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Assessing runners' exposure to natural and built environments in the Netherlands: A descriptive assessment based on GPS tracking

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ABSTRACT

Running is a convenient physical activity that has gained popularity. However, little is known about runners' running environments and how they differ from their residential environments. To fill this gap, this study examines runners' exposure to natural and built environments along their running routes and assesses the difference between running and residential environments. We collected running track data from Endmondo, a fitness data platform, and used it to determine runners' residency. Moreover, we used open geographical data to calculate a range of environmental variables within their residential areas and along their running trajectories. We applied t-tests to assess differences across objectively measured environmental variables between urban and rural runners, considering geographic, temporal and track-specific strata. We found that the running environments of urban and rural runners were diverse and had distinct characteristics. The results suggest policies to promote running acknowledging these differences between running environments in urban and rural areas.

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Built and natural environments; running; The Netherlands

Introduction

The World Health Organization (WHO) recommends that all adults undertake at least 150–300 minutes of moderate-intensity, or 75–100 minutes of vigorous-intensity aerobic physical activity, per week (Bull et al. 2020). These guidelines highlight the importance of regular exercise. Studies suggested that physical activities among urban and rural residents were affected by their geographical differences (Loucaides et al. 2004; Ewing et al. 2014; Regis et al. 2016) in cities and countryside. In this case, understanding the differences of urban and rural environments for exercising is of great importance to promote physical activities. As such, running is a convenient and recreational physical activity contributing to people's physical and mental health (Lee et al. 2017).

In the Netherlands, running has grown in popularity over the past decades (Hover et al. 2015). Some studies reported that running could be encouraged or discouraged by different natural and built environmental factors, but the evidence base is still limited. The suggested factors include accessibility to green spaces (e.g. parks) (Ettema 2016; Deelen et al. 2017; Lee and Kwan 2019), residential density (Cervero and Kockelman 1997), connectivity of streets (Hitchings and Latham 2017), and the degree of urbanization (Tsimeas et al. 2005; García et al. 2011; Golle et al. 2014; Ewing et al. 2014; Regis et al. 2016; Hoekman et al. 2017). However, in most of these studies (i.e. studies of running environments and the

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difference of performance of physical activities in urban and rural areas (Loucaides et al. 2004; Ewing et al. 2014; Regis et al. 2016; Hitchings and Latham 2017), the environmental factors were not measured objectively but collected through self-reported questionnaires based on peoples' perceptions. Evidence is mounting that such subjective measures induce inaccuracy in representing the surrounding environment (Jankowska et al. 2015; Romanillos et al. 2016).

One way to mitigate these uncertainties to a certain extent is to measure the environmental factors objectively through geographic information systems (GISs) and integrate the data with information obtained through Global Positioning Systems (GPS) (Duncan et al. 2009; Deelen et al. 2019). This integrative approach recently gained popularity (Tsimeas et al. 2005; Duncan et al. 2009; Badland et al. 2010; Troped et al. 2010; Golle et al. 2014; Dessing et al. 2016; Tamura et al. 2019), and was accelerated due to the development of GPS-enabled lightweight devices and the use of accelerometers to monitor the intensity of people's physical activity (Jones et al. 2009). For example, Tamura et al. (2019) investigated the association between population density, street density and land use mix using GPS-tracked moderate to vigorous physical activities (MVPA) and light to vigorous physical activities (LPA). They found a negative association between MVPA with street density and land use mix and a negative association between population density and LPA. Dessing et al. (2016) also included residential density, presence of water bodies, the availability of parks and traffic to examine which characteristics affected pupils' choice of daily commuting roads measured by a GPS device.

However, these existing studies based on GPS-based tracking to explore physical activity levels faced some shortcomings (Tsimeas et al. 2005; Duncan et al. 2009; Badland et al. 2010; Troped et al. 2010; Golle et al. 2014; Dessing et al. 2016; Tamura et al. 2019). None focused specifically on running. Furthermore, as mentioned before, characteristics describing a runner-friendly environment (e.g. presence of green spaces), and related to the difference between urban and rural environment were not measured objectively based on GPS (Ettema 2016; Deelen et al. 2017; Lee and Kwan 2019). Thus, in this paper we investigated people's running environment with the assistance of mobile GPS applications to gain insights into the characteristics of attractive running environments. Besides,

To address these limitations, we assess runners' environmental exposure in different urban and rural areas. Furthermore, within the urban and rural strata of runners, we aimed to compare the running environments in terms of running distances, duration and day of the week (weekends vs weekdays). Our results may assist people and the government in garnering insights into the environmental characteristics encouraging running.

Data and methods

Data collection

We collected GPS data from the mobile tracking application Endomondo. Endomondo tracks people's locations by collecting users' GPS data. Users can also upload their tracks automatically via a connection with Garmin Connect, Polar Flow, and the Jabra Sport Life app, in "www.endomondo.com" or manually by drawing their workout route on the Endomondo map including workout-related information (e.g. duration and workout type). We downloaded workouts that users made publicly available as JavaScript Object Notation (JSON). Our eligible subjects for the present analysis were any runners (regardless of any restrictions (e.g. age and sex)) living in the Netherlands using Endomondo and who uploaded their information in the year 2015. For this analysis, 66497 GPS tracks were obtained including the workout id, author id, workout type, workout duration, workout distance, maximum speed, average speed, and the location where the users participated in the physical activity, etc.

Table 1. Basic information of supplementary geographical data and census data.

Data		Publication year	Source
Geographical data	NDVI image derived from Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and Landsat 8 Operational Land Imager	2015	Google Earth Engine cloud computing platform
	Land Use File (Bestand Bodemgebruik)	2015	Statistics Netherlands
	Key Registers Addresses and Buildings (Basisregistratie Adressen en Gebouwen)	2015	Statistics Netherlands
	Key Register Topography (BRT) at 1:10,000	2015	Statistics Netherlands
	Land Use Database of the Netherlands	2015	Wageningen University & Research
Census data	Functional urban areas	2015	Organisation for Economic Co-operation and Development
	6-digit postcode area	2015	ArcGIS Hub
	Neighborhood and neighborhood statistics (Kerncijfers wijken en buurten)	2015	Statistics Netherlands

Apart from the GPS data, we collected geographical and census data (Table 1) describing the characteristics of the environment (Sallis and Owen 1997). All geographic data are publicly available.

Urban and rural residence

Due to a lack of address locations on whether the runners were living in cities or the countryside, we used functional urban areas and the six-digit postal code (PC6) areas to define runners' urban/rural status (Figure 1). Each PC6 area contains, on average, 15–20 addresses. We developed a method (see Figure 2) to define the runners' urban/rural residency. The method began with grouping the track(s) taken by the same runner. Then, the starting and ending points of each track were calculated. There were two scenarios in detecting a runner's home at a six-digit postcode level. In scenario A, the most often selected PC6 area contained the residential buildings and intersected with the starting point of each track. In case the runner had multiple courses, the most frequently referred to the PC6 area were/was chosen. If there was more than one PC6 area with the same frequency, a candidate was randomly selected. In scenario B, both starting and ending points were considered and the starting and ending points were in the same PC6 area in which the residential building was located. If multiple PC6 areas fitted the criteria, similar to scenario A, the PC6 area with the highest frequency were/was chosen. Thereafter, if there was more than one PC6 area with the same frequency, a candidate was randomly selected. Finally, after selecting the matching results (i.e. selected PC6 area) in accordance with method A and B, a runner was characterized as urban, i.e. if the centroid of their PC6 area was situated in one of the functional urban areas (Dijkstra et al. 2019), otherwise, it was classified as rural.

Natural and built environmental variables

Based on previous studies (Troped et al. 2010; Rodríguez et al. 2012; Dessing et al. 2016; Klompmaker et al. 2019; Tamura et al. 2019) and the available data, we calculated six environmental variables: the level of greenness, residential building density, land use mix, street connectivity, urbanisation index and the proportion of water bodies. The environmental exposures were assessed by means of GIS-based buffer analysis. Following earlier studies (Oliver et al. 2007; Badland et al. 2010; James et al. 2014; Farrell et al. 2015; Dessing et al. 2016), we chose three buffer sizes (i.e. 25 m, 50 m and 100 m) to delineate the environmental context along each GPS track. We used 1,000 m radii around the centroid of each PC6 area to capture the residential environmental characteristics as done previously (Berke et al. 2007; Madsen et al. 2014).

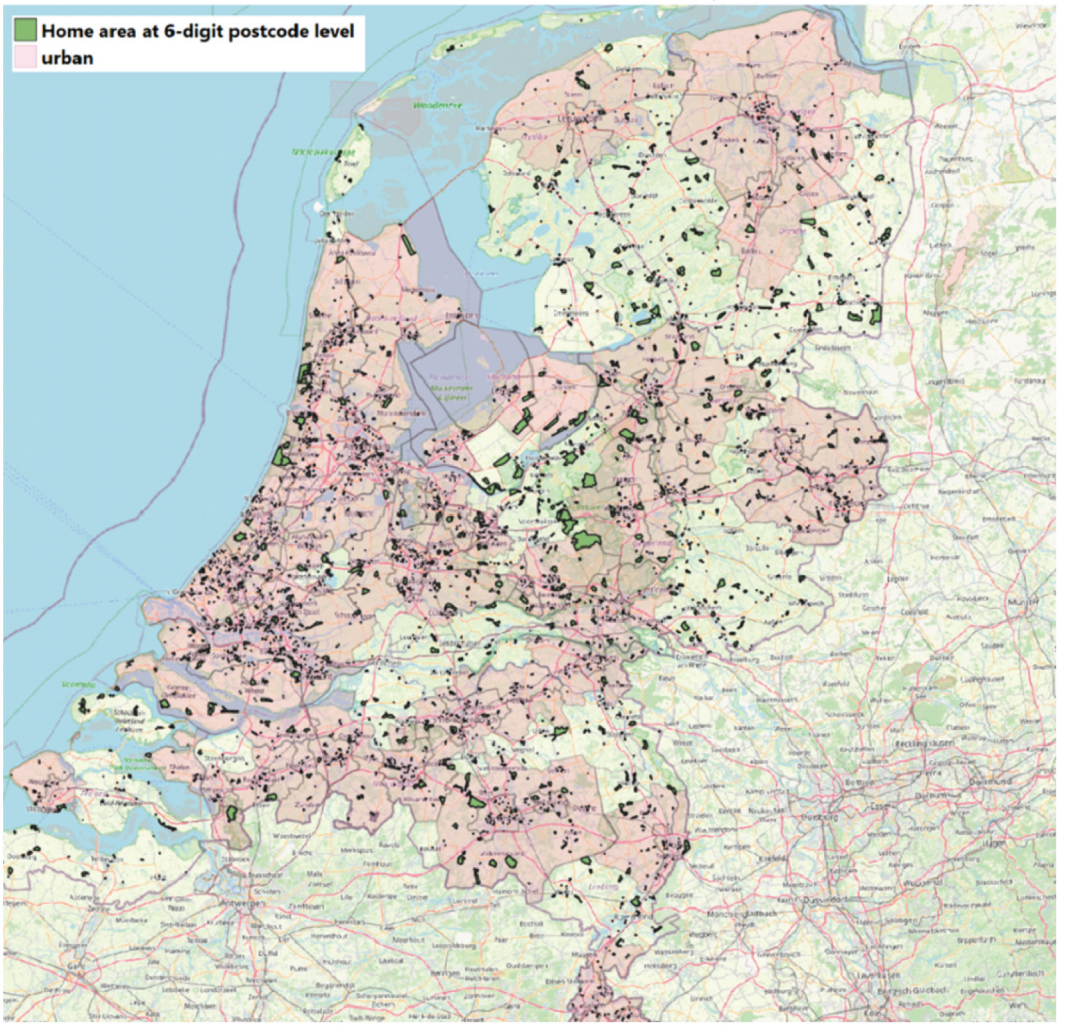

Figure 1. Detected home areas at 6-digit postcode level inside/outside functional Urban areas.

Statistical analysis

In addition to summary statistics, we used t-tests to assess mean differences between the environments of urban and rural runners. To be statistically significant, p-values needed to be < 0.05 (Tsimeas et al. 2005; Jones et al. 2009; Hoekman et al. 2017). We also conducted t-tests to assess the differences of running environment of the sub-groups across urban and rural runners. Further, we conducted stratified analyses based on weekday and weekend runners, runners running inside/outside their residential neighborhoods (Table 1), runners with different running durations (≤30 min and >30 min, running distance (≤3,000 m, 3,001–5,000 m and > 5,000 m) and frequency (≤24, 24–48, > 48 in which 10 and 20 times in five months equals 24 and 48 times a year (Table 2)) (from some runner-friendly websites, for example, 'https://www.active.com/running/articles/how- far-should-you-run' <30 min is recommended for a novice runner and > 3,000 m is proposed to aim further).

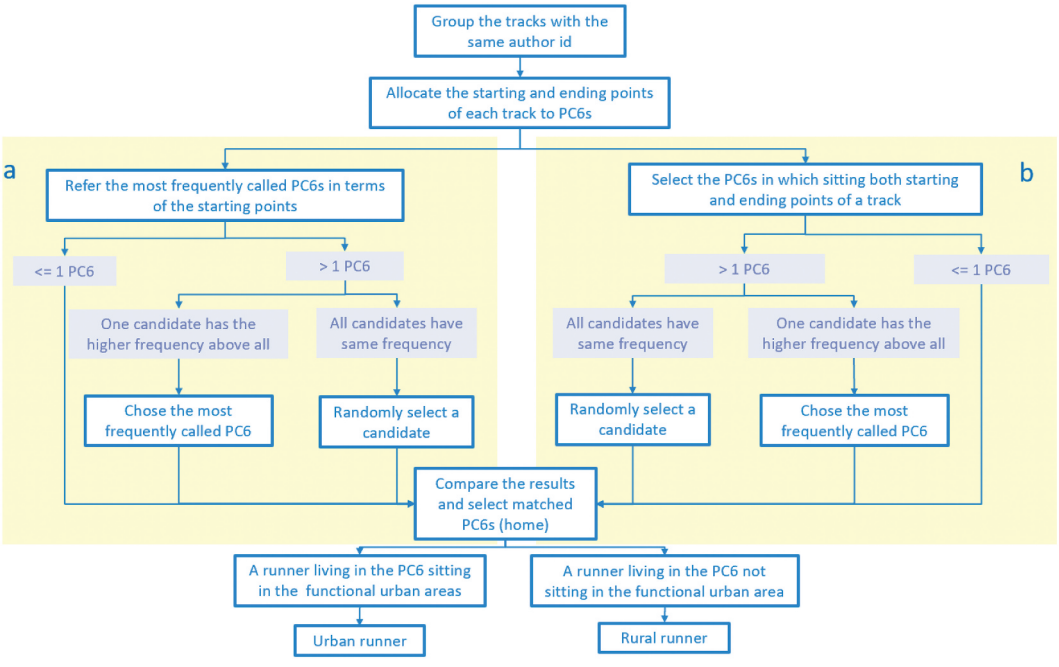

Figure 2. Data processing workflow based on GPS tracks, functional urban areas and 6-digit postcode areas to determine the urban/rural status of a runner.

Table 2. Classifications of GPS data regarding running distance, duration, and frequency.

Running duration (min)	Running frequency	Running distance (m)
≤ 30	≤ 24	≤ 3000
> 30	24–48	3000–5000
	>48	>5000

Results

Descriptive statistics and comparisons of urban and rural runners' running and residential environments

The results from the GPS-based method showed that among all runners, there were 25,720 tracks of 2,853 runners living in urban areas, and 8,140 tracks of 946 runners living in the countryside (Table 3). Besides, Table 3 shows comparisons of running environments of urban and rural runners within 25 m along their tracks. As shown in the table, rural runners were exposed to running environments with higher mean levels of greenness ($p < 0.01$) and lower mean residential building density ($p < 0.01$), urbanization ($p < 0.01$), land use mix ($p < 0.01$), and presence of surface water ($p < 0.01$). Urban runners exercised at places with higher averages of the numbers of dead ends ($p < 0.01$) and ≥ four-way crossings ($p < 0.01$). The running environments were also measured within 50 and 100 m buffers, but we only report the 25 m results in Sections 3.2–3.6. The remaining results are given in Appendix A.

Table 3 shows comparisons of residential environments of urban and rural runners. As shown in Table 3, rural runners were living in environments with higher means of level of greenness ($p < 0.01$), lower means of residential building density ($p < 0.01$), urbanization index ($p < 0.01$), land use mix ($p < 0.01$), less one and ≥ four-way crossings ($p < 0.01$), and fewer water bodies ($p < 0.01$).

Table 3. Descriptive statistics.

Environmental variables		Urban (n^x = 2853) (n^y = 25750) Mean (SD)	Rural (n^x = 946) (n^y = 8140) Mean (SD)
Level of greenness 25m		0.503 (0.093)**	0.546 (0.078)**
Residential building density 25m		0.379 (0.339)**	0.228 (0.268)**
Urbanization index 25m		1.100 (1.190)**	0.614 (0.597)**
Land use mix 25m		0.510 (0.178)**	0.486 (0.183)**
Count of 1-way crossings 25m		2.660 (2.380)**	2.160 (2.020)**
Count of ≥ 4-way crossings 25m		14.60 (14.70)**	9.690 (11.60)**
Proportion of water body 25m		0.262 (0.186)**	0.218 (0.176)**
Level of greenness 1000m		0.472 (0.101)**	0.547 (0.088)**
Residential building density 1000m		0.238 (0.296)**	0.187 (0.294)**
Urbanization index 1000m		1.640 (1.600)**	0.675 (0.599)**
Land use mix 100m		0.609 (0.205)**	0.498 (0.248)**
Count of 1-way crossings 1000m		55.40 (32.30)**	41.70 (28.80)**
Count of ≥ 4-way crossings 1000m		83.00 (62.60)**	41.40 (37.50)**
Proportion of water body 1000m		0.060 (0.078)**	0.050 (0.091)**
Environmental variables		**Residential buffer 1,000m**	**GPS-based buffer 25m**
Urban(n^x = 2853) (n^y = 25750)	Level of greenness	0.472 (0.101)**	0.503 (0.093)**
	Residential building density	0.238 (0.296)**	0.379 (0.339)**
	Urbanization index	1.640 (1.600)**	1.100 (1.190)**
	Land use mix	0.609 (0.205)**	0.510 (0.178)**
	Count of 1-way crossings	55.40 (32.30)**	2.660 (2.380)**
	Count of 4-way crossings	83.00 (62.60)**	14.60 (14.70)**
	Proportion of water body	0.060 (0.078)**	0.262 (0.186)**
Rural (n^x = 946) (n^y = 8140)	Level of greenness	0.547 (0.088)	0.546 (0.078)
	Residential building density	0.187 (0.294)**	0.228 (0.268)**
	Urbanization index	0.675 (0.599)	0.614 (0.597)
	Land use mix	0.498 (0.248)	0.486 (0.183)
	Count of 1-way crossings	41.70 (28.80)**	2.160 (2.020)**
	Count of 4-way crossings	41.40 (37.50)**	9.690 (11.60)**
	Proportion of water body	0.050 (0.091)**	0.218 (0.176)**

**: Statistically significant difference between urban and rural runners at $p < 0.01$ of t-test.
nx: Number of runners.
ny: Number of tracks.
(a) Descriptive statistics and comparisons of running environments of urban and ruralrunners (buffer = 25m).
**:Statistically significant difference between urban and rural runners at $p < 0.01$ of t-test.
nx: Number of runners.
ny: Number of tracks.
(b) Descriptive statistics and comparisons of residential environments of urban and rural runners (buffer = 1000m).
**:Statistically significant difference between residential (1,000m) and running environments (25m) at $p < 0.01$ of t-test.
nx: Number of runners.
ny: Number of tracks.
(c) Descriptive statistics and comparisons of environmental variables of residential (1,000m) and running environments (25m).

Table 3 demonstrates comparisons between the environmental variables of the urban and rural runners' running environment and residential environment. As we can see from the table, both urban and rural runners ran in environments that had more water bodies ($p < 0.01$) and residential building density ($p < 0.01$) but lower urbanization levels ($p < 0.01$) and less one ($p < 0.01$) and ≥ four-way ($p < 0.01$) crossings. Besides, for urban runners, the level of greenness ($p < 0.01$), of their running environments was comparatively higher than it of their living environments and the means of urbanization index ($p < 0.01$) and land use mix ($p < 0.01$) of their running environments were lower than those of their living environments. Moreover, for all environmental variables, the differences between urban and rural were greater than the differences between running and residential environments.

Analysis of runners running on weekdays and at weekends

The differences between running environments of runners running at weekends and on weekdays are shown in Table 4. For urban runners the land use mix ($p < 0.05$) and one-way ($p < 0.01$) and more than four-way crossings ($p < 0.05$) were higher at weekends than on weekdays. The urbanization levels ($p < 0.05$) were higher on weekdays than at weekends. For rural runners, no significant differences between weekdays and weekends ($p > 0.05$) were observed.

Analysis of running tracks inside and outside neighbourhoods

Table 5 shows that more urban and rural runner exercised outside their neighborhoods. For both urban and rural runners, the level of greenness ($p < 0.01$), land use mix ($p < 0.01$), urbanization ($p < 0.01$), the number of cul-de-sac ($p < 0.01$), ≥ four-way crossings ($p < 0.01$), and water bodies ($p < 0.01$) were higher outside the neighborhoods than inside the neighborhoods. Besides, the residential building density within 25 m around the tracks also increased significantly when urban runners exercised outside their neighbourhoods ($p < 0.01$).

Analysis of running tracks classified by running duration

From Table 6, there were less ≤30 minutes tracks than >30 mins tracks taken by urban and rural runners. For both urban and rural runners showed the same difference between shorter/longer duration (i.e. >30 mins tracks had higher averages of level of greenness ($p < 0.01$), land use mix ($p < 0.01$), density of one ($p < 0.01$) and ≥ four-way crossings ($p < 0.01$) and proportion of water bodies ($p < 0.01$) and lower means of urbanization index ($p < 0.01$)).

Analysis of running tracks classified by running distance

Table 6 presents the environmental variables of surroundings of tracks at the three distance ranges (≤3,000 m, 3,000–5,000 m, ≥5,000 m). A large number of urban or rural runners ran

Table 4. Descriptive statistics of surroundings (≤25 m) of routes taken at weekdays and on weekends (buffer = 25 m).

	Environmental variables	Weekdays (n^a = 15746) (n^b = 4983) Mean (±SD)	Weekends (n^a = 6773) (n^b = 2091) Mean (±SD)
Urban	Level of greenness 25m	0.502 (0.095)	0.508 (0.095)
	Residential building density 25m	0.380 (0.354)	0.372 (0.355)
	Urbanization index 25m	1.110 (1.220)*	1.030 (1.210)*
	Land use mix 25m	0.512 (0.181)*	0.522 (0.185)*
	Count of 1-way crossings 25m	2.620 (2.440)**	2.840 (2.920)**
	Count of ≥ 4-way crossings 25m	14.70 (16.20)*	15.80 (16.80)*
	Proportion of water body 25m	0.263 (0.196)	0.267 (0.199)
Rural	Level of greenness 25m	0.547 (0.079)	0.550 (0.077)
	Residential building density 25m	0.225 (0.276)	0.217 (0.288)
	Urbanization index 25m	0.609 (0.575)	0.627 (1.040)
	Land use mix 25m	0.496 (0.186)	0.479 (0.194)
	Count of 1-way crossings 25m	2.090 (2.030)	2.280 (2.370)
	Count of ≥ 4-way crossings 25m	9.520 (11.60)	10.10 (13.50)
	Proportion of water body 25m	0.223 (0.184)	0.217 (0.184)

*: Statistically significant difference between tracks taken at weekdays/on weekends at $p < 0.05$ of t-test.
**: Statistically significant difference between tracks taken at weekdays/on weekends at $p < 0.01$ of t-test.
na: Number of tracks of urban runners.
nb: Number of tracks of rural runners.

Table 5. Descriptive statistics of surroundings of tracks taken inside and outside neighbourhoods (buffer = 25 m).

	Environmental variables	Inside neighbourhood (n^a = 1469) (n^b = 494) Mean (±SD)	Outside neighbourhood (n^a = 20857) (n^b = 6033) Mean (±SD)
Urban	Level of greenness 25 m	0.464 (0.119)**	0.596 (0.092)**
	Residential building density 25 m	0.344 (0.338)**	0.389 (0.345)**
	Urbanization index 25 m	2.140 (3.040)**	1.060 (1.140)**
	Land use mix 25 m	0.316 (0.235)**	0.531 (0.168)**
	Count of 1-way crossings 25 m	1.000 (1.620)**	2.840 (2.630)**
	Count of ≥ 4-way crossings 25 m	4.090 (6.370)**	15.60 (15.60)**
	Proportion of water body 25 m	0.166 (0.212)**	0.271 (0.189)**
Rural	Level of greenness 25 m	0.519 (0.114)**	0.550 (0.075)**
	Residential building density 25 m	0.202 (0.256)	0.236 (0.270)
	Urbanization index 25 m	1.130 (1.190)**	0.581 (0.500)**
	Land use mix 25 m	0.303 (0.214)**	0.516 (0.169)**
	Count of 1-way crossings 25 m	0.894 (0.146)**	2.260 (2.080)**
	Count of ≥ 4-way crossings 25 m	2.170 (3.380)**	10.50 (12.20)**
	Proportion of water body 25 m	0.149 (0.206)**	0.232 (0.176)**

**: Statistically significant difference between tracks taken inside/outside neighbourhood at $p < 0.01$ of t-test.
na: Number of tracks of urban runners.
nb: Number of tracks of rural runners.

more than 5000 m and comparatively, only a small part of the whole ran less than 3,000 m. For urban runners, as the running distance increased, mean values for level of greenness and land use mix increased. Runners taking routes between 3000 and 5000 m ran across places with significantly higher averages of one ($p < 0.01$) and more than four-way crossings ($p < 0.01$). Runners running less than 3000 m chose environments with comparatively higher means of residential building density ($p < 0.01$), urbanization index ($p < 0.01$) and proportion of water bodies ($p < 0.01$). For rural runners, those who running more than 5,000 m were also exposed to environments with a considerably higher mean level of greenness ($p < 0.01$) and land use mix ($p < 0.05$) than others and those running less than 3,000 m came cross places with a higher average urbanization index ($p < 0.01$). Regarding the runners taking 3,000–5,000 m routes, they also ran into environments with higher mean values of proportion of water bodies ($p < 0.01$), residential building density ($p < 0.01$) and numbers of one ($p < 0.01$) and ≥ four-way crossings ($p < 0.01$).

Analysis of running tracks classified by running frequency

Table 6 shows that there were approximately the same number of runners in each group. For urban runners, mean values of density of one and ≥ four-way crossings were higher for groups at higher running frequency levels. The averages of level of greenness ($p < 0.05$) and proportion of water bodies ($p < 0.01$) of runners running more than 48 times a year were significantly higher. Urban runners running less than 24 time a year had comparatively lower means of land use mix ($p < 0.05$) and urbanization index ($p < 0.01$). Among rural runners, those running more than 48 times a year came across places with considerably higher mean values of urbanization index ($p < 0.01$), land use mix ($p < 0.01$), one ($p < 0.01$) and more than four-way crossings ($p < 0.01$). A higher mean value of proportion of water bodies was seen when the level of running frequency increased. Runners with a frequency between 24 and 48 times a year were exposed to environments with relatively higher mean levels of greenness ($p < 0.05$), but lower means of residential building density ($p < 0.05$) and urbanization index ($p < 0.01$).

Table 6. Analysis results of running tracks classified by running duration, distance and frequency.

	Environmental variables	≤ 30 minutes (n^a = 8540) (n^b = 2638) Mean (±SD)	> 30 minutes (n^a = 13982) (n^b = 4436) Mean (±SD)	
Urban	Level of greenness 25m	0.487 (0.106)**	0.512 (0.092)**	
	Residential building density 25m	0.371 (0.356)	0.382 (0.354)	
	Urbanization index 25m	1.280 (1.700)**	0.910 (1.170)**	
	Land use mix 25m	0.342 (0.228)**	0.522 (0.168)**	
	Count of 1-way crossings 25m	2.360 (3.280)**	6.330 (5.440)**	
	Count of ≥ 4-way crossings 25m	5.420 (8.410)**	20.00 (20.50)**	
	Proportion of water body 25m	0.195 (0.218)**	0.286 (0.200)**	
Rural	Level of greenness 25m	0.535 (0.088)**	0.554 (0.072)**	
	Residential building density 25m	0.223 (0.285)	0.233 (0.286)	
	Urbanization index 25m	0.736 (0.744)**	0.549 (0.592)**	
	Land use mix 25m	0.457 (0.211)**	0.514 (0.180)**	
	Count of 1-way crossings 25m	1.420 (1.554)**	2.700 (2.550)**	
	Count of ≥ 4-way crossings 25m	6.090 (7.260)**	11.90 (14.00)**	
	Proportion of water body 25m	0.199 (0.184)**	0.232 (0.183)**	
Environmental variables		**≤ 3000m** (n^a = 4383) (n^b = 1382) Mean (±SD)	**3000 – 5000m** (n^a = 7550) (n^b = 2439) Mean (±SD)	**> 5000m** (n^a = 10589) (n^b = 3253) Mean (±SD)
Urban	Level of greenness 25m	0.482 (0.103)**	0.505 (0.092)**	0.517 (0.098)**
	Residential building density 25m	0.394 (0.368)**	0.376 (0.351)	0.382 (0.411)
	Urbanization index 25m	1.448 (2.011)**	1.062 (1.274)**	0.841 (1.085)**
	Land use mix 25m	0.488 (0.187)**	0.515 (0.176)**	0.552 (0.192)**
	Count of 1-way crossings 25m	8.720 (8.160)**	14.90 (13.50)**	3.707 (3.985)**
	Count of ≥ 4-way crossings 25m	17.20 (18.20)**	30.30 (32.40)**	22.89 (26.42)**
	Proportion of water body 25m	0.300 (0.211)**	0.275 (0.228)**	0.297 (0.215)**
Rural	Level of greenness 25m	0.534 (0.089)**	0.554(0.074)**	0.560 (0.075)**
	Residential building density 25m	0.210 (0.269)	0.199 (0.253)**	0.208 (0.320)
	Urbanization index 25m	0.919 (1.214)**	0.594 (0.650)**	0.432 (0.470)**
	Land use mix 25m	0.445 (0.202)	0.463 (0.185)	0.530 (0.188)*
	Count of 1-way crossings 25m	6.580 (6.370)**	11.70 (10.20)**	3.032 (3.381)**
	Count of ≥ 4-way crossings 25m	9.960 (11.30)**	18.20 (20.10)**	14.85 (17.68)**
	Proportion of water body 25m	0.244 (0.198)**	0.271 (0.201)**	0.245 (0.210)**
	Environmental variables	**≤ 24** (n^a = 7983) (n^b = 2634) Mean (±SD)	**24–48** (n^a = 7410) (n^b = 2136) Mean (±SD)	**> 48** (n^a = 7174) (n^b = 2304) Mean (±SD)
Urban	Level of greenness 25m	0.507 (0.104)	0.505 (0.109)	0.511 (0.104)*
	Residential building density 25m	0.375 (0.406)	0.378 (0.410)	0.385 (0.413)
	Urbanization index 25m	1.077 (1.473)**	1.018 (1.400)	1.000 (1.285)
	Land use mix 25m	0.513 (0.214)*	0.522 (0.210)	0.521 (0.215)
	Count of 1-way crossings 25m	2.621 (3.219)**	2.825 (3.241)	2.851 (3.524)
	Count of ≥ 4-way crossings 25m	14.23 (18.13)**	16.70 (21.93)**	17.62 (22.55)**
	Proportion of water body 25m	0.267 (0.224)	0.263 (0.222)	0.288 (0.216)**
Rural	Level of greenness 25m	0.546 (0.094)	0.560 (0.080)*	0.544 (0.087)
	Residential building density 25m	0.220 (0.323)	0.199 (0.316)*	0.234 (0.337)
	Urbanization index 25m	0.614 (0.833)	0.488 (0.612)**	0.636 (0.768)
	Land use mix 25m	0.483 (0.224)	0.494 (0.211)	0.529 (0.183)**
	Count of 1-way crossings 25m	2.093 (2.792)	2.058 (2.463)	2.582 (3.065)**
	Count of ≥ 4-way crossings 25m	9.963 (14.25)	9.452 (11.98)	12.30 (15.34)**
	Proportion of water body 25m	0.221 (0.211)*	0.206 (0.218)*	0.241 (0.214)**

**: Statistically significant difference between runners running less and more than 30 mins at $p < 0.01$ of t-test.
na: Number of tracks of urban runners.
nb: Number of tracks of rural runners.
(a) Descriptive statistics of surroundings of ≤30 mins and >30mins tracks (buffer = 25m).
*:Statistically significant difference between runners running at different levels of distances at $p < 0.05$ of pairwise t-test.
**:Statistically significant difference between runners running at different levels of distances at $p < 0.01$ of pairwise t-test.
na: Number of tracks of urban runners.
nb: Number of tracks of rural runners.
(b) Descriptive statistics of surroundings of tracks with different distances (buffer = 25m).
*:Statistically significant difference between runners running at different levels of frequencies at $p < 0.05$ of pairwise t-test.
**:Statistically significant difference between runners running at different levels of frequencies at $p < 0.01$ of pairwise t-test.
na: Number of urban runners.
nb: Number of rural runners.
(c) Descriptive statistics of running environments of runners running at different frequencies (buffer = 25m).

Discussion

Main findings

Using running GPS tracks, we assessed runners' exposure to natural and built environments (e.g. green space, blue space, and land use diversity) along their running routes. Furthermore, we also examined runners' exposure to their residential physical environments by deriving the residential locations based on their running trajectories. We distinguished runners into urban and rural analyzed them separately. Our results showed that urban and rural runners were exposed to different running and residential environments. Both urban and rural runners preferred environments with more blue spaces and fewer streets, and a lower density of residential buildings. Thus, our results indicated that both urban and rural runners ran in more natural environments. Compared to rural runners, running routes and residential settings of urban runners were less green, had a higher coverage of residential buildings, a higher address density, a higher degree of mixed land uses, and more cul-de-sacs and well-connected streets, which are common features of an urbanised area (Ewing et al. 2003; Lee et al. 2009). Furthermore, the results also showed that in terms of all environmental variables, the difference between urban and rural running environments was more evident than the difference between their living and running environments. This finding suggests that the differences between urban and rural were more pronounced than the differences between their living and running environments. Moreover, for all runner groups, we found that there were no statistically significant differences across different buffer sizes (Appendix Table 7 Table 18). Additionally, the data showed that at weekends, runners chose environments with more streets and green spaces and lower residential building density. This is probably because runners' leisure time was more abundant, and their running trails were less restricted by their living environment. Another finding from our analysis is that more rural and urban runners ran outside their neighbourhoods than inside their neighbourhoods. When urban and rural runners exercised outside their neighbourhoods, they chose places with more green spaces, water bodies etc. For urban runners, another reason is that those who travelled outside their neighbourhoods were living in environments containing less greenery but more residential units and streets. Urban runners also selected places with more coverage of residential buildings, which was probably due to the fact that there are more residential buildings in urbanised areas.

Apart from that, we divided urban and rural runners into different strata according to their running duration, distances, and frequencies. More green and blue spaces, streets, less addresses and land use with higher heterogeneity were in the surroundings of >30 mins tracks. Similarly, track lengths (>5,000 m) and tracks of runners who trained more frequently contained more vegetation and fewer addresses. This demonstrated that the long tracks (>5,000 m or >30 mins) and tracks taken by more frequently practised runners (running frequency > 48 times a year) were exposed to more natural conditions and fewer built-in features. The result shows congruence with the studies of James et al. (2014) and Tamura et al. (2019), where they found that individuals who spent more time on PA tended to seek green spaces.

Strengths and limitations

This research has a number of strengths. First, we developed a GIS-based method to estimate the difference between runners' running and residential environments based on GPS data. Our approach is more objective than perceived environmental assessments (Deelen et al. 2019). Second, we measured runners' running and residential environments at different geographical scales, which reduced the risk of data aggregation errors (Wang et al. 2021). Moreover, a stratified analysis such as ours to compare the differences across running environments of different groups of runners has rarely been conducted previously.

Despite these strengths, some limitations should be mentioned. First, we did not have access to people's demographic or socioeconomic data (e.g. age and social class) to understand the propensity

for running in a specific environment (Romanillos et al. 2016). Thus, the defined classification of urban/rural runners might not match the runners' true residency in urban/rural areas. Second, only one mobile GPS application (i.e. Endomondo) was used to collect the GPS data and the tracks were collected under the condition that runners made their information public. We cannot exclude that our data faced issues due to self-reporting. As a result, it is likely that the data acquired may not be representative of people's running behaviours across the Netherlands. Third, NDVI satellite images were utilised to calculate the levels of greenness (i.e. within a 25 m, 50 m and 100 m buffer around a running track) to which runners were exposed. However, satellite data do not represent how runners perceive greenery on the ground while they are running because there is no information of what type of green spaces interest urban and rural runners. Apart from these, other environmental variables (e.g. weather, temperature and air quality) which have been revealed as situational barriers to running (Wang et al. 2021) were not accounted for in this study.

Conclusions

We studied the environmental differences between runners in an urban and rural setting. The results indicated that for both urban and rural runners their running environments were restricted by their residency in urban/rural areas. Our results suggest that urban planners should consider the differences of running environments between urban and rural runners when developing policies that encourage running. Furthermore, our results suggest that preserving or upgrading green spaces in urban and rural areas is important to encourage more people to engage in running. Apart from that, including more environmental variables (e.g. weather, temperature and air quality) is recommended.

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CRediT author statement

SZ: Formal analysis, Writing – Original Draft; ZW: Conceptualization, Data collection, Review & Editing; DE: Conceptualization, MH: Review & Editing; Methodology.

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Appendix A

Table A1. Descriptive statistics of running environments of urban and rural runners (buffer = 50 m).

Environmental variables	Urban (n = 946) Mean (SD)	Rural (n = 2853) Mean (SD)
Level of greenness 50 m	0.500 (0.092)**	0.546 (0.076)**
Residential building density 50 m	0.380 (0.343)**	0.216 (0.251)**
Urbanization index 50 m	1.130 (1.360)**	0.626 (0.748)**
Land use mix 50 m	0.505 (0.174)**	0.465 (0.182)**
Count of 1-way crossings 50 m	5.950 (4.990)**	4.770 (4.310)**
Count of ≥ 4-way crossings 50 m	18.80 (19.40)**	11.90 (14.10)**
Proportion of water body 50 m	0.278 (0.197)**	0.246 (0.185)**

**: Statistically significant difference between urban and rural runners at $p < 0.0$ of t-test.
n: Number of runners.

Table A2. Descriptive statistics of running environments of urban and rural runners (buffer = 100 m).

Environmental variables	Urban (n = 946) Mean (SD)	Rural (n = 2853) Mean (SD)
Level of greenness 100 m	0.497 (0.093)**	0.542 (0.076)**
Residential building density 100 m	0.382 (0.345)**	0.216 (0.259)**
Urbanization index 100 m	1.270 (1.240)**	0.662 (0.583)**
Land use mix 100 m	0.504 (0.170)**	0.450 (0.183)**
Count of 1-way crossings 100 m	12.20 (9.660)**	9.630 (8.320)**
Count of ≥ 4-way crossings 100 m	24.59 (24.10)**	15.00 (16.70)**
Proportion of water body 100 m	0.289 (0.202)**	0.259 (0.196)**

**: Statistically significant difference between urban and rural runners at $p < 0.01$ of t-test.n: Number of runners.

Table A3. Descriptive statistics of environmental variables of residential (1,000 m) and running environments (50 m).

Environmental variables		Residential buffer 1,000 m	GPS-based buffer 50 m
Urban	Level of greenness	0.472 (0.101)**	0.500 (0.092)**
	Residential building density	0.238 (0.296)**	0.380 (0.343)**
	Urbanization index	1.640 (1.600)**	1.130 (1.360)**
	Land use mix	0.609 (0.205)**	0.505 (0.174)**
	Count of 1-way crossings	55.40 (32.30)**	5.950 (4.990)**
	Count of ≥ 4-way crossings	83.00 (62.60)**	18.80 (19.40)**
	Proportion of water body	0.060 (0.078)**	0.278 (0.197)**
Rural	Level of greenness	0.547 (0.088)	0.546 (0.076)
	Residential building density	0.187 (0.294)	0.216 (0.251)
	Urbanization index	0.675 (0.599)	0.626 (0.748)
	Land use mix	0.498 (0.248)**	0.465 (0.182)**
	Count of 1-way crossings	41.70 (28.80)**	4.770 (4.310)**
	Count of ≥ 4-way crossings	41.40 (37.50)**	11.90 (14.10)**
	Proportion of water body	0.050 (0.091)**	0.246 (0.185)**

**: Statistically significant difference between tracks taken at weekdays/on weekends at $p < 0.01$ of t-test.
na: Number of tracks of urban runners.
nb: Number of tracks of rural runners.

Table A4. Descriptive statistics of environmental variables of residential (1,000 m) and running environments (100 m).

Environmental variables		Residential buffer 1,000 m	GPS-based buffer 100 m
Urban	Level of greenness	0.472 (0.101)**	0.497 (0.093)**
	Residential building density	0.238 (0.296)**	0.382 (0.345)**
	Urbanization index	1.640 (1.600)**	1.270 (1.240)**
	Land use mix	0.609 (0.205)**	0.504 (0.170)**
	Count of 1-way crossings	55.40 (32.30)**	12.20 (9.660)**
	Count of ≥ 4-way crossings	83.00 (62.60)**	24.59 (24.10)**
	Proportion of water body	0.060 (0.078)**	0.289 (0.202)**
Rural	Level of greenness	0.547 (0.088)	0.542 (0.076)
	Residential building density	0.187 (0.294)	0.216 (0.259)
	Urbanization index	0.675 (0.599)	0.662 (0.583)
	Land use mix	0.498 (0.248)**	0.450 (0.183)**
	Count of 1-way crossings	41.70 (28.80)**	9.630 (8.320)**
	Count of ≥ 4-way crossings	41.40 (37.50)**	15.00 (16.70)**
	Proportion of water body	0.050 (0.091)**	0.259 (0.196)**

**: Statistically significant difference between tracks taken at weekdays/on weekends at $p < 0.01$ of t-test.
na: Number of tracks of urban runners.
nb: Number of tracks of rural runners.

Table A5. Descriptive statistics of surroundings of routes taken at weekdays and on weekends (buffer = 50 m).

Environmental variables		Weekdays ($n^a = 15746$) ($n^b = 4983$) Mean (±SD)	Weekends ($n^a = 6773$) ($n^b = 2091$) Mean (±SD)
Urban	Level of greenness 50 m	0.500 (0.094)	0.505 (0.095)
	Residential building density 50 m	0.381 (0.355)	0.370 (0.363)
	Urbanization index 50 m	1.180 (1.210)	1.110 (1.220)
	Land use mix 50 m	0.506 (0.178)	0.515 (0.181)
	Count of 1-way crossings 50 m	5.900 (5.180)*	6.310 (5.880)*
	Count of ≥ 4-way crossings 50 m	18.90 (21.10)*	20.50 (22.40)*
	Proportion of water body 50 m	0.279 (0.207)	0.285 (0.208)
Rural	Level of greenness 50 m	0.546 (0.079)	0.551 (0.077)
	Residential building density 50 m	0.213 (0.265)	0.206 (0.277)
	Urbanization index 50 m	0.630 (0.590)	0.639 (0.640)
	Land use mix 50 m	0.473 (0.186)	0.456 (0.192)
	Count of 1-way crossings 50 m	4.640 (4.310)	4.860 (0.191)
	Count of ≥ 4-way crossings 50 m	11.70 (14.10)	12.50 (16.50)
	Proportion of water body 50 m	0.248 (0.192)	0.249 (0.192)

*: Statistically significant difference between tracks taken at weekdays/on weekends at $p < 0.05$ of t-test.
**: Statistically significant difference between tracks taken at weekdays/on weekends at $p < 0.01$ of t-test.
na: Number of tracks of urban runners.
nb: Number of tracks of rural runners.

Table A6. Descriptive statistics of surroundings of routes taken at weekdays and on weekends (buffer = 100 m).

Environmental variables		Weekdays (n^a = 15746) (n^b = 4983) Mean (±SD)	Weekends (n^a = 6773) (n^b = 2091) Mean (±SD)
Urban	Level of greenness 100 m	0.496 (0.095)	0.501 (0.096)
	Residential building density 100 m	0.388 (0.355)*	0.366 (0.353)*
	Urbanization index 100 m	1.280 (1.250)	1.210 (1.270)
	Land use mix 100 m	0.506 (0.173)	0.511 (0.178)
	Count of 1-way crossings 100 m	12.20 (10.10)*	12.90 (11.30)*
	Count of ≥ 4-way crossings 100 m	24.60 (26.10)*	26.70 (28.20)*
	Proportion of water body 100 m	0.289 (0.217)	0.295 (0.212)
Rural	Level of greenness 100 m	0.546 (0.081)	0.551 (0.078)
	Residential building density 100 m	0.204 (0.256)	0.191 (0.260)
	Urbanization index 100 m	0.662 (0.593)	0.653 (0.701)
	Land use mix 100 m	0.458 (0.186)	0.441 (0.191)
	Count of 1-way crossings 100 m	9.410 (8.340)	9.900 (9.380)
	Count of ≥ 4-way crossings 100 m	14.80 (16.70)	15.50 (19.30)
	Proportion of water body 100 m	0.261 (0.203)	0.264 (0.199)

*: Statistically significant difference between tracks taken at weekdays/on weekends at $p < 0.05$ of t-test.
**: Statistically significant difference between tracks taken at weekdays/on weekends at $p < 0.01$ of t-test.
na: Number of tracks of urban runners.
nb: Number of tracks of rural runners.

Table A7. Descriptive statistics of surroundings of tracks taken inside and outside neighbourhoods (buffer = 50 m).

Environmental variables		Inside neighbourhood (n^a = 1469) (n^b = 494) Mean (±SD)	Outside neighbourhood (n^a = 20857) (n^b = 6033) Mean (±SD)
Urban	Level of greenness 50 m	0.464 (0.115)**	0.503 (0.092)**
	Residential building density 50 m	0.341 (0.346)**	0.389 (0.347)**
	Urbanization index 50 m	2.010 (2.290)**	1.140 (1.140)**
	Land use mix 50 m	0.342 (0.228)**	0.522 (0.168)**
	Count of 1-way crossings 50 m	2.360 (3.280)**	6.330 (5.440)**
	Count of ≥ 4-way crossings 50 m	5.420 (8.410)**	20.00 (20.50)**
	Proportion of water body 50 m	0.195 (0.218)**	0.286 (0.200)**
Rural	Level of greenness 50 m	0.520 (0.111)**	0.550 (0.076)**
	Residential building density 50 m	0.183 (0.238)*	0.223 (0.263)*
	Urbanization index 50 m	1.100 (1.060)**	0.612 (0.514)**
	Land use mix 50 m	0.320 (0.208)**	0.489 (0.172)**
	Count of 1-way crossings 50 m	1.910 (2.710)**	5.050 (4.480)**
	Count of ≥ 4-way crossings 50 m	2.860 (4.410)**	248.0 (222.0)**
	Proportion of water body 50 m	0.183 (0.227)**	0.261 (0.179)**

*: Statistically significant difference between tracks taken inside/outside neighbourhoods at $p < 0.05$ of t-test.
**: Statistically significant difference between tracks taken inside/outside neighbourhoods at $p < 0.01$ of t-test.
na: Number of tracks of urban runners.
nb: Number of tracks of rural runners.

Table A8. Descriptive statistics of surroundings of tracks taken inside and outside neighbourhoods (buffer = 100 m).

	Environmental variables	Inside neighbourhood (n^a = 1469) (n^b = 494) Mean (±SD)	Outside neighbourhood (n^a = 20857) (n^b = 6033) Mean (±SD)
Urban	Level of greenness 100 m	0.464 (0.11)**	0.499 (0.093)**
	Residential building density 100 m	0.375 (0.369)	0.387 (0.347)
	Urbanization index 100 m	1.960 (2.030)**	1.240 (1.210)**
	Land use mix 100 m	0.385 (0.217)**	0.517 (0.167)**
	Count of 1-way crossings 100 m	4.950 (5.930)**	13.00 (10.50)**
	Count of ≥ 4-way crossings 100 m	8.020 (11.10)**	26.00 (25.60)**
	Proportion of water body 100 m	0.237 (0.209)**	0.294 (0.209)**
Rural	Level of greenness 100 m	0.522 (0.106)**	0.549 (0.077)**
	Residential building density 100 m	0.203 (0.273)	0.209 (0.246)
	Urbanization index 100 m	1.060 (0.962)**	0.639 (0.533)**
	Land use mix 100 m	0.366 (0.209)**	0.468 (0.175)**
	Count of 1-way crossings 100 m	3.960 (5.230)**	10.20 (8.620)**
	Count of ≥ 4-way crossings 100 m	4.300 (5.830)**	16.20 (17.40)**
	Proportion of water body 100 m	0.202 (0.241)**	0.272 (0.180)**

**: Statistically significant difference between tracks taken inside/outside neighbourhoods at $p < 0.01$ of t-test.
na: Number of tracks of urban runners.
nb: Number of tracks of rural runners.

Table A9. Descriptive statistics of surroundings of ≤30 mins and >30 mins tracks (buffer = 50 m).

	Environmental variables	≤30 minutes (n^a = 8540) (n^b = 2638) Mean (±SD)	>30 minutes (n^a = 13982) (n^b = 4436) Mean (±SD)
Urban	Level of greenness 50 m	0.485 (0.104)**	0.509 (0.091)**
	Residential building density 50 m	0.378 (0.361)	0.380 (0.353)
	Urbanization index 50 m	1.360 (1.600)**	0.910 (1.170)**
	Land use mix 50 m	0.479 (0.197)**	0.522 (0.177)**
	Count of 1-way crossings 50 m	4.110 (4.250)**	7.250 (6.790)**
	Count of ≥ 4-way crossings 50 m	12.80 (14.10)**	23.50 (25.60)**
	Proportion of water body 50 m	0.259 (0.218)**	0.292 (0.204)**
Rural	Level of greenness 50 m	0.535 (0.088)**	0.554 (0.073)**
	Residential building density 50 m	0.213 (0.274)	0.219 (0.274)
	Urbanization index 50 m	0.761 (0.718)**	0.575 (0.599)**
	Land use mix 50 m	0.445 (0.206)**	0.486 (0.183)**
	Count of 1-way crossings 50 m	3.210 (3.360)**	5.790 (5.330)**
	Count of ≥ 4-way crossings 50 m	7.610 (9.150)**	14.60 (16.90)**
	Proportion of water body 50 m	0.227 (0.193)**	0.260 (0.191)**

**: Statistically significant difference between running takes less than/above 30 minutes at $p < 0.01$ of t-test.
na: Number of tracks of urban runners.
nb: Number of tracks of rural runners.

Table A10. Descriptive statistics of surroundings of ≤30 mins and >30 mins tracks (buffer = 100 m).

	Environmental variables	≤30 minutes (n^a = 8540) (n^b = 2638) Mean (±SD)	>30 minutes (n^a = 13982) (n^b = 4436) Mean (±SD)
Urban	Level of greenness 100 m	0.482 (0.103)**	0.505 (0.092)**
	Residential building density 100 m	0.394 (0.368)	0.376 (0.351)
	Urbanization index 100 m	1.470 (1.600)**	1.100 (1.220)**
	Land use mix 100 m	0.488 (0.187)**	0.515 (0.176)**
	Count of 1-way crossings 100 m	8.720 (8.160)**	14.90 (13.50)**
	Count of ≥ 4-way crossings 100 m	17.20 (18.20)**	30.30 (32.40)**
	Proportion of water body 100 m	0.300 (0.211)**	0.275 (0.228)**
Rural	Level of greenness 100 m	0.534 (0.089)**	0.554(0.074)**
	Residential building density 100 m	0.210 (0.269)	0.199 (0.253)
	Urbanization index 100 m	0.783 (0.715)**	0.596 (0.571)**
	Land use mix 100 m	0.445 (0.202)	0.463 (0.185)
	Count of 1-way crossings 100 m	6.580 (6.370)**	11.70 (10.20)**
	Count of ≥ 4-way crossings 100 m	9.960 (11.30)**	18.20 (20.10)**
	Proportion of water body 100 m	0.244 (0.198)**	0.271 (0.201)**

**: Statistically significant difference between running takes less than/above 30 minutes at $p < 0.01$ of t-test.
na: Number of tracks of urban runners.
nb: Number of tracks of rural runners.

Table A11. Descriptive statistics of surroundings of tracks with different lengths (buffer = 50 m).

	Environmental variables	≤3000 m (n^a = 4383) (n^b = 1382) Mean (±SD)	3000 – 5000 m (n^a = 7550) (n^b = 2439) Mean (±SD)	>5000 m (n^a = 10589) (n^b = 3253) Mean (±SD)
Urban	Level of greenness 50 m	0.488 (0.119)**	0.500 (0.104)**	0.515 (0.098)**
	Residential building density 50 m	0.367 (0.404)	0.396 (0.407)**	0.378 (0.402)
	Urbanization index 50 m	1.597 (1.804)**	1.162 (1.277)**	0.921 (1.101)**
	Land use mix 50 m	0.425 (0.235)**	0.521 (0.200)**	0.538 (0.195)**
	Count of 1-way crossings 50 m	2.821 (3.389)**	5.279 (4.870)**	8.339 (8.091)**
	Count of ≥ 4-way crossings 50 m	7.542 (9.957)**	16.43 (16.71)**	29.33 (34.45)**
	Proportion of water body 50 m	0.244 (0.248)**	0.280 (0.229)**	0.310 (0.227)**
Rural	Level of greenness 50 m	0.524 (0.110)**	0.549 (0.009)**	0.561 (0.076)**
	Residential building density 50 m	0.195 (0.292)	0.231 (0.224)**	0.197 (0.308)
	Urbanization index 50 m	0.926 (1.124)**	0.642 (0.684)**	0.461 (0.501)**
	Land use mix 50 m	0.411 (0.230)**	0.491 (0.206)	0.495 (0.191)
	Count of 1-way crossings 50 m	2.402 (3.086)**	4.251 (0.206)**	6.633 (7.102)**
	Count of ≥ 4-way crossings 50 m	4.586 (6.767)**	9.958 (11.30)**	19.09 (21.56)**
	Proportion of water body 50 m	0.201 (0.226)**	0.246 (0.214)**	0.275 (0.214)**

**: Statistically significant difference between tracks with different lengths at $p < 0.01$ of t-test.
na: Number of tracks of urban runners.
nb: Number of tracks of rural runners.

Table A12. Descriptive statistics of surroundings of tracks with different lengths (buffer = 100 m).

	Environmental variables	≤3000 m (n^a = 4383) (n^b = 1382) Mean (±SD)	3000 – 5000 m (n^a = 7550) (n^b = 2439) Mean (±SD)	>5000 m (n^a = 10589) (n^b = 3253) Mean (±SD)
Urban	Level of greenness 100 m	0.483 (0.116)**	0.487 (0.112)**	0.511 (0.099)**
	Residential building density 100 m	0.387 (0.403)	0.398 (0.400)	0.370 (0.393)*
	Urbanization index 100 m	1.595 (1.737)**	1.278 (1.334)**	1.025 (1.182)**
	Land use mix 100 m	0.443 (0.226)**	0.519 (0.196)**	0.527 (0.197)**
	Count of 1-way crossings 100 m	2.821 (3.389)**	10.96 (8.966)**	17.07 (15.78)**
	Count of ≥ 4-way crossings 100 m	10.64 (12.72)**	21.84 (21.26)**	37.45 (42.37)**
	Proportion of water body 100 m	0.268 (0.235)**	0.285 (0.241)**	0.319 (0.232)**
Rural	Level of greenness 100 m	0.525 (0.108)**	0.547 (0.086)**	0.561 (0.078)**
	Residential building density 100 m	0.202 (0.298)	0.213 (0.305)	0.180 (0.284)*
	Urbanization index 100 m	0.932 (0.980)**	0.677 (0.718)**	0.484 (0.535)**
	Land use mix 100 m	0.424 (0.223)**	0.472 (0.209)	0.462 (0.194)
	Count of 1-way crossings 100 m	4.888 (5.567)**	8.717 (8.023)**	13.55 (13.75)**
	Count of ≥ 4-way crossings 100 m	6.434 (8.569)**	8.032 (497.2)**	14.85 (17.68)**
	Proportion of water body 100 m	0.224 (0.231)**	0.261 (0.220)**	0.281 (0.235)**

*: Statistically significant difference between tracks with different lengths at $p < 0.05$ of t-test.
**: Statistically significant difference between tracks with different lengths at $p < 0.01$ of t-test.
na: Number of tracks of urban runners.
nb: Number of tracks of rural runners.

Table A13. Descriptive statistics of surroundings of runners running at different frequencies (buffer = 50 m).

	Environmental variables	≤24 (n^a = 7983) (n^b = 2634) Mean (±SD)	24–48 (n^a = 7410) (n^b = 2136) Mean (±SD)	>48 (n^a = 7174) (n^b = 2304) Mean (±SD)
Urban	Level of greenness 50 m	0.504 (0.103)	0.545 (0.093)	0.502 (0.108)*
	Residential building density 50 m	0.374 (0.401)	0.206 (0.305)	0.377 (0.403)
	Urbanization index 50 m	1.151 (1.403)*	1.104 (1.356)	1.090 (1.251)
	Land use mix 50 m	0.506 (0.208)	0.461 (5.692)	0.514 (0.208)
	Count of 1-way crossings 50 m	5.863 (6.455)**	28.82 (30.09)	6.336 (6.708)*
	Count of ≥ 4-way crossings 50 m	18.27 (23.84)**	222.9 (278.8)	21.63 (28.52)*
	Proportion of water body 50 m	0.284 (0.234)	0.251 (0.217)**	0.277 (0.237)
Rural	Level of greenness 50 m	0.545 (0.093)	0.560 (0.081)*	0.545 (0.088)
	Residential building density 50 m	0.206 (0.305)	0.196 (0.312)	0.222 (0.327)
	Urbanization index 50 m	0.640 (0.810)	0.525 (0.614)**	0.667 (0.767)
	Land use mix 50 m	0.461 (5.692)	0.471 (0.212)	0.499 (0.185)**
	Count of 1-way crossings 50 m	28.82 (30.09)	4.610 (5.222)	5.806 (6.314)**
	Count of ≥ 4-way crossings 50 m	222.9 (278.8)	11.75 (15.23)	14.95 (18.72)**
	Proportion of water body 50 m	0.251 (0.217)**	0.233 (0.232)**	0.267 (0.205)**

*: Statistically significant difference between runners running at different frequencies at $p < 0.05$ of t-test.
*: Statistically significant difference between runners running at different frequencies at $p < 0.01$ of t-test.
na: Number of tracks of urban runners.
nb: Number of tracks of rural runners.

Table A14. Descriptive statistics of surroundings of runners running at different frequencies (buffer = 100 m).

	Environmental variables	≤24 (n^a = 7983) (n^b = 2634) Mean (±SD)	24–48 (n^a = 7410) (n^b = 2136) Mean (±SD)	>48 (n^a = 7174) (n^b = 2304) Mean (±SD)
Urban	Level of greenness 100 m	0.500 (0.103)	0.497 (0.107)	0.503 (0.107)
	Residential building density 100 m	0.377 (0.394)	0.379 (0.398)	0.392 (0.401)*
	Urbanization index 100 m	1.246 (1.407)	1.206 (1.299)	1.208 (1.408)
	Land use mix 100 m	0.506 (0.200)	0.510 (0.204)	0.508 (0.212)
	Count of 1-way crossings 100 m	12.13 (12.59)**	13.34 (13.65)	13.11 (12.92)
	Count of ≥ 4-way crossings 100 m	23.89 (29.90)**	27.96 (34.80)**	29.45 (36.33)**
	Proportion of water body 100 m	0.297 (0.235)*	0.284 (0.247)*	0.312 (0.227)**
Rural	Level of greenness 100 m	0.545 (0.094)	0.559 (0.083)*	0.547 (0.088)
	Residential building density 100 m	0.195 (0.290)	0.184 (0.290)	0.207 (0.302)
	Urbanization index 100 m	0.658 (0.734)	0.560 (0.633)**	0.686 (0.770)
	Land use mix 100 m	0.448 (0.214)	0.451 (0.290)	0.476 (0.185)**
	Count of 1-way crossings 100 m	9.142 (10.84)	9.454 (10.10)	11.94 (12.46)**
	Count of ≥ 4-way crossings 100 m	14.32 (20.21)	14.85 (18.60)	18.56 (22.22)**
	Proportion of water body 100 m	0.263 (0.231)*	0.247 (0.247)*	0.277 (0.211)*

*: Statistically significant difference between runners running at different frequencies at $p < 0.05$ of t-test.
*: Statistically significant difference between runners running at different frequencies at $p < 0.01$ of t-test.
na: Number of tracks of urban runners.
nb: Number of tracks of rural runners.