exploratory. Future longitudinal studies could track environmental improvements, outdoor activity, light exposure, and clinical visual outcomes to examine longer-term health benefits. Such studies could also monitor environmental access and activity before, during, and after a defined disturbance. This would help test whether community environments sustain or restore activity opportunities under stress, providing evidence on this aspect of urban resilience.

5.4. Limitations

The main temporal limitation concerns the alignment of activity and visual acuity measurements. Restricting acuity records to examinations within the preceding 12 months narrowed the gap between examination and survey, but did not ensure alignment with current activity reports. These data therefore support exploratory analyses of associations but cannot establish temporal ordering or causal mediation.

Collecting parents' environmental perceptions alongside reports of their children's activities aligns with the study's behavioural focus. However, using the same reporter does not rule out common-method and recall bias. Parent-reported uncorrected visual acuity cannot diagnose myopia or quantify hyperopic reserve. Further validation of the environmental items would strengthen measurement quality. Device-based activity and light measurements, together with standardised clinical examinations, would also improve the accuracy of exposure and outcome assessment.

Mapped indicators reflect subdistrict or town contexts and may not fully capture differences in conditions around children's homes and at their actual activity locations. OSM completeness and tagging quality may vary. Mapped parks and facilities indicate potential resource provision but do not establish maintenance status, public accessibility or suitability for preschool children. Vegetation indicators likewise describe physical conditions rather than site-level usability. The vegetation data also predate the survey and may not capture recent vegetation changes.

This exploratory study used a convenience sample that was not designed to represent Shanghai's preschool population proportionately. Online participation and the recent-examination requirement may have influenced sample composition, while sparse extreme activity categories limited inference in supplementary categorical models. Broader sampling would help assess the transferability of the findings and their relevance to citywide planning. The study contributes to urban resilience research by providing exploratory evidence on everyday environment-activity-health relationships. Testing whether community environments sustain or restore activity opportunities under stress would require repeated observations spanning a defined disturbance.

6. Conclusions

This study offers a behavioural perspective on the health relevance of community environments. Perceived greenery showed the most consistent association with outdoor duration across the primary, contextual, and sensitivity specifications. In the 195-child analyses, this association met the hypothesis-specific Holm criterion but not the main analysis-based criterion. Outdoor duration showed a positive estimated association with reported visual acuity. The corresponding greenery-outdoor-visual acuity indirect estimate

was also positive. Both the outdoor-acuity and indirect estimates had confidence intervals spanning zero in these analyses. Recreational screen time showed little association with visual acuity. These estimates and their uncertainty provide a quantitative basis for refining behavioural hypotheses and guiding future longitudinal research.

The study's broader contribution lies in integrating daily activity into an environment-health research framework, using preschool visual acuity as an empirical case. Its digital environmental representation combines mapped physical conditions with parental assessments of local conditions. This integration allows environmental associations with health to be examined alongside the behavioural links that may connect them. The framework can guide future investigations of these links across different populations, community settings and health outcomes. This approach can inform the health and wellbeing priorities of urban resilience planning, with child-friendly communities as an application context.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/buildings16214386/s1, Supplementary File S1: Questionnaire and informed consent; Supplementary File S2: Essential supplementary tables (Tables S1–S16).

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