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Spatial runner: environmental and musical exposure effects on runners through an idealized routing network

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Master thesis, 30 credits, in *Geomatics*

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ABSTRACT

Physical activities such as running have previously been proven to be positive on the health of individuals who partake in such activities. Further studies have separately analyzed the positive benefits of natural environments, such as forests, and positive effects of music on runners. This study evaluates how the presence or absence of such natural environments with and without musical stimuli effect the stress levels of individuals both physically and psychologically while running a predetermined route in the real world. Spatially Turn-Restricted Weighting Algorithm (STRWA) was created to solve the route creation criteria required of this study. The results of several analysis, both at the macro and micro levels of the study area, show that natural environments give lower physical stress levels than ones which have more urban characteristics. Additionally, music exposure further increases the positive feeling felt by a runner while increasing running speeds and only mildly increasing heart rate.

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LIST OF ABBREVIATIONS

API .... Application Programming Interface

BPM .... Beats Per Minute

cm .... centimeter(s)

CRS .... Coordinate Reference System

GIS .... Geographic Information System

GPS .... Global Positioning System

GRVI .... Green-Red Vegetation Index

GUI .... Graphical User Interface

HEIG-VD .... Haute Ecole d'Ingénierie et de Gestion du Canton de Vaud

HR .... heart rate

kg .... kilogram(s)

km .... kilometer(s)

KML .... Keyhole Markup Language

kph .... kilometers per hour

m .... meter(s)

NR .... the Nature route

NRM .... the Nature route with musical stimuli

OSM .... Open Street Map

RPE .... Rate of Perceived Exertion

STRWA ...... Spatially Turn-Restricted Weighting Algorithm

TSP .... Traveling Salesman Problem

UR .... the Urban route

URM .... the Urban route with musical stimuli

1. INTRODUCTION

Physical exercise is an increasingly important aspect in the modern world where there is an ever increasing level of people who work and live in sedentary environments. More than likely this is caused by the increase in availability and reliance on technology. Of which, occupational and recreational livelihoods depend upon in increasing fashion. This sedentary livelihood increases the chances of negative health effects such as obesity, bone health and cardiovascular problems (Tremblay *et al.*, 2010; Barnes, 2012).

Activities such as running have been on the increase since about the 1970's and shown to have beneficial health effects (Schnohr, 2000). Moreover, there have been studies conducted which show further positivity when music or natural environment is involved in physical exercise (Edworthy and Waring, 2006; Ulrich *et al.*, 1991). Unfortunately, most of the studies presented here have only been conducted in a very sterile environments in very controlled laboratory settings. How then can these kinds of studies be tested in more of a real world scenario?

Physical geography is a field in which real world data is typically collected and analyzed. Aspects of this field include many topics such as vegetation characteristics and routing algorithms in road networks. Both of which can be used to study the interaction of runners in their environment. Routing algorithms are continually being expanded upon and improved to suit the needs of groups who need specific characteristics to formulate their desired results. This formulation can include weighting characteristics of a road network to create desirable routes for runners. As such, it is becoming increasingly viable and important to study how spatial routing tied to various weighting criteria can positively affect and improve both the physical and psychological conditions of runners.

The aim of this project is to study the correlation between the effects of natural and urban environments on a runner when given a predetermined routing network based on set criteria of traversal in a real world scenario. Which additionally includes the added correlation of musical and non-musical stimuli on a runner in environmentally defined routes. This is to towards the idea of reinforcing the connection that musical exposure while running an exercise routine will have a positive correlation with the physiological and psychological responses of a runner. It will be further paired with the idea that natural environments will additionally have this positive correlation.

The structure of this thesis gives a background of previous studies which have shown these positive correlations with music and vegetated environments for runners. This background also includes the technology and theory behind creating networking routes. From this background, hypotheses will be established for testing in this study. These backgrounds and hypotheses are then used to help establish a routing algorithm by which participants in this study will use to test the parameters concluded in the background and methodology for creating several running routes to test the above aim in a real world scenario. Once this has been established, the hypothesis will be tested by these routes to be concluded in the results and discussion of this thesis.

2. BACKGROUND

2.1 Physical exercise

In the modern world, there is an ever increasingly reliance on occupations and leisurely activities that rely on a more sedentary lifestyle to the point of adults spending 70% or more of their time being sedentary (Owen *et al.*, 2010). This way of life has been proven to lead towards obesity, bone health and cardiovascular problems (Tremblay *et al.*, 2010; Barnes, 2012). A way to counter-act this is for individuals to obtain some form of physical exercise in their lives. Running as a form of exercise, has been on the increase since the 1970's and shown that constant runners have a relatively lower risk of death when comparing their blood pressure, cholesterol and BMI to other inconsistent and non-runners (Schnohr, 2000). Not only does running affect the health of individuals but other criteria have been found to enhance both the physical and psychological health of runners.

2.1.1 Environmental exposure

Criteria that have an impact on runners is access and exposure to public greenery, including but not exclusive from parks and forests (Hansmann *et al.*, 2007; Mackay and Neill, 2010). The affect of natural environments on stress has been studied to the extent that exposing a person to the sound and visualization of natural environments results in a very high recovery rate of stress indicators such as muscle tension, heart rate, and blood pressure when compared to sound and visualizations of urban and pedestrian situations (Ulrich *et al.*, 1991). In that study, 120 participants were subjected to a test were they had to watch and listen to two separate 10 minute videotapes while connected to biological stress indicators. The first was stress inducing footage from a work accident prevention video proven previously to cause high stress levels. The second video was a mix of six different environments which included nature, water, and urban environments of various degrees with sounds from their respective scenes. Where 20 participants were subjected to one of the six possible recovery environments. The results of which showed that in all types of stress indicators recorded there was always a positive and much higher reduction in stress indicators with nature environments than with urban settings.

This importance of green areas has been further linked to a connection between obesity and distance to green areas. As distance to green areas increases, the stress and obesity of people increase, though further research is required to justify if this is complete causality or character of the people living in such residential environments (Nielsen and Hansen, 2007). A proposed idea in that study is where this could be a connection between runners or cyclists living in such areas or that these green areas create the space for runners or cyclists, but it is unclear in the study as this was not tested for.

There is further evidence of this connection when a person is exposed to parks and forests leading to lower stress levels (Hansmann *et al.*, 2007). The consensus was conducted pre- and post exposure to these green areas, which led to the observation that long term exposure to natural environments led to a higher stress reduction than those who experienced a short term exposure (Hansmann *et al.*, 2007). Additionally observed is that higher intensity exercise was positively correlated with a greater decrease in stress levels when compared to lower intensity individuals who only walked or relaxed (Hansmann *et al.*, 2007). This was further expanded upon that in both pre- and post exercise measures; there were decreases in stress and improvements in self-esteem when exposed to green areas (Mackay and Neill, 2010). These influences show an increased need to include green areas in a runners exercise routine.

2.1.2 Physical exertion with music

The affect of music on exercise has been conducted within numerous studies. The tempo of music, motivationally deemed music, or simply whether or not a runner is listening to any kind of musical stimuli are just a few of the many studies conducted to test these feedback responses (Szmedra and Bacharach, 1998; Elliott *et al.*, 2005; Edworthy and Waring, 2006). These affects include both physiological and psychological feedback responses when exposed to musical stimuli.

The physiological effects are those including heart rate, speed of the runner and chemical levels in their body (Edworthy and Waring, 2006; Szmedra and Bacharach, 1998). The psychological effects include rate of perceived exertion and positive or negative feelings of the runner where RPE of runners had a positive difference of 0.4 and positive feeling difference of about 1 when listening to music (Edworthy and Waring, 2006). Borgs Rate of Perceived Exertion (RPE scale) was created by Gunnar Borg in 1970 and later revised in the 1980's as a scale of measuring a persons subjective opinion on the level of exertion they experienced while exercising (Borg, 1998). This scale includes a range from 6 to 20 where the lowest value is no exertion and the highest value is maximal exertion (Borg, 1998). The Hardy and Rejeski Feeling Scale was created by Jack Rejeski in the late 1987 and later revised with Charles Hardy in 1989 as a scale for measuring a persons subjective opinion on how they are feeling during exercise (Hardy and Rejeski, 1989). This scale ranges from -5 to +5, where the participant is feeling very bad at the negative end and feeling very good at the positive end (Hardy and Rejeski, 1989).

There is a correlation that when a runner listens to music they have lower plasma lactate and norepinephrine levels, chemical indicators of stress, than a runner who listens to no music (Szmedra and Bacharach, 1998). This is further expanded on that both the tempo and volume of the music a runner listens to affects their heart rate and running speed. Music tempo was shown to have a positive correlation with heart rate (Edworthy and Waring, 2006). Where high tempo music led to a higher heart rate and low tempo music led to a lower heart rate in runners with a 4 to 8 BPM difference. The music tempo additionally affected the speed of a runner in positively correlated manners where music high tempo music listeners were 0.65 kph faster on average (Edworthy and Waring, 2006). That is to say that faster music led to faster running speeds. These positive correlations were also found similar in the volume of music but with a higher dependency on tempo as there was a larger effect with higher tempo between loud and quiet music than with lower tempo between loud and quiet music (Edworthy and Waring, 2006). There is additionally some correlation that selective music deemed through pre-selection to be motivational in aspect lead to an increase in the amount of distance traveled during a set period of running time (Elliott *et al.*, 2005).

Various components of music are correlated not only to the physical aspect of a runner but also towards the psychological. It is apparent that when a runner listens to music as opposed to no music they experience a lower RPE (Szmedra and Bacharach, 1998). This is further concluded that higher tempo is positively correlated with RPE, where volume was found to be dependent on tempo with regards to positively affecting to a greater degree at high tempo rather than low tempo (Edworthy and Waring, 2006). Runners have a greater positive feeling response when listening to music as opposed to not listening to music while exercising (Edworthy and Waring, 2006; Elliott *et al.*, 2005). This correlation is positive in relation to an increase in tempo, but not to the degree as influencing other factors (Edworthy and Waring, 2006).

2.1.3 Weather

In a real world setting, probably the biggest factor to affect a study for runners is the weather. As a runner absorbs more radiant heat depending upon the cloud clover (Noakes, 2002). That is to say that with no cloud cover a runner will experience more heat absorption from the sun than if there was cloud cover. In hotter weather, a runner risks more dangerous rise in body temperature (Noakes, 2002). This can most likely affect a study in various ways such that a participant could be exposed to different temperatures and cloud cover depending upon the time of year, time of day and weather patterns of the time of each test.

2.2 State of technology

2.2.1 Routing

When creating a route, a topological network is necessary. A topological network consists of nodes and edges, also known as points and lines respectively. These points are commonly at the end of lines, vertices of lines or at the intersections of the lines within a network. Routing is the idea for selecting paths within a network to get from one point to another point or multiple points. Routing is typically synonymous with finding the shortest or quickest path between two points of interest, a start point and an end or destination point. Possibly the most commonly used method today for finding this shortest path is by using a routing algorithm based on the first created by Dijkstra (1959) known today as the Dijkstra algorithm. Though other types of similar routing algorithms were created to try and improve upon Dijkstra's method based on certain types of routing criteria such as the A*-algorithm, a direction based routing algorithm (Hart *et al.*, 1968). Though, the focus of this study was to use Dijkstra's algorithm, for its simplicity and harmonization with the development of this study.

Dijkstra's algorithm essentially works by having two separate matrices to store the information about a network to be used for the calculations. One matrix that is constantly static and stores the distances between nodes and the other which is dynamic and changes based on the starting and ending nodes. The algorithm will then iterate multiple times till all nodes have been visited within the network, leading to a result of the shortest possible path sequence between the starting and ending node (Worboys and Duckham, 2004).

The distance metric used to calculate the shortest path in Dijkstra's algorithm is also known as a weight or cost, to travel an edge between nodes. In the case of a road network, the lower weighted roads in a road network will more likely be chosen within a path sequence than those with higher weights. Though the algorithm ultimately determines the least total cost possible to traverse for creating the path sequence. Normally routing algorithms use the distance metric to find this best possible path, but this can be expanded upon to include or use separately other metrics. These can be anything from speed limits to road types.

A more complicated problem than simply traversing between two locations is finding multiple routes within a network with the most cost efficiency. The most common problem being the traveling salesman problem (TSP). TSP states that when given a set of points where the starting point is to additionally be the ending point, what is the cheapest route that one can take in order to travel between these points (Applegate *et al.*, 2007). TSP is tied to this study for the fact that a runner typically will start and end at the same location, either their home or place with shower facilities. This problem has been researched extensively and is continually ongoing with various types of solutions to try and solve this problem Applegate *et al.* (2007). To solve this issue for this study, the solution was to be based on the idea of visiting the nearest unvisited point in the series of destination points, which essentially uses Dijkstra's algorithm between nodes in the network (Worboys and Duckham, 2004).

To the best of my knowledge since conducting this study, there is no algorithm that currently exists which allows for generating round trips. Though, there has been research conducted to try and address issues where multiple parameters are considered than simply the cost as either distance or time. In one such study, a genetic based algorithm was used with TSP to create multi-objective based weighting sequences from various cost criteria to optimize for the best generalized route (Huang *et al.*, 2006). In another study, several routing methods were created and researched for viability through a semantic search engine to create points of interest in a network (Eiter *et al.*, 2016). Their research was based on using points of interest from a semantic search where they were routed to within a convex hull, which is the smallest possible area within a series of points, based on a neighborhood criteria such as a 5 minute walking distance.

2.2.2 Mobile development

With the advancement of GIS technologies and mobile devices in everyday usage, there has been an increase in mobile application development for both collecting GPS data but also creating routes. This is both static and dynamic applications for routing in a network using Dijkstra's algorithm (Lim *et al.*, 2010; Firdhous *et al.*, 2010). Regarding development for collecting GPS data, a mobile application was created by a state authority to track cycle routes of users in a city (Hudson *et al.*, 2011). This kind of development allows for a higher volume of data to be collected by users who are essentially self-monitoring their activities for data analysis.

2.2.3 Self-monitoring trends

This mobile development has also led to people using applications developed for self-monitoring a users daily or specific activities. A previous study was conducted which used publicly available data collected through a personal training application from user created physical activity patterns which recorded geographical data and other attributes (Sileryte *et al.*, 2016). The data was used to find patterns where physical activities occurred throughout several cities. The results showed that users conducting such activities were condensed mostly to recreational areas, though with some variations among the cities. The analysis of such high volume self-monitored data can be used to further develop policies or applications geared towards this kind of information acquired.

3. HYPOTHESES

From the background information from previous research studies, some hypothesis can be formulated in relation to testing participants in a running capacity. Of which, they will be used to create parameters of the study and additionally these hypotheses will be later referenced again in order to discuss the results.

Hypothesis 1: Runners experience a lower level of perceived exertion when exposed to stress reducing criteria

A higher exposure to vegetated environments while listening to high tempo music should result in the lowest level of perceived exertion.

Hypothesis 2: Runners experience a higher level of feeling when exposed to stress reducing criteria

With the reduction of stressful environmental criteria, there would be positive correlation that as the runner is exposed to vegetation and high tempo music there will be the highest level of feeling felt by the individual.

Hypothesis 3: Runners exposed to environments with high vegetation will experience lower heart rates (higher recovery) than those exposed to urban environments

Given that if this is true, then it would be observable that a runner who is exposed to a route that has an environment which has a high ratio of vegetation should experience lower stress levels with a decrease and/or relatively lower average constant heart rate. Those that are exposed to a low ratio of vegetation should experience an increase in heart rate and/or higher average heart rate. This would be not only observable through standardization of the data but also spatially autocorrelated that when the runner meets vegetation areas there would be a positive correlation with lower heart rates.

Hypothesis 4: Runners exposed to high tempo music will run faster than when not exposed to music

As it has already been observed that in very controlled conditions in a laboratory on treadmills that runners will experience higher exertion levels leading to faster running times. Outside of these very controlled conditions it would be valuable to test if this same kind of correlation will also appear in realistic scenarios. To go further in this there would additionally be spatial autocorrelation with running times and distances with separate musical choices even with similar high tempos.

Hypothesis 5: Runners exposed to ideal conditions will exert more energy while maintaining lower stress levels

Given an ideal scenario based on the established criteria, a runner will have a better experience using the routing method established in this study. The ideal criteria being hypothesized as vegetated environments while the runner listens to high tempo music. This should result in a faster running time and relatively higher BPM while keeping lower stress levels.

4. METHODOLOGY

4.1 Conceptual framework

Based on the hypotheses and aim of this project, a framework was created with the idea of how to implement testing both environmental scenarios while maintaining some control over the route taken by participants with the inclusion of a musical component. This idea starts by designing a routing algorithm structure that creates routes based on a set of parameters. These include a component with restrictions for traversing the network and also designated weights for calculation in the Dijkstra algorithm. In this study, a vegetation index and land use classification proximities are used to determine weighting schema of the network while also including distances. These land classifications are used for environmental characteristics.

The routing algorithm that has been developed for this study is designed to generate routes based on different criteria so that various routes could be created on these separate scenarios. This scenario was set that a runner starts at a designated point and will run a route that should take anywhere between 30 minutes to 1 hour which is the equivalence of 4 to 6 km at a running pace of 8 kph. The end result of the algorithm for this study will lead to two routes for testing the natural and urban environments while maintaining similar destinations in the predetermined route. These routes are then tested twice where each environment has the participant listening to a high tempo music track and no musical stimuli, leading to four separate tests for each individual to obtain quantitative data. Additionally, the runners will be asked questions to obtain qualitative data on this study, such as the RPE. These results from which will prove or disprove the hypotheses.

4.2 Study area

This study was conducted in the city of Yverdon-les-Bains, Switzerland. As seen in Figure 4.1. Located at 46.778218 ° North and 6.64149 ° East. Specifically the starting point of the running routes was designated at the at HEIG-VD campus on the street Route de Cheseaux, also known as the School of Engineering and Business Management of the Canton of Vaud in Switzerland. This was chosen as it was in close proximity to the university campus and offices where this study was developed. Additionally, there were shower facilities located within the campus buildings for the participants to use before and after the experiments.

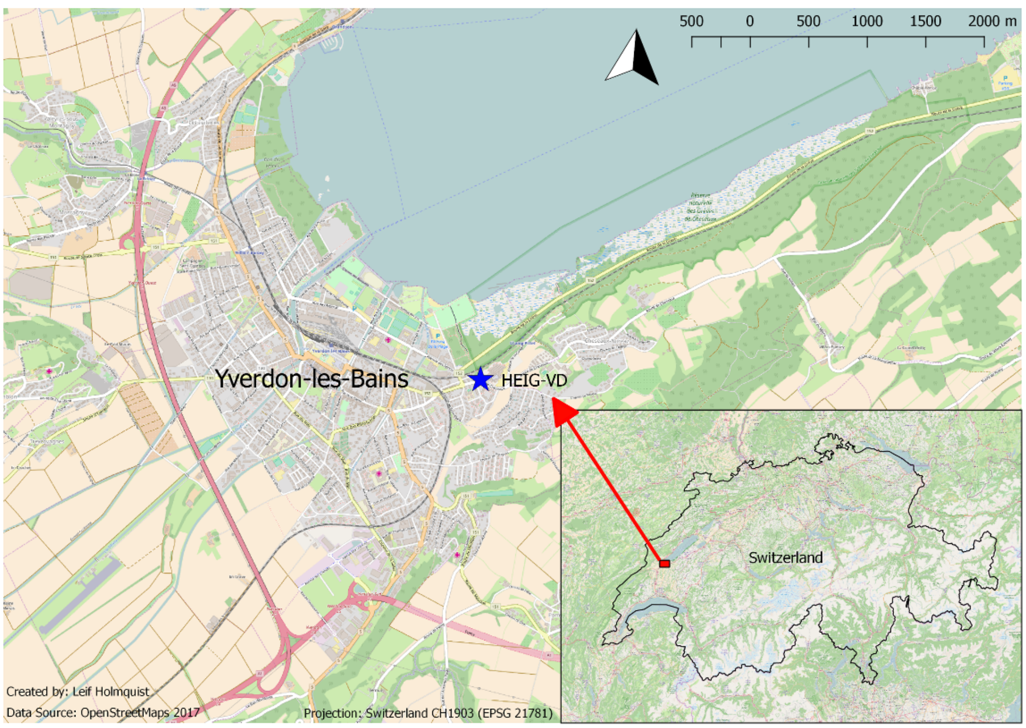


Figure 4.1: Study area of Yverdon-les-Bains, Switzerland

4.3 Data

The majority of data to be used comes from OSM data. This data was used to create the road network structure and routing as well as helping to set some of the environmental characteristics for urban and natural environments. Aerial Photography with a resolution of 0.25 x 0.25 m was obtained from SwissTopo (Swiss Federal Office of Topography) and used to create the vegetation indices of the area in Yverdon-les-Bains. All data was utilized in a local geodetic projection. In this study it was the national Swiss projection of CRS 21781, which was either already in this local projection or projected into. Any user collected data for this study was done by a provided Garmin Forerunner® 620.

4.4 Technical tools

The technical tools that were utilized for this study were mostly open source software. This ranged from database structure to functional programming and the visualization of routes for the running participants. Database and query structure for analyzing the routes on this road network with the algorithm were accomplished in PostgreSQL 9.6. This was managed and visualized in pgAdmin 3, a GUI tool for PostgreSQL. Within this database, pgrouting 2.4.1 was used for needed spatial functions of routing. A PostgreSQL adapter with Python programming structure, psycopg 2.7.1, was used to create the algorithm for this study.

Maps for participants to use for pre-running visualization were created in QGIS 2.18. The GUI aspect of these routes for runners to cross-reference while testing was utilized with Galileo Offline Maps, a mapping application for mobile devices with free and paid versions. The musical testing component of this study was conducted with the help of the Spotify® music application. This is a monthly subscription based application with a range of musical options for use in this study.

4.5 Routing parameters

4.5.1 Turn-restricted road traversal

To create an ideal road network it was further determined to include another realistic parameter in the algorithm for participants in this study. If a runner were to run along the same section of path then it would not be desirable from an aesthetics approach. This is that free runners most likely do not wish to travel the same road twice unless absolutely necessary. The set criteria was that the runner should ideally not backtrack along the same road. That if a road were traversed within the route network, then it would have a significantly higher weight on the second iteration of route creation. The algorithm goes through all iterations and checks the network on each to create further routing and new weighting until the entire route structure is completed.

4.5.2 Environment based weighting

The main idea behind weighting the road network in relation to nearby environment type was to use a mean vegetation index obtained from aerial photography. These photographs contain a Green and Red visible color band usable in the Green-Red Vegetation Index (Motohka *et al.*, 2010):

$$GRVI = \frac{Green - Red}{Green + Red}$$

where the possible ratio is between -1 to +1. Where a +1 ratio is equivalent to very high and dense vegetation with decreasing amount to 0 (Motohka *et al.*, 2010). From 0 to -1 this is equivalent to being observed as dirt and urban structures. Once the GRVI grid had been created by the GRVI algorithm, it could then be used to find the mean GRVI within each section of the road network based on zonal statistics of predetermined buffer zones.

As the GRVI mean within a road section was only a way to measure the vegetation density, a simple conversion method was created for the nature and urban centric classifications. As seen in Table 4.1, as the mean GRVI increases then the weighting of the natural environment decreases. It is the opposite for an urban centric route, where as the mean GRVI increases then the urban environment weight is positively correlated to increase accordingly. These weights are then utilized in Equation 4.1 and Equation 4.2.

Another criteria for including additional weights to the environment characteristic was to use OSM data which included information on the location of forests, nature reserves, parks, and buildings. These were deemed as important identifiers for helping to improve the routing algorithm by giving a higher weight based on the needs of each environmental characteristic. The natural environments were given a buffer zone of an additional 20 m and the

Table 4.1: Greeen-Red Vegetation Index based weighting for environmental categorization

GRVI Mean (x)	Weight^{Nature}	Weight^{Urban}
$0.0 \leq x \leq 0.1$	10	1
$0.1 < x \leq 0.2$	9	2
$0.2 < x \leq 0.3$	8	3
$0.3 < x \leq 0.4$	7	4
$0.4 < x \leq 0.5$	6	5
$0.5 < x \leq 0.6$	5	6
$0.6 < x \leq 0.7$	4	7
$0.7 < x \leq 0.8$	3	8
$0.8 < x \leq 0.9$	2	9
$0.9 < x \leq 1.0$	1	10

urban environment buildings were given a 10 m additional buffer zone. Any overlap between the natural and urban buffers was subtracted with priority given to natural environments.

These zones were then intersected with the road network buffers seen in Table 4.3 to give the topological relationship between the environments and road network. If a road section had the presence of a natural environment or building, then the section was given a zonal weight, Zone_{Urban} and Zone_{Nature}. These land use characteristics gave a better assumption of the urban or natural environments, thus they were given a weight value of 10 to increase the importance of seeking or avoiding the road section within the routing algorithm. The way these weights are utilized can be further observed in Equation 4.1 and Equation 4.2.

$$Cost_{Nature} = \frac{Cost_{Length} * Weight_{Nature}}{\frac{Zone_{Nature}}{Zone_{Urban}}} \tag{4.1}$$

$$Cost_{Urban} = \frac{Cost_{Length} * Weight_{Urban}}{\frac{Zone_{Urban}}{Zone_{Nature}}} \tag{4.2}$$

Where:

Cost_{Length} = distance (m).
Weight_{Nature} = Nature positive weighting based on GRVI mean.
Weight_{Urban} = Urban positive weighting based on GRVI mean.
Zone_{Nature} = Presence or absence of natural land classes.
Zone_{Urban} = Presence or absence of urban buildings.

4.5.3 Music

The selection of high-tempo music for testing was designed to fit the specifications of being between 180 to 200 BPM. This was due to previous research on the subject in which participants were exposed to 200 BPM within a 10 minute time-frame (Edworthy and Waring, 2006). The proposed running routes go beyond 10 minutes to complete, even for the worlds fastest recorded runner in a 5km running course (ARRS, 2017). Also, anything at a constant 200 BPM would not be ideal conditions for participants running these proposed routes. As this would incur a constant high exertion on the runner and could be detrimental on the results of this study.

By not restricting the criteria to 200 BPM, it allows for small recovery times of exertion for the participants. Having this range kept within a 20 BPM window keeps the selection narrow instead of being too broad, while additionally maintaining a high tempo category status. This window also allows for a broader selection of music that would be available for testing. The music was chosen to reflect various genres of music that would fall within this designated BPM range. This was a way to standardize the music by not giving higher influence on one genre. As this could affect certain users personal preferences on musical choice.

The music choices were further selected to be within the criteria that they were available on a streaming service. In this case the Spotify® application was chosen (Spotify, 2017a). The music choices were further aided with some assistance from the Spotify® Running tool which allows for musical selection based on BPM. The source of this song metadata, BPM and duration, came from Spotify®, but was searched through a Spotify® web API. This metadata is not currently searchable through the Spotify® application (Spotify, 2017b; SongBPM, 2017). A list of the music can be found in Table 4.2. The total running time of the playlist is 58 minutes 8 seconds, which should accommodate the slowest runners of the predetermined routes.

4.5.4 Slope

Outside of a gym, the surface that a person runs on is almost never homogeneous and will have variations in the gradient of the road surface. The slope should not be too steep for a runner as it will negatively impact their running technique (Frans Bosch, 2005, p. 232). This gradient should not exceed 10% in order to maintain proper running technique (Frans Bosch,

Table 4.2: Music playlist for high tempo music testing

Musical Artist / Band	Song Title	Genre	BPM (beats per minute)	Duration (mm:ss)
Daniel Deluxe	Purification	Electronic	180	3:10
Cake	The Distance	Rock	183	2:59
Justice	Ohio	Electronic	184	4:01
The Weeknd	Starboy	Pop	186	3:50
AC/DC	Back In Black	Rock	188	4:15
Maroon 5	Animals	Pop	190	3:51
Sia	The Greatest	Pop	192	3:30
Dragon Force	Through the Fire and Flames	Metal	200	7:21
Florence & The Machine	Drumming Song	Rock	200	3:43
Sum 41	Still Waiting	Rock	192	2:38
Dyalla	Little Bit More	Electronic	190	2:24
Utada	Easy Breezy	Pop	188	4:01
Iron Maiden	Speed of Light	Metal	185	5:01
Sung	The Sector	Synthwave	180	3:09
Power Glove	Night Force	Electronic	188	4:15

2005, p. 232). The area in which this study was conducted had slopes which were mostly under 10%. Thus it was deemed that slope should not be considered as it is negligible in the study area to affect this study in correlation to runners.

4.6 Application development

The foundation of this data is built on a PostGIS database structure. The specific spatial database being PostgreSQL 9.6 with the addition of the pgRouting extension library. This library was needed for spatial functions that use routing algorithms in the calculation of route networks and network analysis (pgRouting, 2013). This was further streamlined by using Python to automate the queries through the Psycopg PostgreSQL database adapter.

4.6.1 Pre-processing

The OSM street network data collected was the size of Switzerland, which was eventually reduced to an area slightly bigger than Yverdon-les-Bains based on the extent of several merged aerial photographs of the region. Further processing removed unnecessary columns from the data table that had no relevance and to make visualization of the data easier for the user. All roads in the network that were not designated as pedestrian accessible were removed, which in OSM terminology meant removing designated motorways and motorway links. It was deemed that roads such as highways were neither ideal nor safe for running participants.

From this pre-processed road network, buffers were created around each specific road class type based on their width as seen in Table 4.3. These buffers were then utilized as zones for each road section where a mean GRVI was calculated based on zonal statistics of the buffer within a GRVI raster grid. Any road section having a value less than zero, no vegetation, was set to zero for weighting purposes. The process of creating this designation is discussed further in Section 4.5.2. Once the final weights for a nature route and urban route had been finalized, a topological relationship of the road network was established. This created a node network for setting destination points to be used in the Dijkstra and routing algorithm created for this study.

Table 4.3: Road class buffer zones for Green-Red Vegetation Index zonal statistics

Road Class (OSM Type)	**Buffer Size (m)**	**Total Buffer Width (m)**
Cycleway	2	12
Footway	2	12
Living Street	5	15
Path	1	11
Pedestrian	3	13
Primary	5	15
Residential	3	13
Secondary	5	15
Service	3	13
Steps	2	12
Tertiary	5	15
Track Grade 1-4	2	12
Unclassified	2	12

4.6.2 Processing

Once the data had been preprocessed in the previous description, an algorithm was created. Since this algorithm uses turn-restriction with weighting in a restricted buffer it is to be designated as the Spatially Turn-Restricted Weighting Algorithm (STRWA) hence forth. The main purpose of STRWA was to adhere within the parameters set as previously discussed. With the idea that a runner starts at a specific node and then ends at the same node, similar to TSP.

A buffer was created around this starting and ending node. This was tested at various distances and determined that an ideal buffer for this study would be at 250 m and starting at the Centre de Badminton located in close proximity for the HEIG-VD testing site. When initially creating these routes, solely based on length as a weighted cost, a distance of about 4 to 6 km was created. The buffer perimeter was created to have 8 vertices. As these were not actual nodes in the road network, a bounding box around each vertex chose the closest node based on euclidean distance to the buffer vertex. These nodes would then become the destinations in STRWA and stay constant throughout both routing iterations.

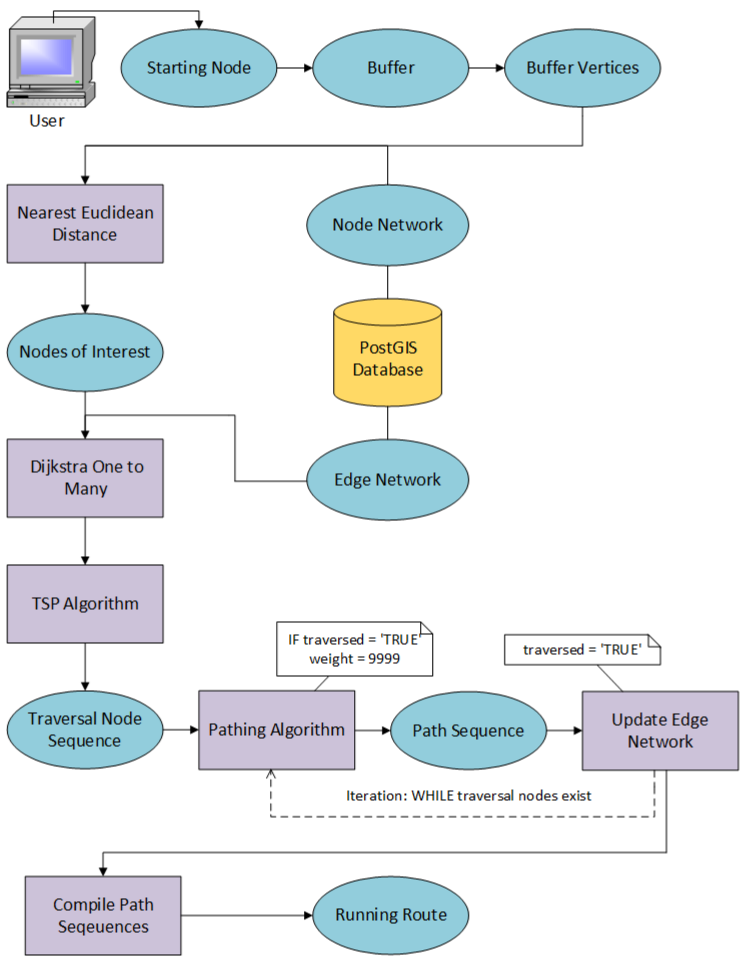


Figure 4.2: Spatially Turn-Restricted Weighting Algorithm: routing algorithm flow

STRWA would then check for the least costing node based on the idea of Dijkstra's One to Many, where the cost (Cost^{Length}) is the distance to travel (pgRouting, 2013). As the first node within the routing array is the starting node, this node is then added as the second node in the array as the first destination for the runner. Subsequently each next node is added to this array based on the least cost by distance until STRWA returns to the ending node which is the same as the starting node. This creates an array that goes from the center of the buffer, and then around the buffer until returning back to the center of the buffer. The basic flow of STRWA can be found in Figure 4.2. Further visualization of this process can be seen in Appendix A.

After this initial array creation, STRWA tests weighting and traversal parameters of the road network. For the turn restricted criteria, this was set by designating a 'TRAVERSED' column to store data in STRWA that would store a 'TRUE' value if a road section had been traversed in the Dijkstra calculation between each node connection. After each calculation between the destination nodes, any road section used was given a 'TRUE' traversal status and this was updated within the road network table as such. Upon each subsequent iteration of this calculation, STRWA checks if the road has been traversed. If a road section has been previously traversed, it is given a weight of 9999. This is essentially similar to giving the cost of using the road section an infinity value, thus causing the route to avoid traversing the same road section twice unless there are no other connections from the node to be traversed.

4.6.3 Post-processing

After creation of the routes, it was observed that there were a few outliers within the finalized routes. This was due to a couple of the destination nodes leading to a road section with only one connection, i.e. a dead end. These outliers were manually removed to adhere with a congruent route for the participants. These routes created for testing the runners were categorized as a nature route and an urban route. The resulting nature route was approximately 4.88 km (4884.10 m), see Figure 4.4. Additionally, the resulting urban route was an approximate 3.43 km (3427.86 m), see Figure 4.3. Once both routes were finalized for the study, they were converted from PostGIS to KML for usage with a mobile application.

4.7 Implementation and data collection

It was determined to use a pre-existing application that would allow for route navigation while allowing for the user to traverse the predetermined

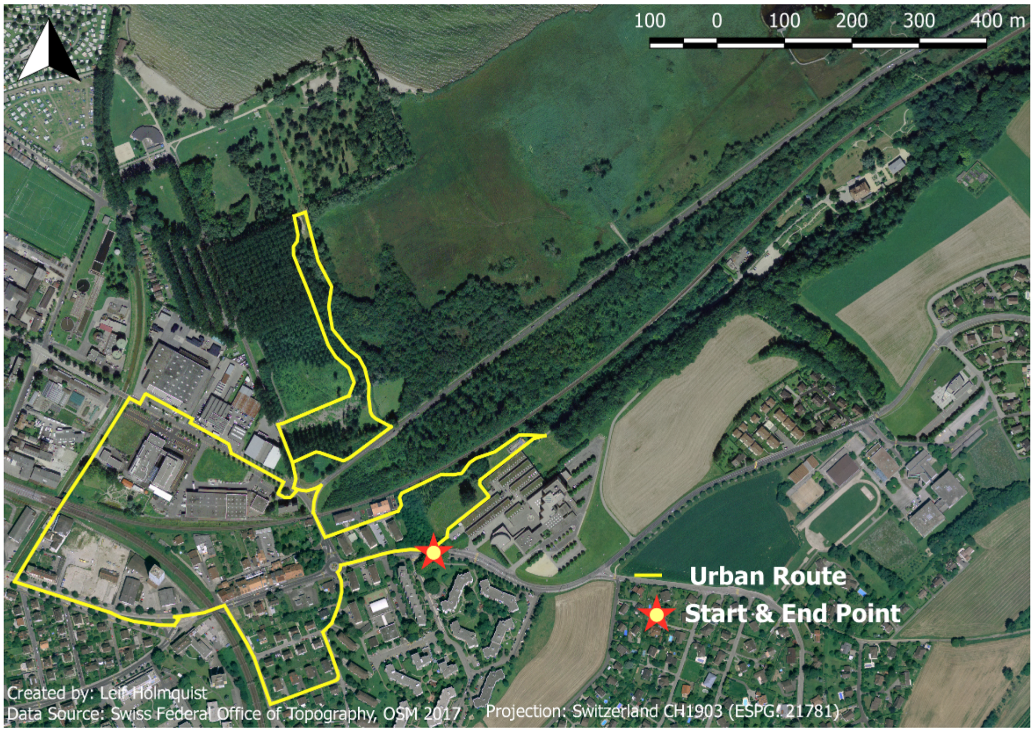


Figure 4.3: Urban route created through the Spatially Turn-Restricted Weighting Algorithm

routes relatively unhindered. The application chosen was Galileo Offline Maps (GOM, 2017). This tool allowed for the importation of routes created in this study from the KML format. It further allowed for the exportation of recorded routes that the participants took in KML format. The application additionally allowed for recording latitude, longitude, altitude, speed, timestamps, horizontal and vertical accuracy. Though this interface was used only to help assist the participants in trying to adhere to the predefined routes as best they could by following it on a mobile device which can be seen in Figure 4.5. This same device was used to play the Spotify® running playlist created for this study as seen in Table 4.2 for the testing routes that involved the musical stimuli.

At the starting location that the participants were to begin and end their route, they were further equipped with a Garmin Forerunner® 620 watch with the Garmin Heart Rate Monitor strapped to the participants chest. These devices allowed for collecting data on the individuals location, speed,

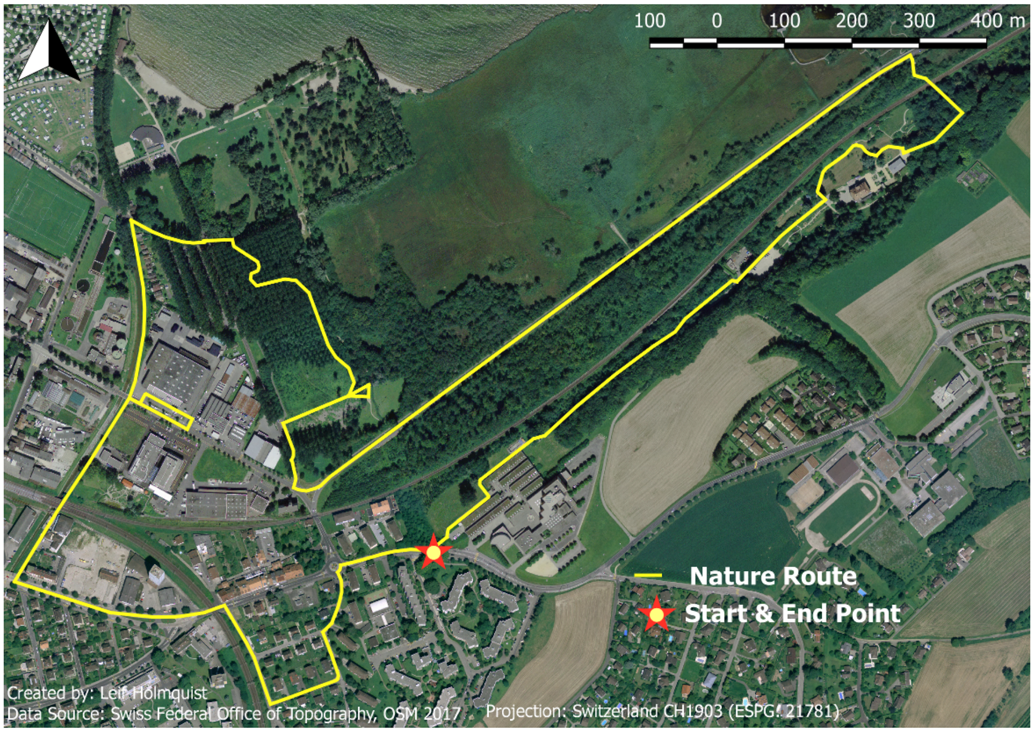
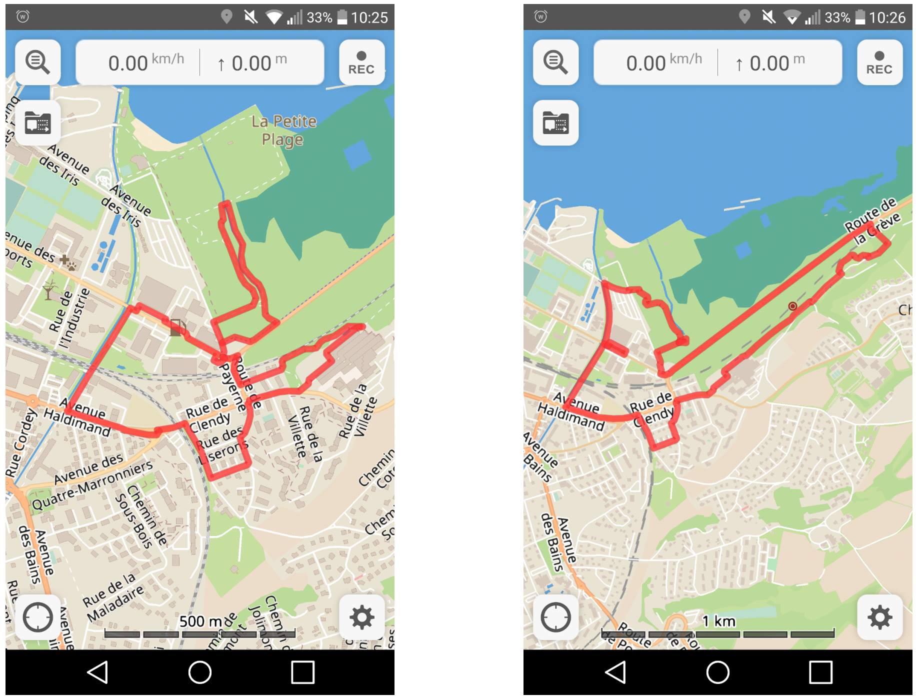


Figure 4.4: Nature route created through the Spatially Turn-Restricted Weighting Algorithm

heart rate and other vital statistics. The participants were additionally given a qualitative and quantitative questionnaire. The questions included biometric information, including data about their RPE, Feeling and activity levels. The qualitative questions were asked both pre-exercise and post-exercise. This questionnaire can be observed in more detail in Appendix B. This study was then conducted over the course of 14 working days between June 1^{st} and June 20^{th} 2017. Each participant had at least a one day minimum rest period between their respective tests.

To expand further on the specifics of testing, the participants were first given the questionnaire to fill in the pre-exercise section. This included some instruction on how the RPE functioned. Participants were also shown a paper map of the route that they would be taking during the testing of that day, including some instruction on the mobile device of the this same route. Once complete, they were then directed towards the starting location and instructed on how to start and stop the Garmin Forerunner® 620 watch



(a) Urban route (b) Nature route

Figure 4.5: Routes imposed on the Galileo interface

for recording their traversed route and told to run the route as they would normally exercise during similar activity.

If they were to run a route with musical stimuli, they were allowed to use their own earphones or those provided through the study. A music playlist was started within a few second window of starting the tracking devices. Upon completing the route for each testing period, they were then given the post-exercise section of the questionnaire to complete. Participants were first given the urban route with no musical stimuli (UR), proceeded by the urban route with musical stimuli (URM). They were then given the nature route without musical stimuli (NR), followed by the same route with musical stimuli (NRM).

5. RESULTS

5.1 Qualitative

The qualitative aspect of this study is to measure the results of responses that the participants gave to the questionnaire regarding most specifically the RPE and Feeling factors with the various routes with or without musical stimuli. The results of which are concluded in this chapter. Additionally, other statistics about the users regarding their general biometrics, activity frequency, musical suitability and their reactions regarding the routes are also included in this chapter. The data is categorized as four main categories throughout this study unless otherwise specified in a section.

The absolute values of the RPE and Feeling scale results are difficult to interpret in this study due to individual characteristics of the runners. Thus it is better and more important to use the change or difference (Δ) between a participants results. The Δ is calculated to determine the shift in RPE and Feeling from the pre- and post-exercise results of each participant. Additionally it should be noted that the runner with ID #3 was unable to finish their fourth test, NRM, thus the data of this participant is missing from the study.

5.1.1 Participant statistics

A total of 9 participants participated in this study. These were mostly composed of faculty or international students at HEIG-VD. The sex of the participants was composed of 7 males and 2 females. The ages of the participants ranged from 20 to 39 with a median age of 24. The heights of these runners ranged from 165 to 190 cm, whose weight range was between 58 to 90 kg. The participants have a mean running frequency of 1.7 times per week with a mean distance of 4.4 km. The full statistics of which can be seen in Figure 5.1, based on the questionnaire pre-exerise results.

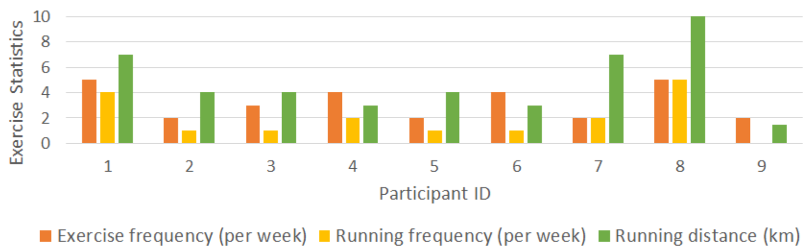


Figure 5.1: Exercise activity. Data collected between May 29 to June 21, 2017. Yverdon-les-Bains, Switzerland. 9 observations.

5.1.2 *Musical choice*

Within the questionnaire that participants were given, an assessment of musical suitability from the listening track from Table 4.2 was questioned for both URM and NRM. The results of which can be seen in Figure 5.2. The results of which were overall positive with an average score of 3.56. From the figure, it can be further noted that about 47% of the tests with music were given a rank of 4 or greater. Going even further that 82% of these tests had a music suitability of rank of 3 or greater.

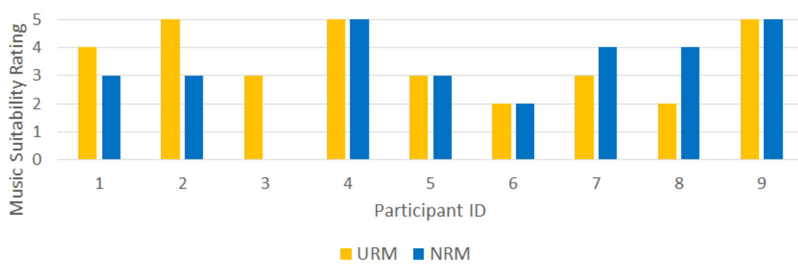


Figure 5.2: On a scale of 0 to 5, was the music suitable for the exercise? Data collected between May 29 to June 21, 2017. Yverdon-les-Bains, Switzerland. 9 observations.

5.1.3 *Rate of perceived exertion scale*

The ΔRPE results show how participants rated their RPE before and after each test and the change in RPE for each specific test. Figure 5.3 shows all mean changes among the participants throughout these tests. The lowest mean ΔRPE experienced by the participants occurs in UR and the highest mean ΔRPE experienced is in NR. UR and URM had a lower ΔRPE overall than NR and NRM.

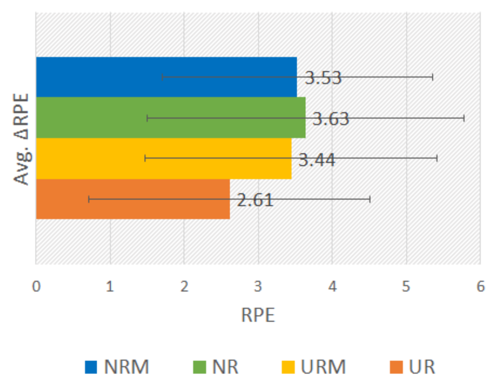


Figure 5.3: Average Rate of Perceived - On a scale from 0 to 10, how much energy do you feel you are exerting? Data collected between May 29 to June 21, 2017. Yverdon-les-Bains, Switzerland. 35 observations.

The music stimuli negatively affected the ΔRPE between UR and URM. This negative difference is -0.83 ΔRPE, which signifies the much better result in UR ΔRPE. Though this same stimuli positively affected NR and NRM where there is a positive difference of 0.10 ΔRPE. More in-depth and supportive data on the individual runners can be seen in Appendix Figure C.1.

5.1.4 Feeling scale

The ΔFeeling scale results show how participants rated their Feeling before and after each test and the change in Feeling within each test as seen in Figure 5.4. This difference is created by deducting pre-exercise from post-exercise results. Lowest mean ΔFeeling occurs in NR. Highest mean ΔFeeling felt by participants within URM. This indicates that the best Feeling was felt among runners in URM.

Musical stimuli positively affected the runners in both environments. There is a positive difference of 0.77 between UR and URM. A similar positive difference of 0.71 is found between NR and NRM. Differences among the separate routes is more positive towards the urban routes. More in-depth and

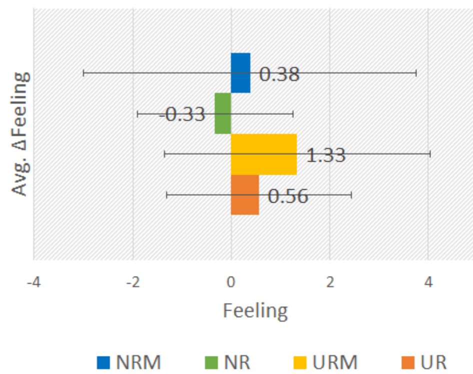
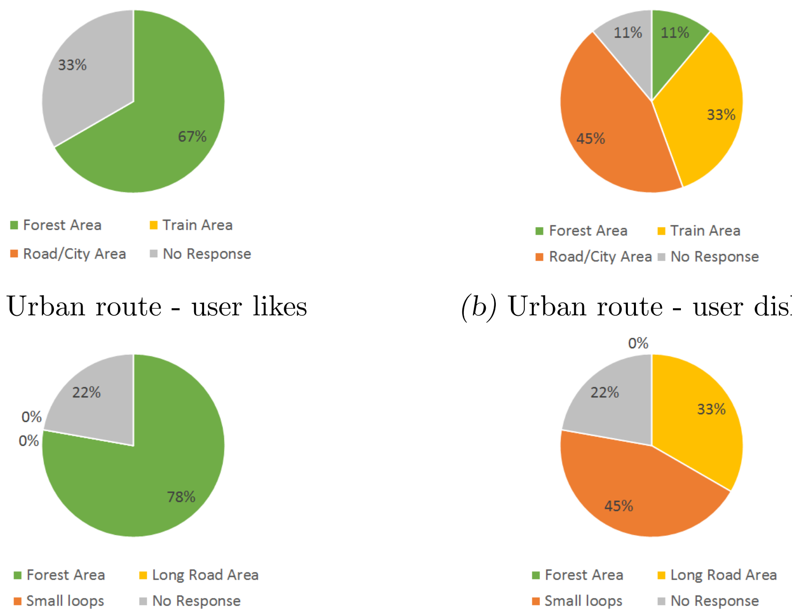


Figure 5.4: Average Feeling - On a scale from -5 to +5, how are you feeling? Data collected between May 29 to June 21, 2017. Yverdon-les-Bains, Switzerland. 35 observations.

supportive data on the individual runners can be seen in Appendix Figure C.2.

5.1.5 User routing reactions

In the post-exercise questionnaire, users were asked "What do you like and/or not like about the course? Additionally, circle on the map". This was a way to semantically assess attributes to the routes that were pleasant or not. In the urban route, 67% of the participants stated that they liked the course for it's forest and nature areas. The major dislikes in this route regarded the city road areas and train crossing. This was mentioned as dislikes by 45% and 33% of the participants respectively. In the nature route, 78% stated that they liked the forest and nature parts of the course, more specifically the forested areas that included lots of shade. The major dislikes in this route mentioned were about several small loops that were present in the course, due to STRWA turn-reversal choices, and the long stretch of road next to the nature reserve in the course. Participant dislike of these were respectively 45% and 33% of the participants. The statistics of which can been seen further in Figure 5.5. Their reasoning for disliking the long stretch of road indicated that it was very hot, had no shade and a lot of vehicle traffic.



(a) Urban route - user likes

(b) Urban route - user dislikes

(c) Nature route - user likes

(d) Nature route - user dislikes

Figure 5.5: User Reactions: What do you like and/or not like about the course? Data collected between May 29 to June 21, 2017. Yverdon-les-Bains, Switzerland. 35 observations.

5.2 Quantitative

The quantitative results of this study are an analysis of the raw data taken from the Garmin Forerunner® 620. These results include the trajectories of all participants along the tested routes taken from the collected GPS data. The trajectories include distances traveled, speed, HR and cadence of the participants. Speed recorded by the devices is calculated in meters per second (m/s) and is an indication of the trajectory speed of a participant. Cadence is the number of steps per minute (spm) that an individual is calculated to be taking at a given point of time as calculated by the HR monitor. It should be noted that due to device error, there was no recorded cadence for the runner with ID #3.

A further analysis of these statical means was conducted to obtain a more in-depth understanding of the results. This is a specific analysis of the relationship between urban and natural environments that is covered further in Section 5.2.3. The other in-depth analysis regards the musical stimuli and how its inclusion or exclusion affects the participants. Local temperature data is further included to better understand the conditions that runners experienced in the outside environments as this can be a possible influencing factor on runners as noted by Noakes (2002).

5.2.1 Accumulative track trajectories

The results of these participant trajectories for each route can be seen in Figures 5.6, 5.7, 5.8 and 5.9. These trajectories show that the participants were able to follow the routes given to them fairly well. Though it should be noted that their are some differences in how the participants traversed each route. The major difference among the trajectories for each test occurred at turning junctions where they interpreted the routing differently in some cases. This led to making some turns too early as seen in Figure 5.6 and 5.7 in the starting portion of the route. Additionally, when participants first ran a new route there are multiple cases of where the users would miss a turn and have to backtrack onto the route.

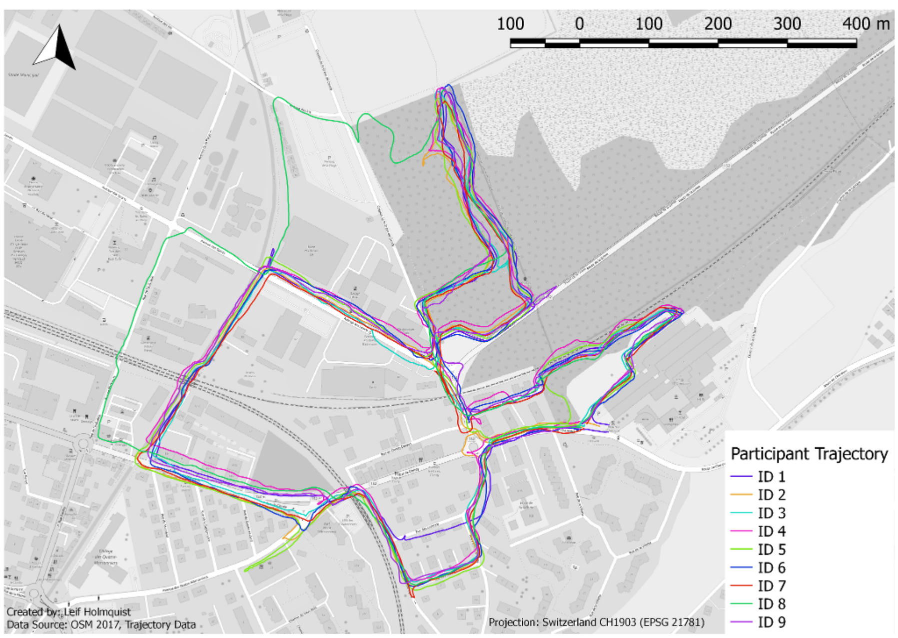


Figure 5.6: Trajectories: Urban Route. Data collected between May 29 to June 21, 2017. Yverdon-les-Bains, Switzerland. 9 observations.

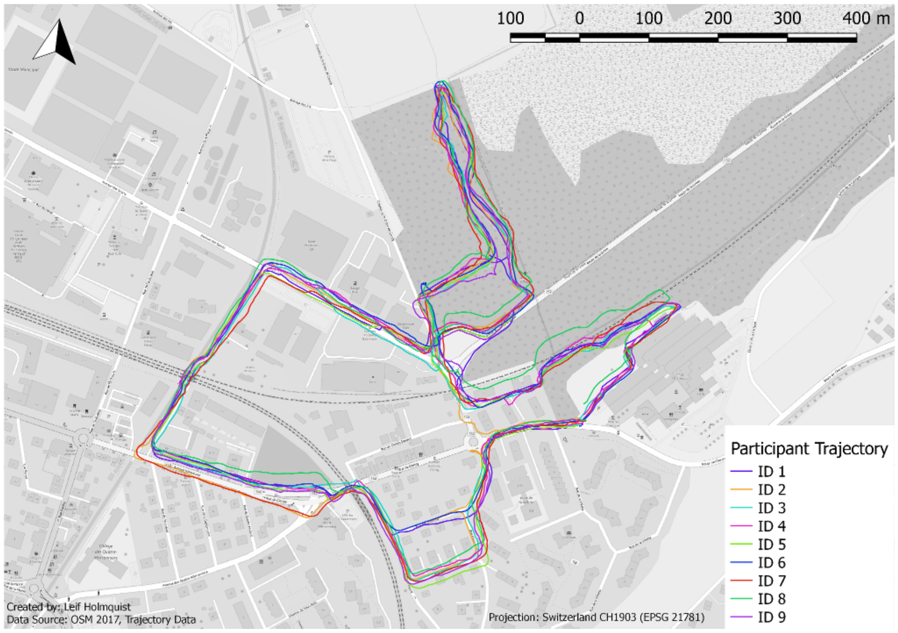


Figure 5.7: Trajectories: Urban Route with musical stimuli. Data collected between May 29 to June 21, 2017. Yverdon-les-Bains, Switzerland. 9 observations.

There are also some errors in the results of participant trajectories. The most obvious error seen in Figure 5.6 where one participant clearly bounded outside the route for a portion of it. There are also other errors in which some participants took the correct route but took a path in the route from a different direction such as the forest section of UR. This is obvious in the individual trajectory data as well as noted by the participants in this study's questionnaire. Some minor errors appear to be caused by GPS inaccuracies which are uncontrollable due to satellite reception and other disturbances. Such as signal backscatter caused by weather or the surrounding environment. This only affects a small portion of visualizing these trajectories and does not negatively affect the statistical results.

5.2.2 Statistical means

The statistical averages calculated among all routes for which the participants were tested on can be seen in Figure 5.10. As should be, NR and NRM take the participants considerably longer as should be with the results

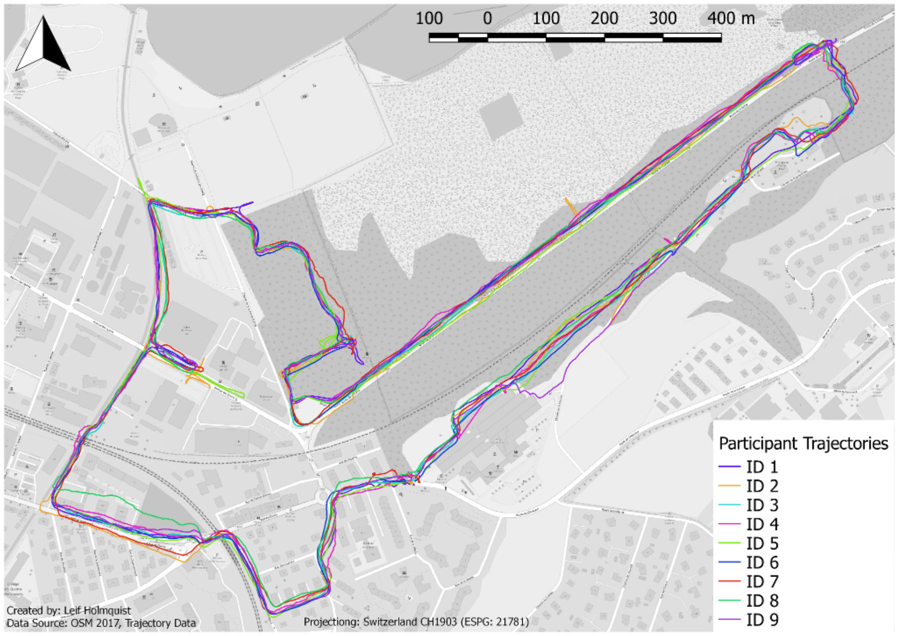


Figure 5.8: Trajectories: Nature Route. Data collected between May 29 to June 21, 2017. Yverdon-les-Bains, Switzerland. 9 observations.

from Section 4.6.3 of creating the two separate routes for testing. Though it should be further noted in Figure 5.10d that when a runner ran the same route for the second time, they completed the route within a shorter total distance. These differences were 202.06 m in the urban routes and 176.56 m in the nature routes. This is likely due to participants being more familiar with the same route on the second iteration which leads to less chances of going off the designated routes they are to follow. This becomes more apparent when considering the overall trajectories of the participants as seen within the results of Section 5.2.1.

The mean HR data shows a decrease in HR with increasing testing order as seen in Figure 5.10b. The highest mean HR occurs in UR and the lowest occurs in NRM. The difference between these is 4.87 bpm in favor of the latter. There is a mean decrease of 1.34 to 2 bpm with each subsequent test. This means that the HR conditions were considerably better in the nature routes when compared to the urban routes.

As seen in Figure 5.10a, mean speed was highest among participants while running URM and lowest among UR by a difference of 0.05 m/s. The

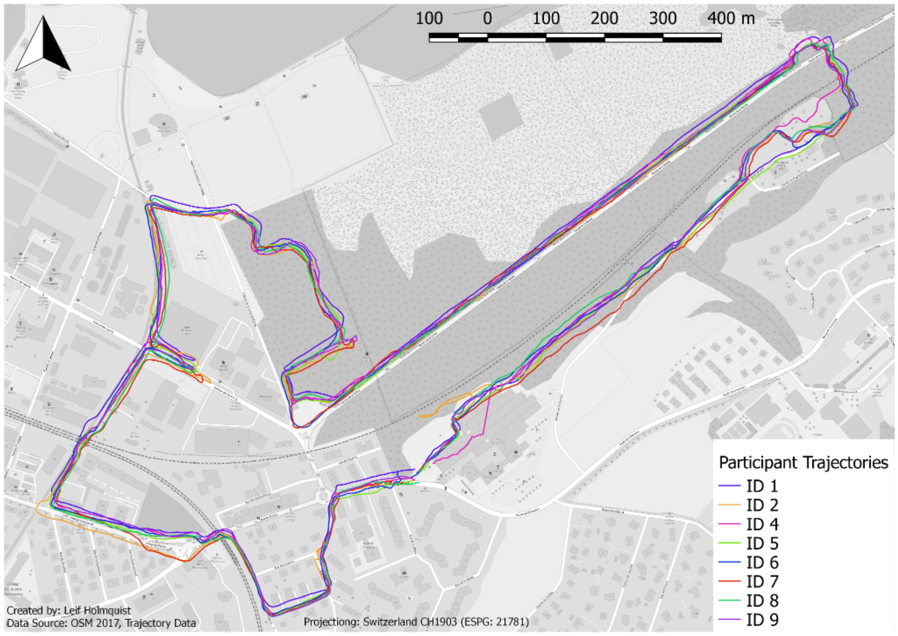


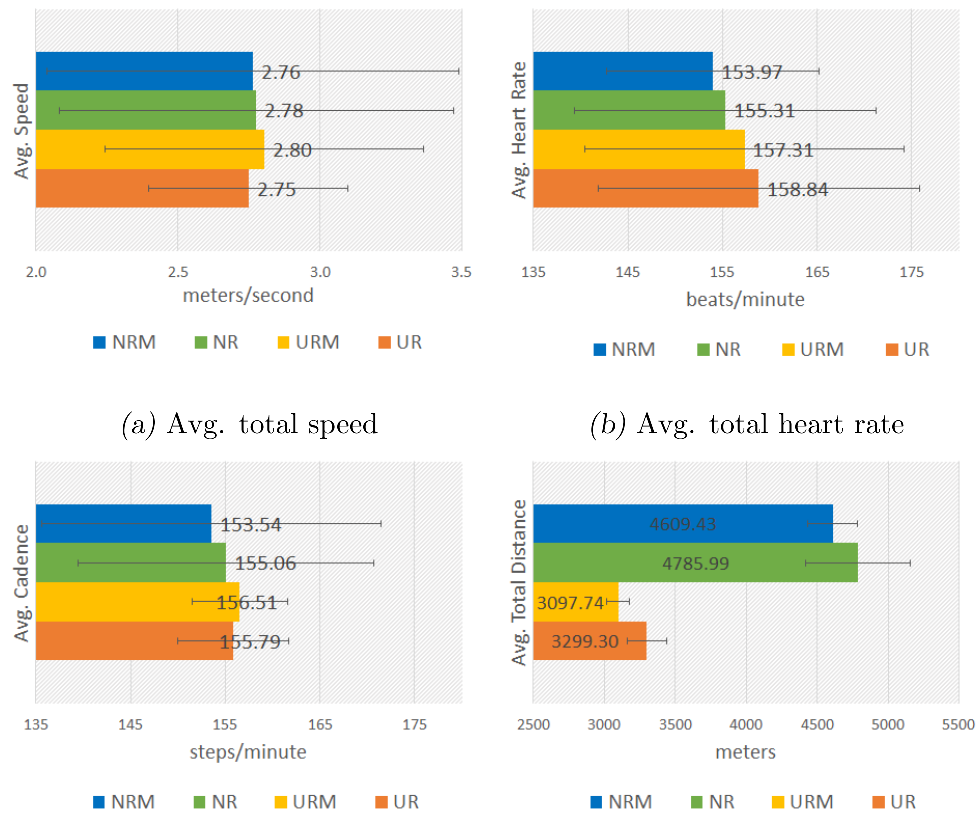
Figure 5.9: Trajectories: Nature Route with musical stimuli. Data collected between May 29 to June 21, 2017. Yverdon-les-Bains, Switzerland. 8 observations.

opposite was seen in NR and NRM which had a slightly higher mean speed in NR by 0.02 m/s. There is notably more variation in the speed when participants were on the musical stimulated tests.

This pattern was similar to the mean cadence where there is lower variance in the urban routes compared to being higher in the nature routes. The other patterns in cadence are additionally similar to the mean speed. Though, the least mean cadence occurs in NRM. More in-depth data for speed, HR, cadence, and distance on the individual runners can be seen in Appendix Table C.1.

5.2.3 Urban vs. forest areas

A buffer analysis is done on the UR and URM trajectories of the participants. This analysis is conducted to obtain more specific results within the urban and natural environment sections of the routes since all of them would still go through some urban or natural environments due to the current de-



(a) Avg. total speed

(b) Avg. total heart rate

(c) Avg. total cadence

(d) Avg. total distance

Figure 5.10: Statistical means among all routes. Data collected between May 29 to June 21, 2017. Yverdon-les-Bains, Switzerland. 35 observations.

sign of STRWA. Two buffers are created to analysis these sections as seen in Figure 5.11. A 300m buffer in a section of the route which is deemed as heavily residential and a 300m buffer in a section of the route which is deemed as more natural environment running within a forest.

The analysis of which can be seen in Figure 5.12. Within these buffer areas there is a correlation that natural environments lead to small increases in HR. There is an opposite correlation that urban environments lead to larger increases in HR. This difference is 2.78 bpm between urban and forest areas. In the same areas with musical stimuli, the difference is 3.88 bpm. Between similar environments, there is a higher ΔHR when musical stimuli

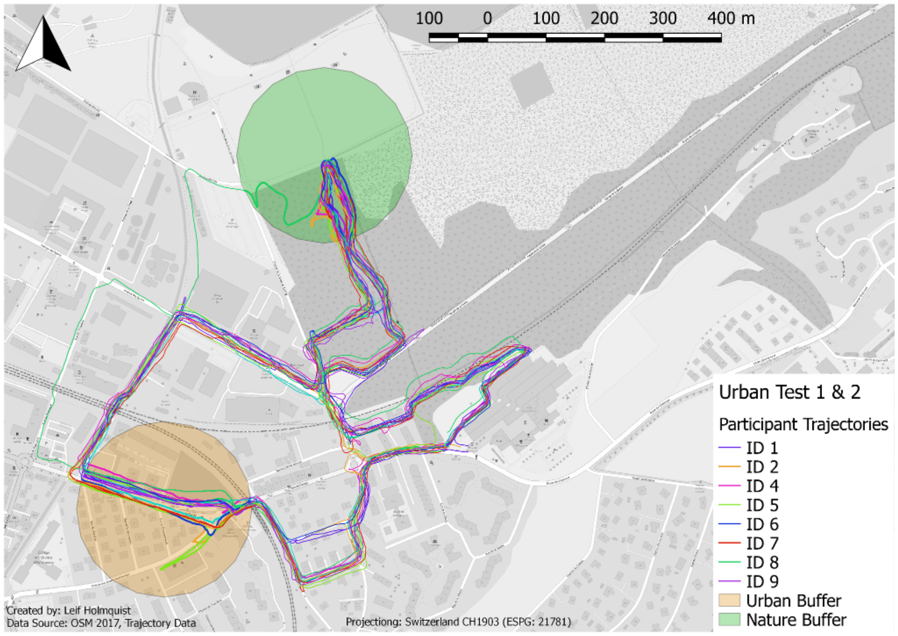
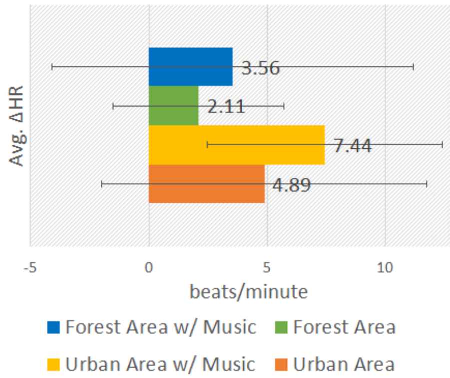


Figure 5.11: Residential and forest buffer zones. Data collected between May 29 to June 21, 2017. Yverdon-les-Bains, Switzerland. 18 observations

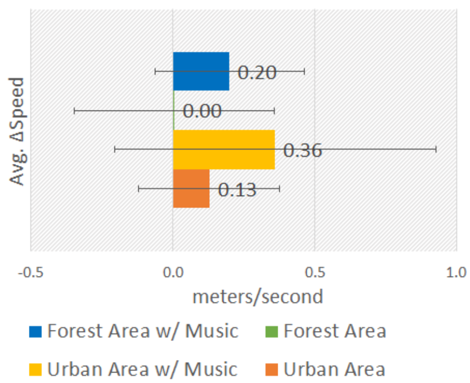
is involved. This difference is 2.55 bpm in the urban area and 1.45 bpm in the forest area. If the lowest ΔHR is the ideal, then the forest area without musical stimuli would be the targeted group.

Though from the results of these buffers regarding the mean speed, the ΔHR positively correlates with increases in speed as seen in Figure 5.12b. The highest mean Δspeed is achieved in the urban area with musical stimuli and lowest is within the forest area without musical stimuli with a difference of 0.36 m/s. The highest Δspeed was achieved among the areas that involved musical stimuli. The difference between their corresponding areas is 0.18 to 0.20 bpm greater than if they did not have this stimuli applied.

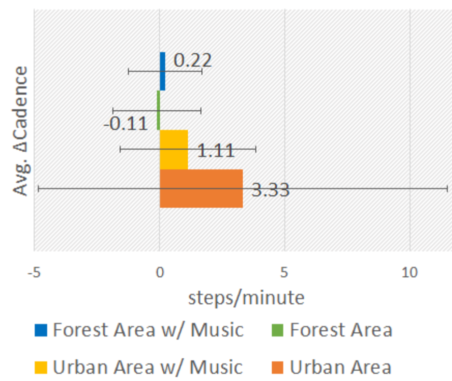
In Figure 5.12c, the highest mean Δcadence occurs in the urban area. When musical stimuli is involved, the cadence is decreased by 2.22 spm. This means that runners achieved the highest mean Δspeed in fewer steps over the same distance. Lowest Δcadence occurs in the forest area without musical stimuli with fewer spm at the end of the forest than from the beginning. This means that runners kept an equal mean Δspeed while reducing their mean Δcadence.



(a) Avg. ∆heart rate



(b) Avg. ∆speed



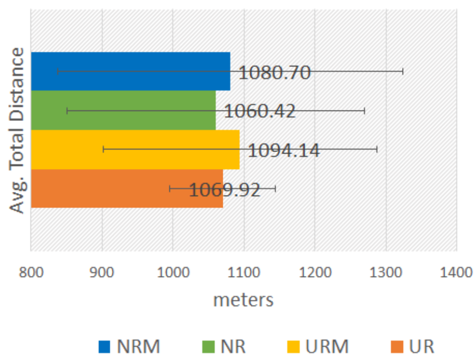
(c) Avg. ∆cadence

Figure 5.12: Urban vs. nature - buffer analysis. Data collected between May 29 to June 21, 2017. Yverdon-les-Bains, Switzerland. 18 observations.

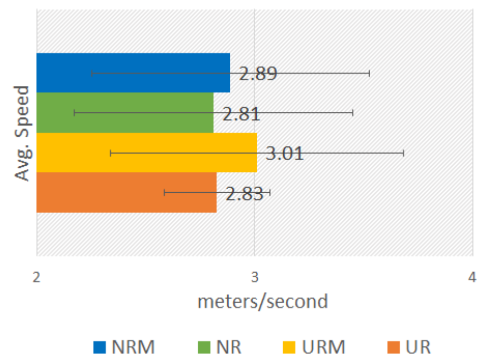
5.2.4 Music stimuli analysis

The music that is analyzed for comparison among all trajectories was the second song on the playlist, The Distance by Cake, as seen in Table 4.2. This is analyzed because it allowed time for the participants to warm up in their run. Which includes the time traveled along the route and allowing the participants to become accustomed towards the musical stimuli. This song starts at about three minutes into the run and lasts for another three, this time-frame is then analyzed across all trajectories.

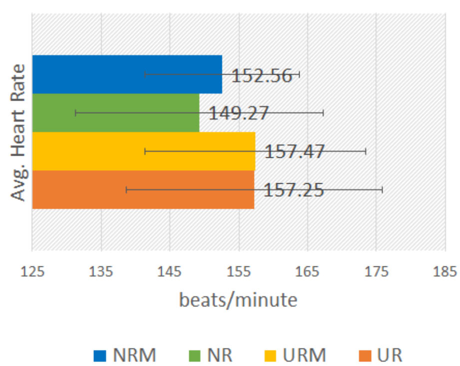
Analyzing the results of this time-frame across all routes can be seen in Figure 5.13. Overall when the participants were exposed to musical stimuli they ran a higher mean distance than when not exposed to music, see Figure 5.13a. The difference between these is 20.27 to 24.22m of additional distance traveled on URM and NRM. This same correlation is seen in the speed of these runners where there is a higher mean speed when participants were exposed to musical stimuli as seen in Figure 5.13b. This holds true that in order to travel a further distance in the same time period, a person must travel at a faster speed.



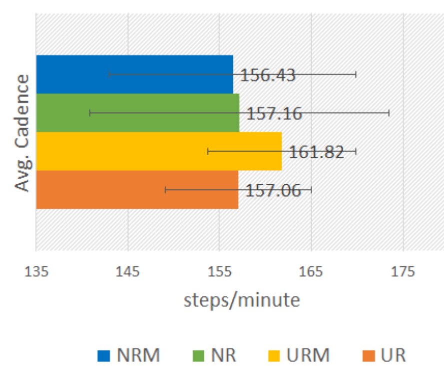
(a) Avg. distance traveled



(b) Avg. speed



(c) Avg. heart rate



(d) Avg. cadence

Figure 5.13: Music analysis results - 191 to 370 seconds. Data collected between May 29 to June 21, 2017. Yverdon-les-Bains, Switzerland. 35 observations.

With a higher mean distance and speed, there is an increase in mean HR when exposed to musical stimuli. Though, the higher mean HR is not as highly correlated compared to the distance and speed. As the mean heart rate in an urban environment with musical stimuli is only slightly higher, 0.22 bpm, than the urban environment without musical stimuli as seen in Figure 5.13c. Though it should be noted that there is smaller variation in HR when users are listening to music in these same environments. This is a standard deviation of 11.18 and 16.03 bpm when exposed to music and a standard deviation of 18.07 and 18.67 bpm.

The cadence of these participants is higher when listening to music, but only in the first iteration in which it is tested in URM. Overall, the cadence is about equal among the other experiments. This means that on the natural route with musical stimuli, the runners took longer strides to achieve a higher distance and speed. This further correlates with the larger mean HR difference between the natural environment tests as compared with the smaller mean HR difference between the urban environment tests as more energy was exerted.

5.2.5 Temperature conditions

The weather conditions that the participants ran along all minimally variable. Ranging from partly to mostly sunny conditions. Though the temperature is an increasing factor as the weather became warmer during the study. This can been seen in Figure 5.14. The mean temperature is considerably lower when participants ran UR by about 37%. The other tested routes are similar in temperature but there is a clear increase that the mean outside temperature was higher with each test.

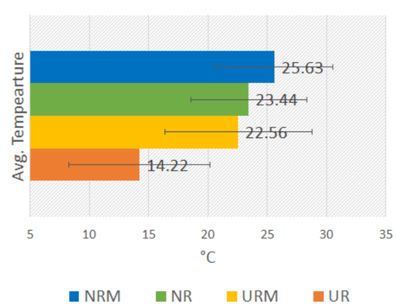


Figure 5.14: Average temperatures. Data collected between May 29 to June 21, 2017. Yverdon-les-Bains, Switzerland. 35 observations.

6. DISCUSSION

This section will present the hypotheses that have been previously established and tested for in this study. An evaluation of these hypotheses will then be conducted to understand how the study results adhered to the stated hypotheses. This section additionally includes prospectives on the study about problems encountered and additional thoughts pertaining to possible improvements in this study.

6.1 Stress reducing criteria

Hypothesis 1: Runners experience a lower level of perceived exertion when exposed to stress reducing criteria

The music stimuli was initially seen as a stress reducer according to Edworthy and Waring (2006), where it should positively affect the RPE by a difference of 0.40. Within the confines of this study, there is no clear indication that this is true. As the urban environments have a high negative difference between each other. And the nature environments have only a small positive difference that is not similar to what was found by Edworthy and Waring (2006). This is possibly due to the effect of musical stimuli which increases a runners activity and leading to higher physical exertion. The music does not appear to counteract this additional exertion psychologically in this study.

Between the nature and urban environments, there is only a negative difference between the categories and their respective environmental counterparts. This goes against Ulrich *et al.* (1991) where natural areas were observed to be lower stress environments compared to urban areas. Though the observance in this study could be due to short-term as opposed to long-term exposure of the natural environments. As short-term occurred in this study, it was observed by Hansmann *et al.* (2007) that long-term exposure to natural environments is a greater influence on stress reduction.

Additionally, it did not appear that most of the participants understood RPE fully. In most cases, it took a while to explain what RPE was before they stated that the participants understood what it was. This is additionally confirmed by the fact that some participants would write higher values of RPE than what should be properly expected on the pre-exercise portion of the questionnaire. Although Δ in these values is calculated, this still leads to higher differences between participants. If two runners mark a pre-exercise RPE of 0.5 and 4, then both mark a post-exercise RPE of 7, they will have considerable differences between their outcomes.

Hypothesis 2: Runners experience a higher level of feeling when exposed to stress reducing criteria

Although music induced higher physical exertion, there is a clear indication that the participants experienced higher levels of feeling when exposed to URM and NRM as seen in Figure 5.4. Edworthy and Waring (2006) observed that this positive feeling difference with musical exposure was close to a Feeling of 1, which is close to what was observed in this study. With both musical stimuli tests having nearly identical positive differences to their respective urban or nature counterparts.

Though comparatively between UR and NR, there is not a higher level of feeling experienced in NR. In fact, this is almost the opposite of what is observed with the musical stimuli. As there is a nearly identical negative difference in feeling when comparing UR to NR and URM to NRM. It is an odd correlation as a majority of users responded that they liked the forest areas along both routes and disliked the more urban characteristics of the same routes as can be seen in Figure 5.5.

Several components that most likely affected the RPE and Feeling results in an unforeseeable way were the additional length of the nature route and the temperature difference between tests. Although it was known that the nature route was an additional 1.45 km, this was not deemed to be excessive as the urban route was already a short distance for normal runners. This was also an unavoidable difference with how STRWA is structured more around routing than distance priorities. The participants that were found for this study unfortunately had a wider range of physical exercise experience which likely led to higher variations in how they perceived their RPE and Feeling values. This includes the variations in biometric data collected as a few of the participants verbally informed me that they were sore from the first or second test and would most likely go at a slower pace than their previous tests.

Since the temperature increased significantly for most participants during their later runs this would have been a larger physical strain on them. This kind of strain has been previously pointed out by Noakes (2002). This temperature increase could also further explain why the runners experienced a general increase in mean RPE relative to the mean temperatures as seen in Figure 5.3 and 5.14. This might also explain the relatively lower mean Feeling levels experienced during the nature route tests. As is further evident in Section 5.1.5, where users pointed out the importance of shade in the later tests.

6.2 Natural environment exposure

Hypothesis 3: Runners exposed to environments with high vegetation will experience lower heart rates (higher recovery) than those exposed to urban environments

The participants did experience an overall lower HR when they ran the nature routes as seen in Figure 5.10b. The mean HR over the entire length of the routes is affected by the types of environmental factors present. Not only is the mean HR lower in the natural environments, but the musical stimuli has reduced mean HR among both urban and natural environments. Thus it can be observed that a lower mean HR can be enhanced by including musical stimuli over the entire length of a running route.

This is further fortified at the micro-level results observed in Section 5.2.3. As seen in Figure 5.12a, the nature environment has a lower ΔHR by more than a factor of 2. Although this means that the mean HR of a runner does not decrease while in a natural environment. This shows that for relatively equal distances, a runner will have a slower increase in HR when exposed to a natural environment as opposed to an urban one. The Δ in HR increases when exposed to music for both routes in relatively equal proportions. This means that the effect of environmental factors on the HR of a runner should be independent on whether they are exposed to musical stimuli or not.

6.3 Musical effects

Hypothesis 4: Runners exposed to high tempo music will run faster than when not exposed to music

In Section 5.2.4, Figure 5.13, it is very apparent that for the same length of time a runner is effected by whether they listen to music or not. These runners have a higher mean speed when listening to high tempo music than when they did not for the same route. This higher mean speed difference is largest among the urban route and is identical to what was observed by Edworthy and Waring (2006) of a 0.65 kph (0.18 m/s) mean speed increase. This is reinforced by the results that they ran longer distances while listening to music within this same time period. The mean HR being similar between the musical and non-musical tests during a short time period is close to what was observed by Edworthy and Waring (2006).

In the overall results of the entire course, there is also a higher mean speed among runners who listened to music as seen in 5.10a. Though this difference is not as large compared to the micro-level results and slightly less in NRM when compared to NR. Section 5.1.2 shows that the music chosen for the participants should not affect them in any overall negative way which the quantitative results reinforce with generally better or equivalent HR results.

6.4 Routing effects

Hypothesis 5: Runners exposed to ideal conditions will exert more energy while maintaining lower stress levels

The route that was considered in this test to be the most idealized, NRM, had runners experience more exerted energy as can be observed in Figures 5.10a, 5.12b and 5.13b. The HR, an indicator of the stress levels, was lowest total in NRM than the urban environments but not lower than NR at the micro-level as seen in Figures 5.12a and 5.13c. Though this possibly could be caused by the considerably higher temperature that was experienced by the runners when this test occurred and requires further study.

The participants however did experience the lowest mean HR when comparing the routes at a macro-level as seen in Figure 5.10b. This is a more realistic indicator than the micro-levels since this encompasses the entirety of the nature route with all natural buffers affecting the routing. Runners did not experience the lowest RPE and Feeling levels, which are other indicators of stress, during the most idealized test. But comparatively between NR and NRM, there are lower levels of these two stress indicators in NRM and a higher propensity toward forest environments based on the results of Section 5.1.5.

6.5 Non-controllable variables

Since this study was conducted in a real world scenario, there are multiple variables that were mostly uncontrollable during the tests. One of these is the weather conditions that the participants experienced while running. As the weather could be rainy, cloudy or sunny. The temperature could range from cold or not. Though in this study, the runners only ran on non-rainy days which were mostly sunny or partly cloudy. The temperature variable is something that most likely affected the later tests in this study and is already previously discussed in this chapter.

Another uncontrollable variable is the behavior of participants in the field. A participant could theoretically walk at any point of the study, miss directions in the route, and behave physically or psychologically different based on the day or musical stimuli. Though from the results of Section 5.1.2 there should not be any negative influence of the music. It was noticed through some minimal observation in the raw data that some participants did slow down at certain points during their later tests. The ones that seemed to influence this data had verbally informed me that they were sore from previous tests and might not run as fast as earlier tests. This was something that unfortunately could not be deterred from the study and most likely affected the mean results of these tests to some degree.

6.6 Prospective

6.6.1 Research issues

Like most research, there were some problems that were encountered in the study. Within the pgrouting library for PostgreSQL, there is a function for the traveling salesman problem called '`pgr_TSP`'. This was initially thought of as a function that would be more usable in this report but it was discovered there were some issues with its application in the way that was needed. This is probably due in part to the fact that it designed to take only points of interest into consideration. If a user does not know their exact points of interest from the beginning, in the case of this report, then the function will simply choose all points within a buffer region.

To further clarify, if a user has a vast road network to traverse then this will in turn have an extensive number of nodes. The function will use all of these nodes within its buffer as points of interest, thus forcing the algorithm to traverse through every single node. This creates a situation of undesirability as the created route becomes unimaginably complicated and illogical with roads traversed in multiple instances with a very cost ineffective route. Both of which were highly undesirable for the project. This led to development of an algorithm to backbone off of TSP with the required parameters and turn-restriction limiters.

In regards to the Spotify Running tool within the Spotify application, there are some notable discrepancies in how it chooses songs when the BPM is set by the user. When a song appeared desirable for this study, it was checked for its metadata properties. In some cases, there was an observable difference in what the tool determined as suitable for a specific BPM but in the metadata it was listed as a BPM that should not be in the category for choosing. This increased the tediousness of this task to find music that fit within the desired parameters.

The Forerunner® 620 device which recorded the data for this study was extremely unintuitive when it came to its extraction of the raw data. To clarify, this raw data was exportable in several formats by Garmin but all formats, other than the raw data format, did not include the useful data required for this study. Which led to a workaround in this study of formating the raw data into a usable format. This raw data additionally had a Garmin specific format for the x and y coordinates which was impossible to decipher and being told by Garmin staff that this was 'proprietary information'. In future studies it would be recommended to avoid this product and others related to Garmin related products for research purposes if a researcher is unable to properly extract and project the GPS data they collect.

A very finicky part of the process was that the watch device only allowed for a single user's biometric information held in the device. Before each participant would begin their run, the previous participants information would need to be erased and the new runners data added. This was a very time consuming and tedious process even for the 35 tests that were conducted in this study. With the participants being very confused by RPE, it would speed up the process in the future to inform the participants ahead of time and make sure they understand how RPE works before conducting testing.

Another issue involved the service road class in the OSM data. A majority of this road classification was driveways and one-way streets. It was initially deemed as an unnecessary road class to keep as it would help to improve STRWA. Though, after testing without this road class it was noticed there were further issues caused by the removal of this class because it contained some important road connections within the road network of Yverdon-les-Bains. It could be beneficial in future studies to exclude this road class or use road data other than OSM data.

6.6.2 Future work

After completing and reflecting upon this study, there are also various improvements that could have been done on this study to improve both results and further studies related to this specific study. When building upon this study, it would be advisable to obtain a larger sample of participants. It was not controllable in this study to do so, as it was conducted through willing volunteers to participant in this study. The results of which was only a small sample size of 9 participants.

The area in which this study was conducted is located near the outskirts of a city. This possibly led to some less than ideal optimization by STRWA as it did not have as many road connections to work with. It was noticed from some initial testing that when placing the starting point in the center of a city, there was better optimization of the nature and urban routing. This is because the city center has more and better possibly connections for allowing network routing with parameter and turn-restriction limiters. In future studies it would ideally be better to start in a city center rather than on the outskirts of a city with little road connections if optimizing the routing with STRWA.

Although most of the participants viewed musical stimuli presented to them in a positive or neutral way, it was transcribed and verbally discussed during the questionnaire that they preferred more or less of songs in the track list. This was dependent upon the individual tastes of the participants. Future studies could incorporate this individualistic taste to design a study with musical stimuli that better suits each individual and see how positively or negatively this can affect their psychological and physical responses.

The vegetation weights in STRWA worked for the intended purposes of this study. But the participants did expose a minor unforeseeable issue. In the nature route, there was a long section which was routed through due to its proximity to a natural reserve which had a higher positive weight for natural routing. This long section was next to small highway that was not recognized as a highway in the OSM data. This unfortunately made participants dislike this portion of road immensely due to less shade provided and vehicular pollution.

These vegetation weights could thus be tested further in various methods for future studies. A hypothesized methodology could be to remove the road buffers step which would create a lower GRVI value for the positive vegetation weights. Another study could research the effects of different natural environment weights to find an optimal route in a network. This could involve both the effects of weighted variation among natural land use classes and GRVI weights.

7. CONCLUSION

Although runners did not experience the predicted levels of qualitatively measured stress factors in the positively weighted vegetated environments; they did experience more predicted levels of quantitatively measured stress factors in the same environments. These environments result both in lower heart rates and slower changes in heart rate. Runners additionally made it clear how they are highly attracted to areas which have cooler temperatures and provide protection from the sun in shady forested areas. These factors strongly indicate how important it is for runners to expose themselves near environments which have higher vegetation than those which do not.

Despite the suboptimal results in RPE levels, there is a clearly very positive influences of musical stimuli involved in running for how a runner feels. This positive influence on feeling is independent of the environment in which a person runs. Influence of music clearly plays a factor in helping reduce heart rate while maintaining higher levels of physical activity such as speed, cadence and distance. If a runner's goal is to obtain higher physical activity levels in their routine then the importance of including music into it is apparent from this study.

Ultimately, the aim of this study was reached to reinforce the idea that there are positive effects of music and natural environments on runners both physically and psychologically. Even though part of this study was meant to test the real world geographical aspect of runner responses, further analysis should be conducted to rule out any influence a longer nature route and higher temperatures played on the qualitative results. Despite the 35 tests conducted in this study, the sample size of individuals was quite small with only 9 participants. It would be further beneficial towards this study to conduct more encompassing and conclusive research to enhance the creditability of this study and further the field of geographical studies. Overall, this research helps validate how important the inclusion of music and nature are to increasing positive reactions in runners for reaching higher levels of efficient training activity.

This study further shows the viability of using STRWA for future research and development. As this application of STRWA can be improved to include user customization in which the user can maximize or change weights to suit their needs. STRWA can also be used in other applications separate from running. These could be related to bicycle routing for finding ideal paths based on further vegetation weighting or other weighted characteristics such as desired gradients. Another application could include tourism guidance where prominent scenery and attractions are prioritized while giving the ultimate tourist experience.

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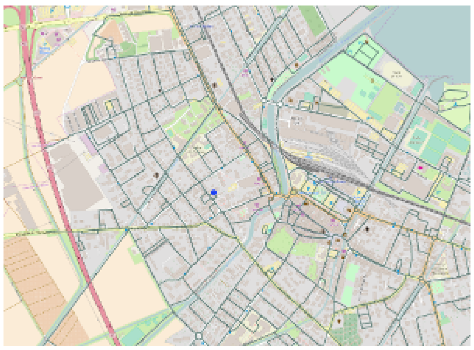
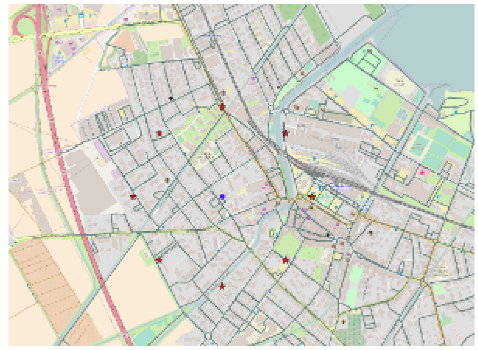
APPENDIX

A. ALGORITHM VISUALIZATION

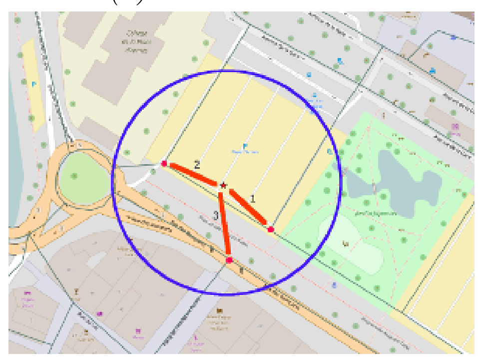


(a) Designated starting/ending node

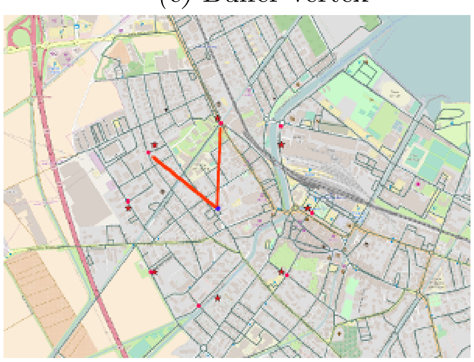


(b) Buffer zone vertices's

(c) Buffer vertex



(d) Nearest node - euclidean distance



(e) Dijkstra one to many

(f) Node sequence from STRWA

Figure A.1: Spatially Turn-Restricted Weighting Algorithm: basic visualization

B. TESTING QUESTIONNAIRE

Test Number # _________

Participant ID # _________

Test type: _________

Spatial Runner Questionnaire

Pre-exercise

1. Age? _________ Sex? (M/F) _________

2. Height? (cm) _________ Weight? (kg) _________

3. On a scale from -5 to +5, how are you feeling? _________
   + 5 = Very Good
   + 4
   + 3 = Good
   + 2
   + 1 = Fairly Good
   0 = Neutral
   - 1 = Fairly Bad
   - 2
   - 3 = Bad
   - 4
   - 5 = Very Bad

4. On a scale from 0 to 10, how much energy do you feel you are exerting? _________
   (See Borg CR10 Scale Printout)

5. How often do you exercise? _________ time(s) per week

6. How often do you normally go running as an activity? _________ time(s) per week

7. How far do you normally run on average? _________ kilometer(s)

8. Do you normally listen to music while exercising? ☐ Yes ☐ No

Post-exercise

1. On a scale from -5 to +5, how are you feeling? _________

2. On a scale from 0 to 10, how much energy do you feel you are exerting? _________
   (See Borg CR10 Scale Printout)

3. On a scale of 0 to 5, was the course easy to follow? _________

4. On a scale of 0 to 5, would you run this course again? _________

5. What did you like and/or not like about this course? Additionally, circle on the map.

6. On a scale of 0 to 5, was the music suitable for the exercise? (If applicable)

   ____

7. Further comments?

C. ADDITIONAL DATA GRAPHS

Figure C.1: Δ RPE: On a scale from 0 to 10, how much energy do you feel you are exerting? Data collected between May 29 to June 21, 2017. Yverdon-les-Bains, Switzerland. 35 observations.

Figure C.2: ΔFeeling: On a scale from -5 to +5, how are you feeling? Data collected between May 29 to June 21, 2017. Yverdon-les-Bains, Switzerland. 35 observations.

Table C.1: Statistical averages. Data collected between May 29 to June 21, 2017. Yverdon-les-Bains, Switzerland. 35 observations.

ID	Urban	Urban w/ Music	Nature	Nature w/ Music
1	2.97	2.99	3.70	3.68
2	2.38	2.38	2.08	2.02
3	2.58	2.56	2.57	NA
4	2.39	1.90	1.84	2.28
5	3.03	3.49	3.17	3.62
6	3.26	3.36	3.53	2.88
7	2.72	2.90	2.71	2.63
8	3.09	3.40	3.35	3.26
9	2.32	2.28	2.03	1.75

(a) Average Speed (m / s)

ID	Urban	Urban w/ Music	Nature	Nature w/ Music
1	119.75	122.21	143.86	147.43
2	177.08	166.80	165.84	158.79
3	175.23	169.11	166.73	NA
4	160.91	135.53	124.91	149.75
5	153.80	166.19	158.16	170.57
6	161.17	158.61	169.67	148.25
7	151.79	168.25	159.10	155.67
8	161.17	159.43	170.63	165.96
9	168.64	169.65	138.85	135.33

(b) Average Heart Rate (beats per minute)

ID	Urban	Urban w/ Music	Nature	Nature w/ Music
1	156.85	153.66	172.04	169.74
2	159.01	159.74	155.73	149.84
3	151.91	153.27	NA	NA
4	159.17	150.68	132.86	138.92
5	155.15	160.60	160.13	163.72
6	163.70	164.37	170.18	169.60
7	149.82	153.14	150.69	150.26
8	161.20	161.51	166.47	167.22
9	145.31	151.63	132.38	119.05

(c) Average Cadence (steps per minute)

ID	Urban	Urban w/ Music	Nature	Nature w/ Music
1	3188.53	2999.90	4727.16	4548.30
2	3105.41	2958.40	5686.50	4981.25
3	3280.00	3206.40	4473.90	NA
4	3349.66	3094.22	4457.28	4360.58
5	3599.96	3126.96	4827.42	4531.46
6	3269.07	3080.42	4780.23	4615.47
7	3355.00	3099.03	4689.89	4640.47
8	3257.50	3131.16	4539.50	4554.26
9	3288.57	3183.15	4892.03	4643.68

(d) Total Distance (meters)

Institutionen för naturgeografi och ekosystemvetenskap, Lunds Universitet.
Studentexamensarbete (seminarieuppsatser). Uppsatserna finns tillgängliga på institutionens geobibliotek, Sölvegatan 12, 223 62 LUND. Serien startade 1985. Hela listan och själva uppsatserna är även tillgängliga på LUP student papers (https://lup.lub.lu.se/student-papers/search/) och via Geobiblioteket (www.geobib.lu.se)
The student thesis reports are available at the Geo-Library, Department of Physical Geography and Ecosystem Science, University of Lund, Sölvegatan 12, S-223 62 Lund, Sweden. Report series started 1985. The complete list and electronic versions are also electronic available at the LUP student papers (https://lup.lub.lu.se/student-papers/search/) and through the Geo-library (www.geobib.lu.se)

400 Sofia Sjögren (2016) Effective methods for prediction and visualization of contaminated soil volumes in 3D with GIS
401 Jayan Wijesingha (2016) Geometric quality assessment of multi-rotor unmanned aerial vehicle-borne remote sensing products for precision agriculture
402 Jenny Ahlstrand (2016) Effects of altered precipitation regimes on bryophyte carbon dynamics in a Peruvian tropical montane cloud forest
403 Peter Markus (2016) Design and development of a prototype mobile geographical information system for real-time collection and storage of traffic accident data
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405 Gea Hallen (2016) Porous asphalt as a method for reducing urban storm water runoff in Lund, Sweden
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412 Louise Hannon Bradshaw (2017) Sweden, forests & wind storms: Developing a model to predict storm damage to forests in Kronoberg county
413 Joel D. White (2017) Shifts within the carbon cycle in response to the absence of keystone herbivore *Ovibos moschatus* in a high arctic mire
414 Kristofer Karlsson (2017) Greenhouse gas flux at a temperate peatland: a comparison of the eddy covariance method and the flux-gradient method
415 Md. Monirul Islam (2017) Tracing mangrove forest dynamics of Bangladesh using historical Landsat data
416 Bos Brendan Bos (2017) The effects of tropical cyclones on the carbon cycle
417 Martynas Cerniauskas (2017) Estimating wildfire-attributed boreal forest burn in Central and Eastern Siberia during summer of 2016
418 Caroline Hall (2017)The mass balance and equilibrium line altitude trends of glaciers in northern Sweden
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