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Analyzing the effects of nature exposure on perceived satisfaction with running routes: An activity path-based measure approach

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ABSTRACT

Studies on the linkages between nature exposure and physical activities often focus simply on the immediate vicinity of home locations, but path-based exercises, such as running and cycling, are continuous activities and cover a broad spatial extent. Thus, the traditional home buffer approach fails to acknowledge the settings where road running actually occurs. This study employed an activity path-based measure approach using public participation GIS (PPGIS) to investigate the associations between running satisfaction and nature exposure. The mapped routes (N=545) that included an assessment of satisfaction level were collected from 249 runners resided in the Helsinki Metropolitan Area, Finland. Logistic regression analyses revealed a positive association between running satisfaction and nature exposure, including eye-level greenness, top-down greenness and blue space density. Top-down greenness was assessed by Normalized Difference Vegetation Index (NDVI) and the eye-level greenness by Green View Index (GVI), the latter one of which uses a deep learning algorithm. Running environment was more satisfying in those routes with more public transport nodes. Other traffic-related factors breaking the momentum of runners such as traffic light density were inversely related to running satisfaction. Demographic characteristics such as education background also played a significant role in the perceived satisfaction with running routes. The positive impacts of nature exposure on running satisfaction further verify the linkages between landscape and public health.

1. Introduction

1.1. An emerging focus on environmental predictors of running behaviour

Promoting physical activity is proven to be beneficial for public health, including preventing various non-communicable diseases, such as coronary heart disease, type 2 diabetes and breast cancers, as well as increasing life expectancy (Lee et al., 2012). In addition, physical activity promotion also results in alleviating greenhouse effect through the encouragement of active transportation, the stimulation of public spaces utilization, and the improvement of social cohesion (Kohl et al., 2012). As an individual and non-organised sport, running is one of the most frequently practised physical activities to reduce cardiovascular mortality risk (Breuer et al., 2011; Lee et al., 2014; Pedisic et al., 2020), as well as to improve mental health (Oswald et al., 2020; Roeh et al., 2020). Many studies have focused on promoting running behaviour through interfering the socioeconomic and demographic factors, including the improvement of physical skills and the provision of adaptive physical education and counselling services (Bedimo-Rung et al., 2005; NICE, 2009), but the environmental determinants of running behaviour have rarely been acknowledged. The interventions in these relatively unchangeable socioeconomic and demographic characteristics are insufficient to promote running activity, resulting in an increasing interest on the environmental predictors that can be modified by landscape and urban planning strategies (Deelen et al., 2019; Shashank et al., 2021).

1.2. Perceived satisfaction: a critical catalyst of running exercise

Perceived satisfaction is a significant concept and applies to subjective satisfaction with a running route (Ettema, 2015; Ta et al., 2021b). It is used to uncover whether the actual appearance and dedicated urban infrastructure (e.g. well-lit urban trails, water fountains, public stretching and exercise equipment, and signage and wayfinding system)

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correspond with the aspirations and preferences of runners. Which running routes and what kind of environmental features are more satisfying and why? On the one hand, exposure to nature has been recognized to increase perceived satisfaction, encourage running involvement, improve mood states and reduce stress and cardiovascular diseases (Calogiuri and Elliott, 2017; Deelen et al., 2019; Ettema, 2015; Lee et al., 2014; Roeh et al., 2020). The preference for greener environments can be explained by evolutionary and psychological reasons – greener environments help our ancestors to survive and thrive (Jiang et al., 2015). Furthermore, traffic related factors including slope, intersections and traffic lights have been reported as reliable negative predictors of perceived satisfaction with running routes (Schuurman et al., 2021; Shashank et al., 2021) because these attributes can affect running performance and experience. Knowledge on the perceived satisfaction with running environment has important implications for urban planning policy to provide better infrastructure and facilities for running (Krajter Ostoić et al., 2017; Ta et al., 2021b). Therefore, raising the perceived satisfaction is crucial to promoting running activity (Wong et al., 2018).

1.3. Running satisfaction and nature exposure: an important but often neglected link

Research on the roles of nature exposure in promoting physical activity mainly concentrates on walking and cycling (Ki and Lee, 2021; Lu et al., 2019), leaving a gap on the associations between the features of urban greenness and running behaviour. Empirical studies about the influence of nature exposure on running satisfaction have almost solely focused on non-spatial analysis instead of spatial statistics (Deelen et al., 2019; Ettema, 2015). To our knowledge, the linkages between the different forms of nature exposure (e.g. eye-level greenness, top-down greenness and blue space density) and running satisfaction have also been largely overlooked. This is partly because running has specific features in terms of intensity and spatial extent (Bodin and Hartig, 2003; Ettema, 2015), making the actual running environment relatively difficult to locate and analyse spatially. Besides, the movement and speed of running also affect the visual perception of greenness, as well as the associations between landscape and running performance (Jiang et al., 2021). The eye-level greenness is often excluded in environmental health research due to methodological limitation, namely it is difficult to measure objectively. In this study, we mainly focus on the quantification of eye-level greenness with the precise spatial units indicating the settings where running actually occurs.

1.4. Critical knowledge gaps and research questions

There are several critical knowledge gaps in the literature exploring running environment and perceived satisfaction. First, only a few studies have examined the influence of environment on running satisfaction (Deelen et al., 2019; Ettema, 2015), but these studies often lack of a spatial approach. Second, most studies consider only the existence of greenness (e.g. Schuurman et al., 2021), ignoring the amount of both the top-down and eye-level greenness exposure. Third, only a few studies adopt an activity path-based measure approach (Gerstenberg et al., 2020; Korpilo et al., 2018; Meyer et al., 2019), which can closely represent the perceptible area surrounding the running routes. The knowledge gaps mentioned above prevent urban planners and related decision-makers from developing evidence-based landscape strategies to promote running behaviour and perceived satisfaction by modifying the environmental conditions.

This study adds to current literature by conducting a PPGIS-based survey and multiple regression analyses to investigate the environmental determinants of running satisfaction. This study aims to provide valuable insights for implementing landscape and urban planning strategies to promote running activity. We ask three key research questions:

Q1: To what extent is nature exposure (i.e. eye-level greenness, top-down greenness and blue space density) associated with runners' perceived satisfaction?

Q2: How do other activity-influencing built environmental factors (e.g. public transport nodes, traffic lights and street density) affect running satisfaction?

Q3: Does the perceived satisfaction with running environment differ by demographic characteristics, such as gender and education background?

2. Literature review

2.1. Built environment and running

Based on the socio-ecological framework for physical activity proposed by Sallis et al. (2006), running behaviour is affected by individual characteristics (e.g. gender, age, education level and motivation), sociocultural environment (e.g. social cohesion of a neighbourhood and activity-related policy support), built environment (e.g. traffic condition, land-use mix, terrain slope and urban density) and natural environment (e.g. nature exposure and weather). There is a growing focus on the relationships between running behaviour and built environment characteristics, although the total amount of studies is still limited. These running-influencing environmental factors can be classified into the traffic-related attributes affecting runners' momentum, the comfort and safety of routes, and urban configuration (Collinson, 2008; Deelen et al., 2019; Ettema, 2015).

First, running as a type of vigorous-intensity physical activity often covers a larger spatial extent with higher speed as opposed to walking. There is an overwhelming consensus that traffic-related attributes breaking the momentum of runners are negative determinants for running satisfaction and frequency (Deelen et al., 2019; Ettema, 2015; Shashank et al., 2021). In the Netherlands, Ettema (2015) found that the impediments of unleashed dogs and cyclists were inversely associated with the perceived satisfaction and involvement of running activity, respectively. In addition, a rough runnability index proposed by Shashank et al. (2021) indicates that minimizing the interactions with traffic lights and intersections can facilitate running rates, while continuous paths in natural settings, which are away from other traffic, help to maintain momentum and thus can increase the odds of running.

Second, a large number of empirical studies have demonstrated that the comfort and safety of running paths are important predictors for running rates and satisfaction (Collinson, 2008; Deelen et al., 2019; Ettema, 2015). Road runners prefer to run on asphalt and other smooth pavement because these surfaces are comfortable, injury-preventive and restorative (Deelen et al., 2019; Hockey and Collinson, 2006). Conversely, a poor running surface is negatively related to the perceived satisfaction with a route (Ettema, 2015). The terrain slope, which shapes the comfort of running experience, has indirect effects on running performance and perception of difficulty (Campbell et al., 2019). Besides, perceived danger and experiencing threats from strangers are both negatively associated with running frequency (Ettema, 2015).

Third, besides traffic-related factors and the comfort of running routes, urban configuration also correlates with running activity (Sallis et al., 2016). Ettema (2015) used the city size as a proxy for urban density and investigated its association with running satisfaction, the result of which indicated that densely populated urban area decreases the enjoyment of running due to the hindrance of traffic. The association between street density and running behaviour depends on specific settings – higher street density increases the odds of jogging in rural settings, but leads to lower running rate in urban area (Hou et al., 2010). In addition, Troped et al. (2010) argued that the higher level of land use mix and population density can promote moderate-vigorous physical activity.

2.2. Nature exposure and running

Urban greenness has been documented to increase the rates, frequency and perceived satisfaction of physical activity (Ettema, 2015; Lu et al., 2019; Schipperijn et al., 2013). In Norway, Calogiuri and Elliott (2017) indicated exploring nature is the second-most mentioned reason for performing physical activities, surpassed only by convenience motives. Increasing nature experience of residents can significantly predict the boost of perceived satisfaction and physical activity engagement (Chang et al., 2020; Edwards et al., 2014; Ta et al., 2021a). Besides, running is more likely to occur in larger sized natural environment as opposed to spatially concentrated activities (Jansen et al., 2017). The existence of trees along the routes is found to be positively associated with running satisfaction (Schuurman et al., 2021). These studies reach a consensus that the actual exposure to nature results in the promotion of running satisfaction, but the association between streetscape greenery and running satisfaction is still largely overlooked.

To our best knowledge, less is known about the relationship between streetscape greenness and running behaviour compared to the other forms of physical activities such as walking and cycling (Ki and Lee, 2021; Lu et al., 2019; Wu et al., 2020). The use of Google Street View (GSV) panoramas is affordable, user-friendly and time-saving. Thus, GSV imagery tool has been proliferated to perform automated environmental assessment in health field (Rzotkiewicz et al., 2018), including measuring daily accessed street greenery. In terms of the assessment of Green View Index (GVI) by GSV, it is demonstrated that the GSV imagery method for street greenery is more efficient and accurate than the field survey approach (Berland and Lange, 2017). Additionally, street greenery has been documented to be a stronger predictor of physical activity, compared to the top-down greenness assessed by Normalized Difference Vegetation Index (NDVI) or other traditional approaches. This is because the eye-level greenness assessed by GVI can more closely reflect the actual greenery exposure for pedestrians than the top-down greenness (Lu et al., 2019). Similarly, Ki and Lee (2021) reported that street greenness can predict walking behaviour better than the conventional greenery variables since it represents the amount and quality of tree cover from a pedestrian perspective. The GVI extraction of the deep learning method using GSV is a promising approach to capture street greenness. However, the attribute of eye-level greenness is often excluded in the running satisfaction literature adopting spatial approaches. This is partly due to the lack of the geo-located data of the running routes with individual perceptions.

2.3. Spatial units of analysis

Circular or network buffers created around individual home locations have often been used as the spatial units to study how environmental variables affect physical activity behaviours (Ki and Lee, 2021; Vich et al., 2019). The utilization of home location buffer focuses simply on the environmental characteristics in the immediate vicinity of individuals' home locations (Laatikainen et al., 2018). Nonetheless, running routes often stretch over broader spatial extents than walking and other spatially concentrated activities. Thus, the home buffer approach fails to acknowledge the settings where road running actually occurs. Hirsch et al. (2014) revealed the spatial patterns of running routes using a sports-tracking app to address this limitation, but this approach still fails to associate the environmental factors with individuals' perceptions, such as perceived satisfaction and restorativeness.

The utilization of public participation GIS (PPGIS) approach has proliferated in the field of health environment (Jiang et al., 2019; Kajosaari and Pasanen, 2021) since it has potential to integrate the information about human behaviour and experiences with specific physical environment by collecting location-based knowledge. These empirical studies often use digital tools to map location-based behaviours and perceptions from respondents, making it possible to conduct joint analysis of personal-based and place-based data collected by PPGIS method together with other geographic data such as georeferenced census data (Kajosaari and Pasanen, 2021). PPGIS mapped routes have been implied to study the spatial behaviours and activities in urban forests and parks (Gerstenberg et al., 2020; Korpilo et al., 2018; Meyer et al., 2019). These studies demonstrated that the drawn routes can offer valuable insights on the general spatial patterns and concentration of physical exercise (Korpilo et al., 2018). Hence, the PPGIS-based mapped routes have the potential to promote knowledge on the linkages between runners' perceived satisfaction and the characteristics of the environment where running actually takes place.

3. Methods

The purpose of this study is to investigate the associations between perceived satisfaction with running routes and nature exposure along with other built environmental variables. First, we employed the PPGIS method to bridge the gap between the spatial units originated from the traditional home locations and collected mapping routes. The activity path-based measures provide spatially explicit data (Meyer et al., 2019) and can more precisely reflect the settings where the running activity actually occurs due to the continuous nature of running. Second, we assessed the eye-level greenness by using a deep learning technique of fully conventional neural network for semantic segmentation of Google Street View (GSV) images (Li et al., 2015; Toikka et al., 2020). The deep learning approach can represent the actual exposure of runners to greenery on streets. Furthermore, this innovative approach can address the limitations of previous eye-level greenness measuring methods based on site surveys (Ki and Lee, 2021; Lu et al., 2019). Next, we conducted multinomial regression analyses using running satisfaction as outcome and exposure to environmental conditions as predictor to examine the associations between environmental variables and running satisfaction.

3.1. Participants and running data

With a population of 1.2 million, the Helsinki Metropolitan Area is the most densely populated urban area in Finland and comprises the municipalities of Helsinki, Espoo, Vantaa and Kauniainen. The running behaviour data for this study were obtained from the Runnable City survey, which was conducted by a map-based online platform – Maptionnaire between March and April 2019. This survey was conducted amongst the runners who posted their running experiences on Facebook or Instagram over the past three years. A message with a link of the survey and a brief introduction of the study was delivered to the participants via Facebook or Instagram. The data consisted of personal characteristics (i.e. gender, age, education level and income level), running satisfaction level, and the geo-referenced data of home locations and running routes. Some data were irrelevant to the study and is thereby not mentioned here. In the main mapping task in the survey, we requested the respondents to draw their most frequently practised running routes (Gerstenberg et al., 2020; Korpilo et al., 2018) and to indicate the satisfaction level for each route by asking 'How satisfied are you with this route on a scale from 1 to 10′. On average, runners indicated a satisfaction score of 7.83, ranging from 5 to 10. Following the existing literature on satisfaction levels (Braunsberger and Gates, 2009), the equal interval scales approach was applied to define unsatisfied (scores of 5 and 6), satisfied (scores of 7 and 8), and extremely satisfied (scores of 9 and 10).

3.2. Urban greenness and blueness

Both the NDVI and GVI were measured within the buffer zones to investigate the association between urban greenness and running satisfaction. The NDVI along with blue space density are the common attributes to indicate the levels of urban greenness from a top-down perspective, which excludes the three-dimensional greenery forms on streets (Ki and Lee, 2021). The NDVI was calculated with the following equation: NDVI = (NIR-Red)/(NIR + Red), where NIR is the near-infrared band and Red is the visible red light. The NDVI values range from -1.0–1.0, with negative values representing water or barren areas and higher positive values indicating more vegetation greenness. The average NVDI value within the buffer zone of a specific running route was calculated based on the NDVI raster file. The blue space density was calculated by the proportion of aquatic environmental exposure within the route buffers.

The GVI, which indicates the amount of eye-level greenness perceived by runners on streets (Jiang et al., 2017), was measured by averaging the GVI values of GSV images obtained within the running route buffers. First, sample points for collecting GSV images were created randomly with a 50 m interval along the street networks. The coordinates of these points were utilized to download GSV images if a street view panorama exists within 50 m of the sample point location. Six GSV images were obtained for each point with headings of 0° (North), 60°, 120°, 180°, 240° and 300° (Fig. 1). Only the images that were taken between May and September were collected to make sure the foliage is green. The GVI values were calculated using a deep learning technique of fully conventional neural network for semantic segmentation (Ki and Lee, 2021; Li et al., 2015). The GVI for each sample point was defined as the average GVI value of six images from that location. All the processes for GVI calculation mentioned above were performed using Python scripts (Toikka et al., 2020).

3.3. Independent variables: predictors of running satisfaction

We assessed running-influencing environmental factors within the running route buffers. Independent variables comprise nature exposure (including GVI, NDVI and blue space density), other built environmental factors as well as demographic characteristics. Built environmental variables include intersections density, public transport nodes density, traffic lights density, street density, population density, terrain slope and land-use mix. These variables have been reported to affect running satisfaction in previous studies (Campbell et al., 2019; Deelen et al., 2019; Ettema, 2015; Schuurman et al., 2021; Shashank et al., 2021). Intersections, public transport nodes and traffic lights densities are defined as the number of respective points per unit area. Land-use mix, or entropy index, is calculated by measuring the levels of heterogeneity of land uses within the buffer zones. Three land use types were investigated: residential, commercial and open green space. The slope was calculated using a slope map generated from a GDAL-supported elevation raster. The slope within a buffer zone was measured by the average value of the raster file. Personal characteristics include gender, age, education background and income level. The average house price of the neighbourhood where the respondent lives was employed as a proxy for the income level.

We performed visual inspection to increase the reliability of the mapped routes by eliminating the running routes without an assessment of satisfaction level or regarded as unreasonable (in total 64), e.g., when a route was drawn by a single straight line covering a broad spatial extent. After the data cleaning process, we acquired 545 mapped routes for data analysis. All variables were calculated within the buffer of 50 m, 100 m and 200 m of each running route (Fig. 2) approximating street segment width, street segment length, and line of sight, respectively (Morrison et al., 2019). Using multiple buffer sizes can alleviate the modifiable area unit problem (MAUP), which may potentially lead to inconsistent analysis results due to the different spatial scales of aggregated unit (Lu et al., 2019). All spatial analyses were performed in QGIS 3.10 software.

3.4. Statistical analyses

After data cleaning, the characteristics of green space (including blue space) and other built environmental variables were summarized through descriptive analysis. To compute the required sample size, we conducted an a priori power analysis using G*Power (Faul et al., 2009). The result indicated 478 samples were required to achieve a statistical power of 95 % at alpha level of 0.05 and to identify the index of the effect size odds ratio of 3.47 (which is equivalent to Cohen's d = 0.5 (Chen et al., 2010) and suggests a moderate effect size). In our study, 545 running routes that included an assessment of satisfaction level were collected, which is larger than the required sample size of this research.

The multinomial logistic regression analyses were performed using SPSS version 22 to assess the effects of nature exposure and other built environmental variables on the runners' satisfaction level. The running satisfaction is the dependent variable and is subdivided into three categories: unsatisfied, satisfied and extremely satisfied. Independent variables consist of NDVI, GVI, blue space density, other running-related environmental factors together with individual characteristics as covariates because these variables have been regarded as running-influencing factors in previous research (Deelen et al., 2019; Ettema, 2015; Shashank et al., 2021).

4. Results

4.1. Participant characteristics

The individual characteristics of the survey participants including the satisfaction levels of running environment are shown in Table 1. In general, runners indicated relatively high level of satisfaction. The proportions of runners reporting unsatisfied, satisfied and extremely

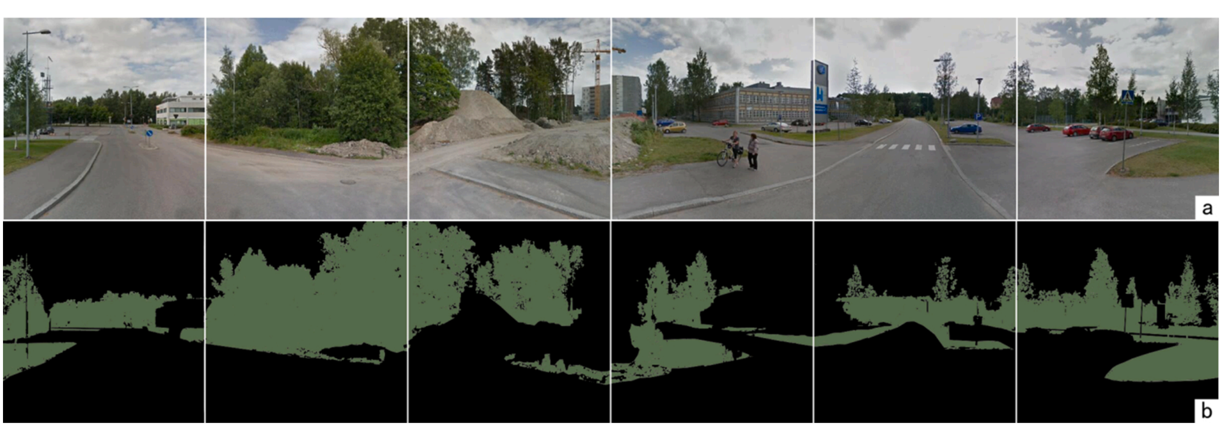

Fig. 1. An example of GSV images (a) in its original form collection and (b) in the labelled form showing greenery pixels with semantic segmentation technique.

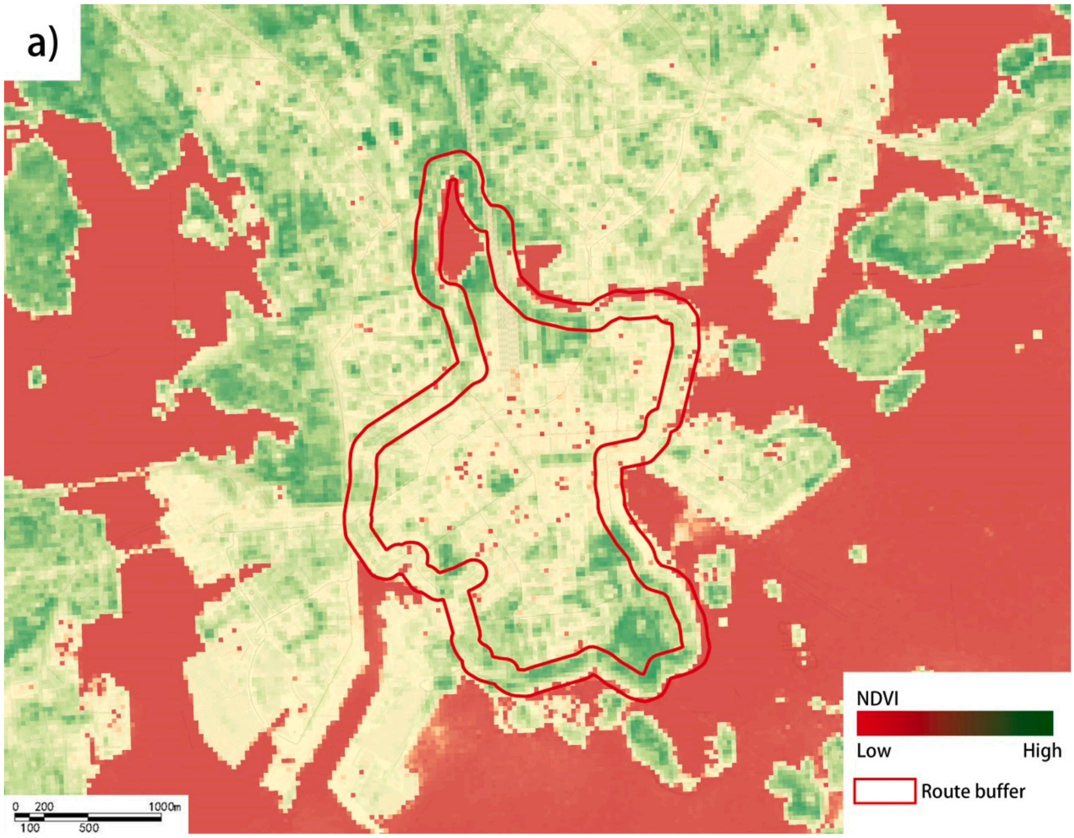

Fig. 2. Top-down greenness assessed by NDVI (a), eye-level greenness assessed by GVI (b), and blue space density (c) in the 100 m buffer of a running route. The blue space buffer is created using 100 m buffer of coastline and 50 m buffer of other water bodies (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

satisfied were 22.0 %, 40.2 % and 37.8 %, respectively. There were slightly more male (54.6 %) than female runners (45.4 %), but the running environment was deemed as unsatisfactory by more females than males (27.0 % vs 17.6 %). The elderly (born between 1960 and 1979) constituted about 18.9 % of all participants but almost half of them were extremely satisfied with their running routes. Runners with basic education comprised only 14.5 % of the sample but had the highest proportion of running routes being rated as unsatisfactory (35.0 %). About 36.5 % of runners lived in the area with the lowest house price (between 2500 and 4000 EUR/m^2). However, most of them considered the running routes as extremely satisfying (43.1 %).

4.2. Description of running environment

The descriptive statistics of the characteristics of the green and blue spaces and other built environmental variables are shown in Table 2. The average top-down greenness values calculated by NDVI were 0.23 in all three buffer zones. The average eye-level greenness values assessed by GVI were 29.89 %, 29.88 % and 29.80 % for the 50 m, 100 m and 200 m buffer zones, respectively. The NDVI and GVI were highly correlated (Pearson correlation $r = 0.833$, 0.837 and 0.842 in the 50 m, 100 m and 200 m buffers, respectively; p-values < 0.001 in all buffers). The average blue space density values decreased by buffer size and were 34.95 %, 33.24 %, and 30.27 % for the 50 m, 100 m and 200 m buffers, respectively.

4.3. Predictors for running satisfaction

We examined how nature exposure and other built environmental factors influenced the satisfaction levels of runners using three logistic regression models (Fig. 3). The category of extremely satisfied was used as a reference group.

The top-down and eye-level greenness were both positively associated with the running satisfaction for the unsatisfactory group in three models. For the runners who indicated they were unsatisfied with the running routes, the exposure to more eye-level greenness was negatively associated with the odds of reporting unsatisfied in all three models, odds ratios (95 % CI): 0.91 (0.84–0.98) in 50 m buffer, 0.89 (0.83–0.97) in 100 m buffer, and 0.91 (0.84–0.98) in 200 m buffer. Similarly, the runners who reported unsatisfied and exposed to more top-down greenness were less likely to indicate unsatisfied in all three buffers, odds ratios (95 % CI): 0.79 (0.69–0.90) in 50 m buffer, 0.79 (0.69–0.91) in 100 m buffer, and 0.74 (0.64–0.85) in 200 m buffer. Blue space density was also positively associated with perceived satisfaction with running environment for the unsatisfactory group. The runners who reported unsatisfied and ran in the routes with more blue spaces were less likely to indicate low level of perceived satisfaction in three buffers, odds ratios (95 % CI): 0.97 (0.95–0.99) in 50 m buffer, 0.96 (0.94–0.98) in 100 m buffer, and 0.94 (0.91–0.97) in 200 m buffer.

Public transport nodes were positively associated with running satisfaction in all three models except for the unsatisfactory group in the 50 m buffer, indicating that the threshold distance for public transport nodes density variable exists between 50 m and 100 m. In terms of the satisfactory group, traffic light density was negatively associated with running satisfaction for the three buffer zones. Street density was also negatively linked to running satisfaction except in the 50 m buffer. Among the individual characteristics, only education background indicated significant association with running satisfaction for the unsatisfactory group in all three buffers. To be specific, the runners with basic

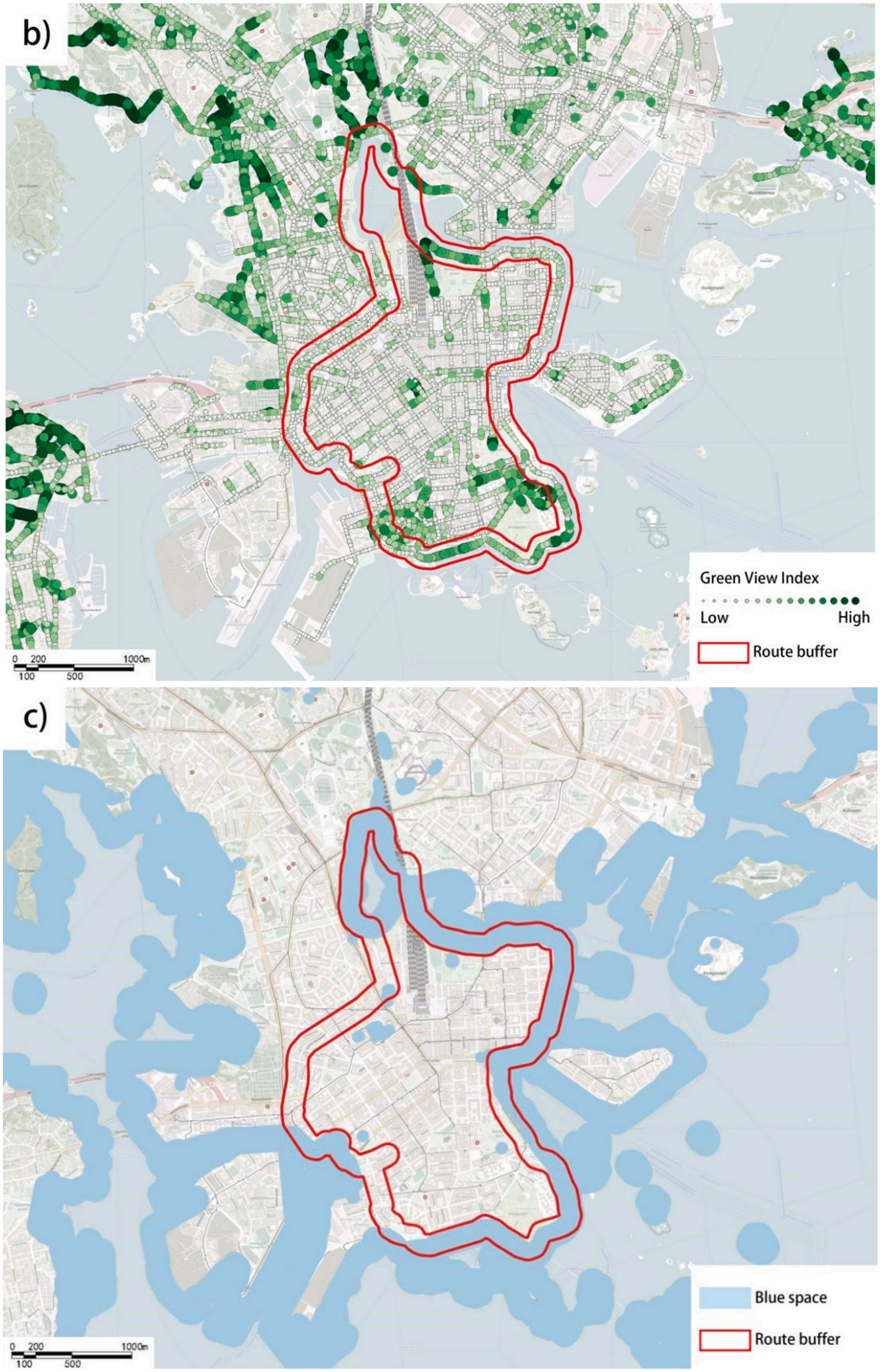

Fig. 2. (*continued*).

education were 5.60, 4.44 and 3.40 times more likely to indicate unsatisfactory perceptions than the runners with graduate degrees in 50 m, 100 m and 200 m buffers, respectively.

5. Discussion

In this study, we analysed 545 PPGIS-based drawn routes marked by

Table 1
Participant characteristics (N = 249).

Variables	N	%	Satisfaction levels		
			unsatisfied	satisfied	extremely satisfied
Gender					
male	136	54.6	17.6 %	44.9 %	37.5 %
female	113	45.4	27.0 %	34.1 %	39.0 %
Year of birth					
1990–2005	104	41.8	24.9%	35.2 %	39.9 %
1980–1989	98	39.4	21.0%	46.9 %	32.1 %
1960–1979	47	18.9	20.2%	30.9 %	48.9 %
Education level					
Basic education	36	14.5	35.0 %	35.0 %	30.0 %
Undergraduate	95	38.2	21.6%	37.0 %	41.4 %
Graduate	118	47.4	20.1%	42.6 %	37.3 %
House price (EUR/m2)					
2500–4000	66	36.5	19.2%	37.7 %	43.1 %
4001–7000	77	30.9	26.6%	37.2 %	36.2 %
7001–9000	23	9.2	34.5%	36.9 %	28.6 %

Table 2
Descriptive statistics for environmental variables (N = 545).

Variables	Buffer = 50 m		Buffer = 100 m		Buffer = 200 m	
	Mean	std. dev.	Mean	std. dev.	Mean	std. dev.
Green/blue spaces						
Top-down greenness (NDVI)	0.23	0.07	0.23	0.07	0.23	0.07
Eye-level greenness (GVI/%)	29.89	10.80	29.88	10.65	29.80	10.50
Blue space density (%)	34.95	25.18	33.24	22.98	30.27	18.72
Built environment						
Intersection density (no./km^2)	89.77	65.01	64.65	42.44	52.15	33.05
Public transport nodes density (no./km^2)	84.14	74.58	64.32	54.59	53.58	45.45
Traffic lights density (no./km^2)	11.73	14.85	7.82	9.29	5.77	6.90
Street density (km/km^2)	40.82	15.41	37.23	13.51	35.28	12.87
Population density (ppl/km^2)	361.00	245.28	368.68	243.02	381.64	237.20
Terrain slope (degree)	5.05	1.01	5.06	0.95	5.04	0.88
Land-use mix (entropy score)	0.67	0.12	0.68	0.12	0.69	0.12

249 runners in the Helsinki Metropolitan Area, Finland. Overall, runners indicated a high level of satisfaction (an average score of 7.83). The perceived satisfaction with running routes was positively associated with nature exposure including eye-level greenness, top-down greenness and blue space density. Furthermore, the traffic-related factors breaking runners' momentum, such as traffic light density, had negative effects on running satisfaction. The evidence-based knowledge opens up a larger potential to develop urban planning and design strategies to promote running behaviour by modifying the exposure to environmental conditions.

5.1. Exposure to nature and running

It is generally documented that exposure to green and blue spaces encourages the odds, frequency and satisfaction with running activities (Ettema, 2015; Schuurman et al., 2021; Tan et al., 2021). Consistent with this, we found streetscape greenery was positively associated with running satisfaction (Deelen et al., 2019). Our study adds to the literature since street greenness assessed by GVI utilizing sematic segmentation technique takes not only street trees, but also other forms of urban greening into consideration, such as vertical greening. Additionally, the eye-level greenness measured by GVI may better reflect the three-dimensional greenery perceived by runners on streets, especially the vigour and vitality of greenery, than the traditional measurements of greenness such as park density and NDVI. Consequently, the GVI approach can more accurately reveal the amount and quality of street greenness exposed to runners.

A positive association between top-down greenness and running satisfaction was found in the models. This result contrasts with the finding of a cycling study by Lu et al. (2019). An explanation may be that running is more likely to occur within urban forests and parks than on urban roads with other traffics since green running environments are deemed as more attractive and restorative than urban settings (Bodin and Hartig, 2003). Another study by Ettema (2015) also demonstrated that runners prefer natural outdoor environments over urban settings because green spaces help runners to escape from daily hassles. Nonetheless, compared to running, cycling as a mode of transport more often takes place in town with low levels of nature exposure (Lu et al., 2019).

The results of blue spaces are in line with previous literature indicating that higher levels of aquatic environment density significantly promote perceived running satisfaction. Blue natural outdoor environments are often regarded as esthetical and attractive amongst green spaces, boosting the promotion of physical activities such as running and jogging (Karusisi et al., 2012; Völker and Kistemann, 2015). The proximity to blue spaces is positively associated with the odds of physical exercises (Edwards et al., 2014; Karusisi et al., 2012). Besides, exercising in blue spaces is more likely to be associated with restorative benefits than in built outdoor settings (Kajosaari and Pasanen, 2021).

The positive relationships between nature exposure and running—as one type of moderate to vigorous physical activity—are also consistent with the findings of previous studies on the benefits of green and blue spaces on public health (Triguero-Mas et al., 2015; Völker et al., 2018). The visibility of greenery was found to be positively associated with health benefits, both physically and mentally (Rzotkiewicz et al., 2018). Similarly, Nutsford et al. (2016) demonstrated the positive relationship between the exposure to visible aquatic environment and lower psychological distress.

5.2. Other built environment characteristics

Besides nature exposure, we also observed statistically significant associations between running satisfaction and traffic related variables. The results of public transport nodes are consistent with previous findings that greater accessibility is positively associated with physical activities (Sung et al., 2014). Public transport nodes are more likely to locate in densely populated and mixed developed areas. The presence of pedestrians and facilities, such as cafes and shops creates convivial public spaces, resulting in improved running satisfaction (Ettema, 2015). However, the traffic lights density is inversely associated with the running satisfaction. This is supported by studies (Deelen et al., 2019; Ettema, 2015) indicating that the hindrance from other traffic prevents runners from maintaining their momentum and has a negative influence on perceived satisfaction. The street density is also negatively related to running satisfaction. This finding is supported by the fact that runners prefer unpaved roads in natural environments with low path density over paved roads in town where runners may have to stop for other traffic users (Ettema, 2015).

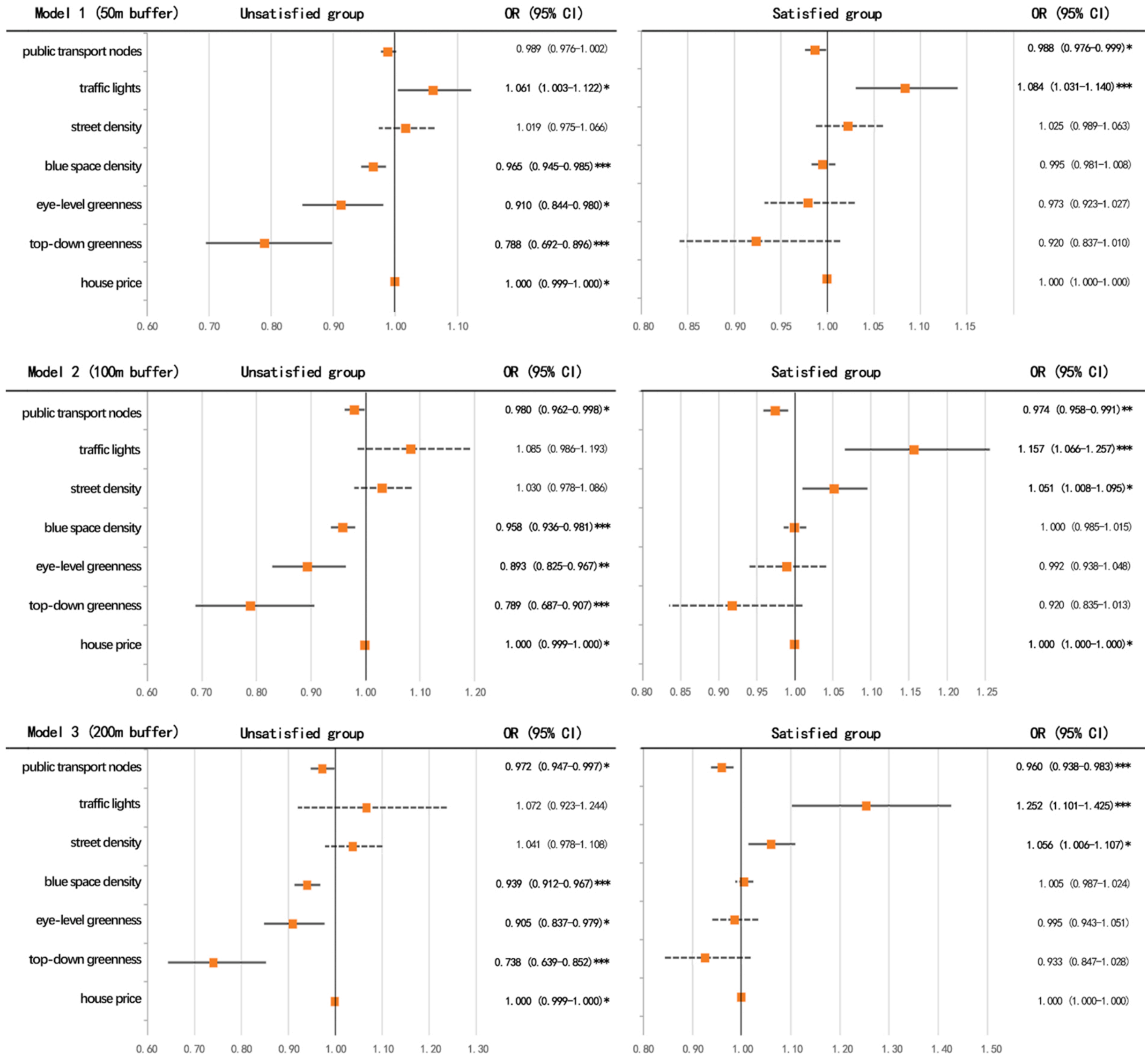

Fig. 3. Multinomial logistic regression outcomes of key environmental predictors of perceived satisfaction in the 50 m, 100 m and 200 m buffers. The full lines indicate significant relationship while the dashed lines represent insignificant relationship.

We found no significant relationship between the land use mix entropy and perceived running satisfaction, which is inconsistent with findings in the study by Sung et al. (2014). This difference might be explained by the buffer mechanism: the running environments were investigated by developing buffers around the running paths, which are highly integrated with the street networks. Therefore, the buffers may not perfectly reflect the land use patterns of the surroundings compared to those using home location for buffer analysis. Another explanation may be that the land uses are relatively homogenous in the study area. The running satisfaction is also not related to population density, the variable of which was found to be positively associated with the odds of physical activities in other international studies (Boakye et al., 2021; Lu et al., 2019). One potential explanation for this is the study area is sparsely populated as opposed to the densely populated city—Hong Kong—used in other study (Lu et al., 2019).

According to the model of customer satisfaction developed by Kano et al. (1984), must-be qualities are regarded as basic needs and the fulfilment of these requirements will not enhance running satisfaction. Attractive qualities are not expected by runners, and the fulfilment of them will lead to paramount satisfaction. One-dimensional qualities are explicitly requested by runners and the performance of these attributes is positively and linearly related to the satisfaction level (Sauerwein et al., 1996). We can postulate that nature exposure, just like the must-be requirement, will reduce perceived satisfaction if not fulfilled. Similarly, public transport nodes density can be considered as one-dimensional quality—the higher the public transport nodes density is, the higher the running satisfaction will be and vice versa. Traffic lights density can be regarded as attractive requirement since lower traffic lights density will generate more than proportional satisfaction. Hence, the provision of running routes with easy access to public transport, a minimum of interactions with traffic lights, and increment of nature exposure can act as a practical strategy to enhance running satisfaction.

5.3. Individual characteristics

Among the individual characteristics variables, gender was not significantly associated with running satisfaction. This result is supported by LaCaille et al. (2004) who indicated that running satisfaction is significantly linked to exercise setting instead of gender. Our study only found higher education index to be positively associated with higher levels of perceived satisfaction with running environment.

Education level, according to Tan et al. (2021), was also one of the individual characteristics influencing the odds of individual-based exercises. We tentatively suggest that leisure running is more likely to be performed by better-educated residents in the Helsinki Metropolitan Area who have higher awareness of health, and report a higher level of running satisfaction.

5.4. Implications for landscape and urban planning

Our findings have the potential to grasp several implications for landscape and urban planning. First, running satisfaction is not only affected by top-down greenness but also by eye-level greenness. Hence, planners and related policy makers should also take street greenness into account instead of only focusing on the size, accessibility, and the number of greenspaces. The visibility of street greenery is also closely related to the running experience. Second, blue space density is also positively related to running satisfaction. Hence to facilitate running involvement, more attention should be paid to the provision of waterway views at jogging paths (Tan et al., 2021). For example, running routes should be planned or built adjacent to or along those aesthetical aquatic environments. Third, running satisfaction is positively linked to public transport nodes density, but reversely related to the existence of traffic lights which breaks runners' momentum (Ettema, 2015). Therefore, urban planners and designers should facilitate running routes with a minimum of interactions with traffic lights and easy access to public transportation.

5.5. Strengths and limitations

This study has several strengths. First, we utilize the running routes collected by PPGIS approach to investigate the relationships between perceived satisfaction with running routes and nature exposure. This activity path-based measure approach enables us to investigate the running-influencing environmental variables within and along the running routes, making it possible to accurately represent those exact geographic units that runners are exposed to. Most researchers utilize circular buffers or administrative units as the spatial units to analyse the relationships between physical activities and environmental characteristics. However, these geographic units fail to reflect the physical environments where the activities actually take place (Laatikainen et al., 2018), especially those physical activities with continuous movement, such as walking, running and cycling. Second, to our best knowledge, this is one of the first studies that uses a deep learning technique to assess eye-level greenness and to relate it with running satisfaction. Third, our study uses multiple buffer sizes for assessing environmental factors to achieve robust findings and avoid the modifiable area unit problem.

Certain limitations must be acknowledged. Our sample was drawn from the participants with running experiences in the past three years. Participants without related experiences were excluded. Thus, we fail to analyse the associations between environmental characteristics and the odds of running. Hence, future studies should also include those participants without running experience and investigate why they choose not to run. Besides, although those running routes that are too coarse to analyse have been eliminated, the accuracy of the drawn line data collected from runners using public participation GIS approach still needs further evidence. Hence, future studies should improve the spatial accuracy of running routes, for example, by integrating PPGIS data with volunteered geographic information (VGI) data. This study also neglects the impact of the perceived aesthetics and the perceived safety of the running routes. Future research may investigate the impact of perceived environment on running satisfaction.

6. Conclusions

This study contributes to a more complete insight into the associations between perceived satisfaction with running environment and nature exposure. We adopted the PPGIS-based mapped routes buffer approach, which can precisely record the settings where running activity actually occurs. The main finding in this study is that exposure to nature can be regarded as must-be qualities, indicating that once these requirements cannot be fulfilled, the satisfaction with running routes will decrease dramatically. Our findings also suggest that the traffic-related factors maintaining runners' momentum can be considered as attractive qualities. For example, low density of traffic light delights the runners and results in promoting perceived satisfaction. Public transport nodes density is viewed as one-dimensional quality: the more accessible the running environment is, the merrier the runners will be. To develop a running-friendly city, future urban planning and design policies should be oriented towards improving runners' nature exposure, including eye-level greenness, top-down greenness and the exposure to blue space. The positive impacts of nature exposure on running satisfaction further verify the linkages between landscape and public health.

CRediT authorship contribution statement

Dengkai Huang: Conceptualization, Methodology, Software, Data curation, Formal analysis, Visualization, Writing - original draft, Investigation, Writing - review & editing. **Bin Jiang:** Writing - original draft, Writing - review & editing, Supervision. **Lei Yuan:** Conceptualization, Supervision, Project administration, Writing - review & editing, Funding acquisition.

Declaration of Competing Interest

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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