A CASE STUDY ON THE EFFECT OF ROUTE CHARACTERISTICS ON DECISION MAKING IN THE SPORT OF ORIENTEERING

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A CASE STUDY ON THE EFFECT OF ROUTE CHARACTERISTICS ON DECISION MAKING IN THE SPORT OF ORIENTEERING

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ABSTRACT

A CASE STUDY ON THE EFFECT OF ROUTE CHARACTERISTICS ON DECISION MAKING IN THE SPORT OF ORIENTEERING

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Orienteering is a sport where athletes need to find located targets at certain points on a predetermined terrain or in the city with the help of a map. In this sport where performance is measured with time, it is important to combine their physical endurance with mental processes and their ability to adapt to the environment and optimize them correctly. One of the outcomes that we can best observe these choices is the routes chosen and each route has its own environmental characteristics. Therefore, athletes need to analyze these characteristics well and as a result, they need to choose the most suitable route for themselves. In this thesis, the components affecting route selection are investigated. For this purpose, athletes' data was obtained through GPS containing watches from an orienteering race held by Turkey Orienteering Federation. The collected data were examined by quantitative and qualitative methods, and a general understanding of athletes' behavior was obtained and the distinction of modelable and subject-dependent factors in decision making of athletes was made. From the modelable components, a model that computes the shortest distance based on the distance and terrain surface has been created and then its compatibility with the behaviors of athletes was examined. Additionally, the results were supported by various statistical analyzes. According to the results of the study, environmental variables play a major role in the decision-making of athletes and model performance is more accurate in short-distance routes than long-distance routes in greater need of reducing the cognitive load.

Keywords: Orienteering, decision-making processes, embodied cognition, bounded rationality, fast and frugal heuristics

ÖZ

ORYANTİRİNG SPORUNDA ROTA ÖZELLİKLERİNİN KARAR VERMEYE ETKİSİ ÜZERİNE BİR DURUM ÇALIŞMASI

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Oryantiring, sporcuların önceden belirlenen bir arazide veya şehir içinde belirli noktalara yerleştirilen hedefleri harita yardımıyla bulmasını içeren bir spordur. Performansın zamana bağlı olarak ölçüldüğü bu sporda, fiziksel dayanıklılığı, zihinsel süreçlerle ve çevreye adapte olma yeteneğiyle birleştirmek ve bunları doğru şekilde optimize etmek önemlidir. Bu seçimleri en iyi şekilde gözlemleyebileceğimiz çıktıların başında, bir hedeften diğerine giderken seçtikleri rotalar gelmektedir ve her bir rota kendine özgü çevresel karakteristiklere sahiptir. Dolayısıyla sporcuların her bir adımda bu karakteristikleri iyi bir şekilde analiz edip, fiziksel kuvvetlerini harita okuma becerileriyle birleştirmeleri ve bunun sonucunda kendileri için en uygun rotayı seçmeleri gerekmektedir. Bu tezde, rota seçiminde etkili olan bileşenler araştırılmıştır. Bu amaçla, Türkiye Oryantiring Federasyonu tarafından düzenlenen bir oryantiring yarışı parkurundan, içinde küresel konumlama sistemi bulunan (GPS) saatler aracılığıyla, sporcu verileri elde edilmiştir. Toplanan veriler nicel ve nitel yöntemlerle incelenerek, sporcuların davranışlarına dair genel bir kavrayış elde edilmiş ve sporcuların karar vermesinde modellenebilir ve özneye bağlı etmenler ayrımı yapılmıştır. Modellenebilir bileşenlerden mesafe ve arazi yüzeyini temel alan ve en kısa mesafeyi hesaplayan bir model oluşturulmuş ve sonrasında sporcuların davranışlarıyla ne kadar uyumlu olduğu incelenmiştir. Ayrıca, sonuçlar çeşitli istatistiki analizlerle de desteklenmiştir. Araştırmanın sonuçlarına göre sporcuların karar vermesinde çevresel değişkenlerin büyük bir rol oynadığı ve model performansının kısa mesafeli rotalarda, bilişsel yükü azaltma ihtiyacı daha çok olan uzun soluklu rotalara göre daha isabetli olduğu gözlemlenmiştir.

Anahtar Sözcükler: Oryantiring, karar verme süreçleri, bedenlenmiş biliş, sınırlı rasyonellik, hızlı ve basit sezgiseller

To My Family

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LIST OF ABBREVIATIONS

CP	Control Point
DEM	Digital Elevation Model
GIS	Geographic Information Systems
GPS	Global Positioning System
FFH	Fast and Frugal Heuristics
IOF	International Orienteering Federation
ISOM	International Specification for Orienteering Maps
LCP	Least Cost Path
LTM	Long Term Memory
SI-Card	SportIDENT Card
SI-Station	SportIDENT Station
STM	Short Term Memory
OCAD	Software for Orienteering and Cartography
OR	Operations Research
RG	Route Gadget
TOF	Turkey Orienteering Federation
Vo2Max	Maximal Oxygen Uptake

CHAPTER 1

INTRODUCTION

Orienteering is an outdoor sport that combines the mind and body in the most literal sense of the term. The phrase of ***running while playing chess*** is frequently used to emphasize the cognitive part of this sport in addition to its physical part. The major task in this sport is to navigate between control points in a predetermined order with the help of a map and compass (*Appendix A.2.*). Orienteering can be done by walking or running at any speed, but in a competition, participants should complete the course as fast as they can, by choosing their best route. Since orienteers are exposed to unfamiliar terrain, they must grasp the characteristics of the terrain quickly and must give immediate decisions.

International Orienteering Federation (IOF) classifies orienteering under four disciplines: foot orienteering, mountain bike orienteering, ski orienteering, and trail orienteering. The rules are the same in all of them, but equipment like bicycle, ski, and mapping become different a little bit. In this thesis, the usages of orienteering related terms will refer to foot orienteering.

An orienteering map is drawn upon peculiarities of terrain or urban areas. These maps are similar to standard topographic maps; however, specific shapes like forest density, water features, trail features, earth features, and human-made features are added on contour lines from the orienteering legend. To be familiar with which features signify which terrain shapes, an orienteering legend can be seen from *Appendix A.4.* and *A.5.*

While the symbols in terrain areas include mostly landforms, in urban areas, this focus shifts to buildings and man-made objects. Elevation changes are more significant in terrain areas; they affect the type of races done. For instance, terrain areas are generally preferred for middle-distance or long-distance competitions, and urban areas are for short distance and high-speed competitions, which are called as “sprint.” In addition, there are also some technical differences among them.

In the middle distance, the range is 4 - 6 km and the expected duration is 30 - 50 minutes. The distance between control points is short (100-300m), but the requirement for direction changes is high, so that much concentration to the map and good map reading skills are important. Shortly, it is technically more complex than long distance. In long-distance, the optimal distance is changed 6 to 8 km; however, it is possible to see distances up to 14 km as well. It is prepared with the expected winning time of 90 to 100 minutes for men and 70-80 minutes for women. In this race, the aim is to measure the durability and endurance of orienteers and it is not as technical as the middle distance is. The distances between control points vary. For instance, the first three control points can be close to each other and the control points afterward can be located 1 - 2 km farther than previous ones. Hence, the ability to focus on significant terrain shapes and simplifying the map gains importance for the controls that require to cover long distances. In the last type, sprint, the distance changes between 1 to 3.5 km and the expected winning time are 12 to 15 minutes. Sprint races measure the route selection ability of an orienteer under high speed, so under high heart rate. They are easier than middle or long distances in terms of technicality.

In an orienteering map, control points are placed to indicate in which order the controls should be visited, and control description is given on one of the corners on the map and separately (see *Appendix A.6.)*. The piece given separately is attached to the arm via tape or clue-holder, because changing the map position to check the control description may cause a distraction. Symbolization in this description gives information about the location and the landform of the place of a control point.

In a competition, there exist many courses for different age categories and classes, and control points are different for each of them. Some control points might be common for different categories, but the order to visit the same control point or previous control points would probably be different. The confirmation of whether an orienteer is on the right control point is done by comparing the number over the SI-station and the control description. When athletes arrive at a control point, they need to punch the specified area on the map or to read their SI-card to SI-station by placing it in to prove they reach to the right control point (see *Appendix A.1.*). After the course is completed, the competitor can take a printout that shows total time and split times that are the time spent between each control point.

As understood from this general structure, orienteering requires too many abilities to complete the course successfully. The performance in orienteering is measured the time elapsed, reducing the time is the primary concern of all athletes. According to the previous studies, Jones (2015) mentioned four factors that affect an orienteering performance as plan, direction, picture, and route choice. He also stated that the first three factors have their base from the navigation techniques, and the last one, route choice is mostly related to the perception of the viewer. Guzman (2008) indicated the importance of map reading, symbol knowledge, and map-terrain-map identification by referring to the studies of Seiler (1985), Ottosson (1986), and Mínguez (2002) for the performance. Eccles and Arsal (2014) emphasized the importance of the map, environment, and travel.

The knowledge acquired from these studies and *Figure 1* give us the constituents of an orienteering course and these constituents should be reviewed to gain a deeper understanding of how decisions are made in that sport.

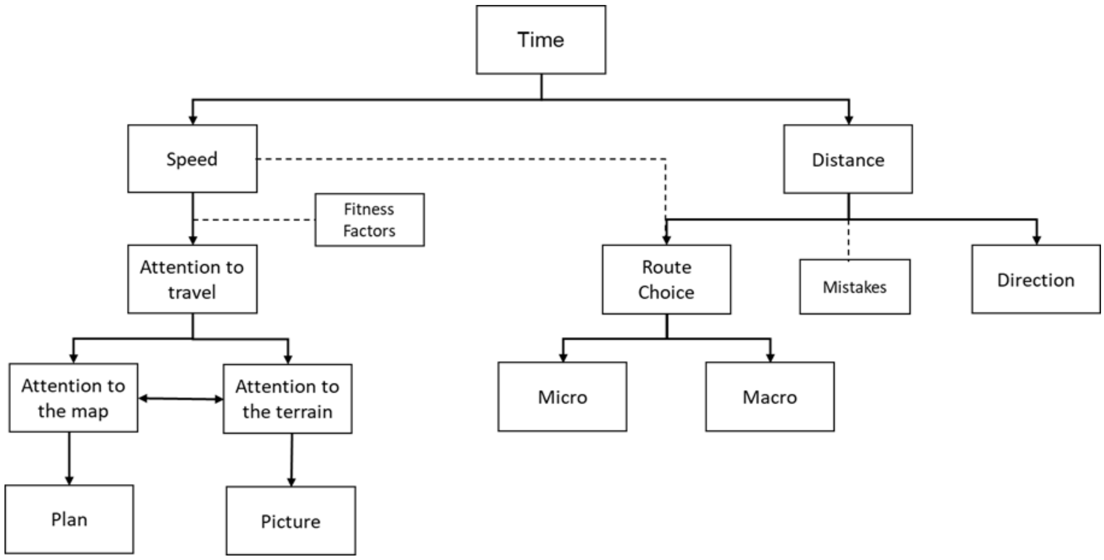

Figure 1. A decision model for factors affecting orienteering performance

(Adapted from Jones, (2015))

The constituents above that are used for decision-making are mainly affected by two systems: the environment and the human body. There have been some limitations of these two systems arising from their nature. In the environment level, Mottet and Saury (2013) classify these constraints by 3 categories as terrain, the course, and the equipment like the map, the control description, a compass, and a control card. First, terrain properties like ground surface, elevation, elevation change to the direction of movement, features on the terrain like buildings identify the limitations of the environment. Second, the area where the course was planned and targets placed identifies the frame of where athletes are nearly going to pass. Last, auxiliary equipment is the mediators in the establishment of a connection with the environment. The expertise level in the usage of these tools puts a boundary and athletes can use them in the limitation of their bounded rationality (Simon, 1982).

In the human body level, limitations can be examined under two sub-categories as physical and psychological factors. The human body's evolutionary physical structure has limitations. For example, there are specific speed limits that a person could reach just like the limits of a cheetah or a lion could. These speed limits also change according to the physical strength of the people, and physical measurements such as max speed, oxygen uptake level (Vo2Max), and endurance capacity helps us to identify these constraints. The limits of these constraints can be improved by increasing physical strength; however, until that time, a man's limits are up to these values. On the other hand, some base values indicate a precaution. For example, in the case of exceeding Vo2Max, the body would adapt itself from aerobic to anaerobic oxygen uptake, so this value is a boundary of that change and body would start to release lactic acid, which causes to decrease in functionality of mechanisms that are a part of what Fodor (1983) classifies high-level systems.

Psychological factors do not only involve notions like motivation and morale but also attention, thinking, decision-making should also be included under this sub-category. From the information processing perspective, low-level perceptual systems take various inputs from the environment within their limited capacity. Then, they are processed by high-level systems with the involvement of the domain knowledge. Choosing the most economical routes and selecting the most adaptive behaviors at the same time is achieved by this combination. But, there is a known fact that the construction of adaptive behaviors and the working of the body in the environment harmoniously is a long time-taking process. Maintaining decision-making processes within multi-criteria systems is a very complex task because of the previously mentioned constraints.

So, this thesis aims to investigate how decision-making processes happen within this complex, dynamic, and uncertain system and which strategies are applied to manage the time-pressure effectively. Research questions to accomplish this purpose are addressed below:

Q.1. Which strategies are applied based on route characteristics?

Q.2. Which strategies are implemented to manage environmental and bodily limitations, and to what extent can they be modeled?

Q.3. How to conceptualize behaviors of athletes in an orienteering course with cognitive terms of bounded rationality, fast and frugal heuristics, and situated and embodied cognition?

In orienteering literature, most of the studies are related to the psychological or physical side of this sport or the models in the area of OR ignore its behavioral side. After the research questions are answered based on the behavioral outcomes of athletes, we could identify the parameters that are effective in decision-making. So, we could improve the sense of how the most satisficing routes are selected by evaluating these bodily and environmental parameters. Moreover, by analyzing whether the parameters are suitable for modeling, the gap between psychology and computation will be reduced. Of course, no one expects to model all aspects of orienteering in just a model, we will try to accomplish a very small part and we will discuss other possible ideas on that topic.

In the following chapters, Chapter two presents a literature review of the relevant contexts of orienteering. Additionally, it establishes a background for both orienteering and previously made studies to clarify the relation of this sport with decision making. In Chapter three, the details of the methodology and results of the related analysis are presented. Finally, Chapter four presents a discussion that evaluates our findings and the research pursued to answer research questions, and then it gives concluding remarks and possible future works.

CHAPTER 2

LITERATURE REVIEW

2.1. Basic Terms of Navigation

Navigation takes at the heart of the orienteering, so understanding the intrinsic competence of humans and animals is very crucial to explain the natural tendencies in orienteering. In this way, we can observe the applied navigational strategies during an orienteering course and understand their interwoven relations.

Navigation is formed of two components, wayfinding, and motion. Wayfinding comprises of cognitive elements in the navigation so that it focuses on the tactical and strategic parts of the movement. For instance, Tolman's cognitive maps (Tolman, 1948), in other words, the relationship of mental representation of the environment in the head with the environment itself, are investigated under this term. Motion is related to the motoric element and it is divided into various sub-groups like active/passive transport, maneuvering, etc. The characteristic properties of these subgroups are the focus of the perspective of the body in the orientation. These two components of navigation cooperate harmoniously in a navigation task since navigation performance strictly depends on them. Measuring the effectiveness of navigation performance, equipment and techniques in a navigation task should take part in this evaluation. For instance, using a map concurrently while navigating at the same time is quite different from only following a given route on the map without navigating and should be evaluated differently.

In a navigation task, different types of spatial knowledge usage may be required. Thorndyke and Goldin (2012) classify them as landmark knowledge, procedural knowledge, and survey knowledge by referring to previous studies. Their usage changes accordingly to the representation of the knowledge of the environment, sources provided by the environment and the appropriateness of the task type.

Landmark knowledge focuses on the visually acquired parts of the information like perceptual icons or images, and they can be acquired via primary or secondary sources of knowledge. Procedural knowledge, on the other hand, focuses on the actions and their order during a route.

Landmarks' visiting order, actions to be taken in these landmarks, and the direction of the turns take place in this content. The last type, survey knowledge constitutes its knowledge based on the fixed frame of reference. It focuses on the location of objects and the distance from each other via a two-dimensional coordinate system so that the *"bird's eye"* phrase is suitable for this type. They can acquire knowledge via a map or a repeated navigation experience.

Before starting navigation, spatial knowledge *"where I stand"* should be acquired. If this knowledge is gained directly from the environment, the source of this knowledge is named as primary. In the research of Åkesson et al. (2014) on the biological compass in animal navigation, cues, in the primary source category, such as sun, star, and odors are used to navigate. On the other hand, if the source of the knowledge is acquired via mediators like maps, photographs, videotapes, verbal directions or virtual environments, it is named as secondary. The navigation that includes secondary source usages should first answer the question of *"where am I?".* I mean the spatial location should be stabilized before starting navigation. For instance, in the shopping malls, *"You are Here"* maps are placed in order to help in the identification of someone's current location. Then, as a necessary condition, the egocentric perspective must be turned to a geocentric perspective. Before explaining the requirements of perspective changes occur, mentioning landmarks and planning would be helpful in terms of understanding distinction.

Landmarks are known as the significant cues/features in an environment, and they are important in the identification and then the planning of a route while moving from one place to another. As Richter et al. (2004) stated, a route consists of decision points and actions to arrive at that point. In a route, different reference systems like egocentric reference, allocentric, and absolute references are in use. Egocentric reference represents the point of view of the Wayfinder, allocentric references represent the objects in the environment and absolute references represent the referees that occur out of the environment. The directions like north, south, etc. take place in this content and these referees also called as landmarks like the objects in allocentric references. Landmarks can be classified under two terms: point-like and linear. While point-like landmarks symbolize small or restricted areas like buildings, human-made objects just like in an orienteering map, linear landmarks are scattered in a larger area like a river, forest boundary.

In the planning part, if the instructions come from the outside, then the transition of egocentric to geocentric is not required. As Schwering et al. (2017) cited by Maguire and colleagues'(2006) research on taxi-drivers, turn-by-turn navigation as an example of outside instruction prevents the improvement of navigation abilities and survey knowledge because survey knowledge develops with the training of navigation tasks. In the cases where egocentric to geocentric transition required, another complex step is added to the navigation process, which is the mental rotation. This term may be clarified by saying the manipulation of 2-D to 3-D representation (Darken & Peterson, 2001).

2.2. Tasks in an Orienteering Competition, Route Choice, and Mistakes

In orienteering competitions, competitors are exposed to different environmental conditions arising from the terrain, the distance of races, types, etc. and the rules of the competitions, movements or reactions of the competitors in a course constitute a holistic behavior. A rough description should be done to understand the components of the orienteering that bring a whole course together.

Before starting an orienteering competition, athletes have no prior knowledge where the controls are placed. There is an assigned start time for each athlete at starting, they take their map and then, their time is recorded until they arrive at the last control point at the finish. The point where athletes take their maps to their hands does not usually be the same as the start point on the map. So, they first need to move to the starting point that is demonstrated with the triangle icon on the map. In this condition, the organization should mark this path with tape pieces or other significant markers. The aim of this application is to give the possibility to athletes to hold their maps correctly, fold them and plan the first route or more.

From the start point to the first control point, the route should be planned by dividing the whole distance into the small parts, because aiming to go directly is not preferable because of possible distractions through the route. Hence, identifying significant and distinct properties during the route and confirming them by comparing the environment and map, constitute characteristic behaviors of orienteers. They rehearse this process while reaching each control point because it is highly possible to get lost within familiar shapes in the terrain. The increase in the distance between the current location and the last reliable point causes an increase in the time spent for error recovery. So, the last reliable point should be as close as possible to the target point.

In orienteering, attack points are functional and useful in dividing the main goal to sub-goals and while athletes move towards their designated attack point, each symbolization over the map is not read, and it is called as “simplification”. These two techniques are applied to different degrees by each athlete. Thierry Gueorgiou, the World Champion in 2003, (Kocbach, 2007) stresses the importance of making simpler mental images to become faster. Selecting the most visible and distinct features in route planning contributes to the “visibility map” in the head. So, as long as the athletes are able to find their way by looking at the minimum number of features, they do not need to read all the features and this method increases the speed by decreasing the cognitive load.

Since the only start, control and finish points are indicated on the map, the route between points is decided by athletes' preferences and determined by their physical and technical skills. So, there can be more than one route as you can see from *Figure 2*.

A decision making task is inevitable at that stage, from these three routes (A, B, and C), competitors may choose one of the routes or s/he can prefer to go similar but different from these routes. In this determination, personal experience, map reading skills, compass usage, and orienteering techniques are effective (Juhas, Baĉanac, & Kozoderović, 2016). So, competitors should know their own abilities and identify the most economical routes by considering and optimizing them.

Figure 2. Possible routes from a leg in the sprint race of Eurometeeing in Denmark (Kocbach, 2018)

In the route selection, we can observe some strategies to reduce the cognitive load. For example, the routes that are formed by more decision points/actions require more cognitive processing (Richter, Klippel, & Freksa, 2004). Both of the routes would arrive at the same point; however, the mental effort and difficulty level of the routes would be different.

Also, spatial chunking in a route would be useful in terms of reducing the information required. They are classified as numerical, landmark, and structure chunking. These chunking strategies are also applied in orienteering courses. There are two conditions to be counted as numerical chunking: identification of decision points until a direction change ("turn left after passing three buildings/two buildings and one intersection") and a decision point with a direction change ("turn left"). In landmark chunking, the second type of numerical chunking is supported by an object ("turn left after the building"). The last one, structure chunking, is mostly related to the direction changes based on the form/shape of the object.

Another issue after the route selection is to stick to that selection. Even a route is detected, at first sight, maintaining this first decision may not be simple as it seems. Orienteers can decide to change the route meanwhile or another route might emerge when looking at the map once again, or confronted terrain may slightly be different from expected terrain. These instant changes towards varying conditions make us consider on planning issues.

I will mention the intentional deviation from a specified route; however, deviation from the selected route can also originate from unintentional deviations such as unsettled distance perception or too much reliance on the compass. As Eccles and Arsal (2014) explain that attention, perception, and information encoding or retrieving of information, experienced orienteers are different than novice orienteers. Because of time spent on practicing leads to improvement in cognitive skills and behaviors related to effective orienteering and navigating. The adaptation ability comes with the practicing will provide some advantages such as the improvement of domain-specific knowledge, adaptation in memory, fast information encoding, and retrieval. For instance, while an experienced orienteer is more successful in calculating the distance between control points, a novice orienteer may not be as successful at calculating distance. A novice orienteer may pass her/his designated attack point or s/he may think to come before s/he reaches that point more likely than experienced orienteers. Besides, the deviation of compass 10% in 100 meters is a known fact. So, any intended or unintended deviation from the route cause to small or large scaled error.

As Bacanac et al. (2016) stated, Boga (1997) identifies the most common errors as:

> missing the first control point (CP), parallel and similar terrain error, running too fast that does not provide good map reading, wasting a lot of time near the CP, losing contact with the map and the terrain, not checking the direction, moving too fast after the checked CP in the wrong direction, poor distance judgment, poor or no attack point, loss of concentration, distractions.

After that, Stevanović (1999) classifies these errors as technical, tactical and psychological, misinformation and organizational errors. I think these five categories are detailed and they can be classified as technical and psychological by ignoring organizational mistakes. Tactical errors can be accepted as insufficient optimization of technical and physical skills. When the classification of Stevanović (1999) is considered, the mistakes related to route choice or route execution take place under tactical errors, which is more related to decision-making processes and the criteria that affect this process will be discussed more detailed in *Chapter 3.*

All route selection, route execution and recovery from error steps are peculiarly rehearsed while reaching to each CP. Tactics applied in a control point will most likely be not the same as in another. Managing all direction changes, applying different tactics before having any prior knowledge, coping with the environmental difficulties, focusing on the map, and controlling psychological conditions at the same time are necessary to balance many factors. So, it is not a surprise that most articles define experienced orienteer as who has been conducting ten or more years in orienteering.

2.3. Relation of Orienteering with Cognitive Framework

One more historical development in psychology and cognitive sciences that has an impact upon the tasks in the orienteering is embodied and situated cognitive approach. In the rest of the article, many cognitive processes and relation of these terms to orienteering will be mentioned to put the issue here in its proper historical and conceptual perspective.

As mentioned earlier, orienteering is both physical and psychological phenomena. Our focus will be upon recent scientific paradigms of embodied and situated cognition to model this sport, but a summary of the historical development of cognitive psychology is necessary. Because, first of all, orienteering is a cognitive psychological phenomenon. Behaviorism was prominent in the beginning years of psychology as a science, and the knowledge accumulated about what we know today comes from early animal laboratory studies. Indeed "cognitive map" term was first used by Tolman (1948) and it is not by chance that what rat makes in a maze is very similar to orienteering except that highly probably rats are not able to read maps.

The second stage in psychology can be named as cognitivist psychology, and today most of the terms used in cognitive activities, including orienteering as well, come from this era. So, a general framework of memory should be mentioned to put decision-making in its proper place. Although there are and can be numerous models of memory, the literature is in general based upon Schneider and Shiffrin's model of memory. Very briefly, the cognitive mechanism that interacts with an environment composed of three main structures: iconic memory, short term memory, long term memory.

Iconic memory or very short term memory is short in duration since it holds information for the environment as a close approximation of stimulus itself like seeing a blurred image of forest and color of that forest. Upon identifying the stimulus, the short term memory stage comes. Short term memory may be up to 2 seconds or a little longer. Then, the related items are transferred to long term memory or decay in short term memory. Short term memory can also be divided working part and storage part like holding the information of forest in mind while calculating what to do next after arriving in the forest. Attention is a short term memory phenomena and can be considered as limiting short term memory sources to the most related thing such as the river beside of that forest. Long term memory can be divided into two main parts and also a third part qualitatively different but important for especially in sport psychology. The most easily understood part is the knowledge part of long term memory. Most of the items we say that come from this part. Most of what we say we know is learned; learning takes place as a process from physical stimulus to that part of LTM. The second major part is episodic memory and this part defined the things we remember as referring to ourselves and time perception of ourselves, that is to say, what we know things as they refer to ourselves. The third interesting part is procedural memory that something learned but not easily declared that they are learned. For instance, most exercises in sports lead to the development of the ability of that sport, but people hardly ever report that what they learned.

In orienteering, you have to learn some skills, properly recall them whether from the knowledge part or procedural part, evaluate in short term memory with attention and divided attention since you have to deal with many things at once, and decide upon what to do at a certain time.

The third major paradigm is a recent movement in cognitive studies that is embodied and situated cognition paradigm. Mainly this school says that:

i) we know as much as our body and with our body, not solely with brain and mind,

ii) and we restricted by our body and environment that surrounds our body.

For instance, we do not represent everything in our mind, but the stimulus from the environment evokes or shapes that related thing we deal at that moment. Behaviors are selected as an interaction between body and environment.

After these paradigms, when we look at the decision making processes, which are our main focus, we can see that there are different approaches to decision making. From the point of view of visions of rationality (Gigerenzer, Todd, & ABC Research Group, 1999), decision making has been investigated under two terms: demons and bounded rationality. The first item, demons, does not take into account constraints like time, knowledge, and computational power, and the decisions upon this term are given as if there are boundless knowledge and resources that extend to eternity. Although decisions appearing as a result of these unlimited sources are seemed unrealistic, they are useful in establishing a context for comparing their relevance with reality, so the ecological rationality.

Demons are handled under two subgroups: unbounded rationality and optimization under constraints. Unbounded rationality is formed by Laplace's inspiration for God-like superintelligence, so there is no limitation in search time or resources. In the modeling of this rationality, approaches derived from probability theory like the maximization of expected utility and Bayesian models are used. On the other hand, optimization under constraints and bounded rationality use a limited information search. From these two demons classification, optimization under constraints promises to constitute more realistic models that represent the real world but these models require more knowledge to calculate costs and benefits of a system than the models in unbounded rationality. However, these models ignore the limitations of mind by assuming that the mind can calculate all costs and benefits effectively.

The second item, bounded rationality, was put into words for the first time by Herbert Simon. Even some researchers perceived this term as a reduction of optimization under constraints, Simon rejected this point of view by claiming that the limitations of the human mind and environmental structure are effective in choices, and these two components do not exist in the content of optimization under constraint. We can reinforce the scope of the bounded rationality term by exemplifying Simon's analogy for scissors. According to this analogy, one side of the blade should be seen as the human mind and other side as the environment, and without having one side, it is not possible to see how the scissors function. Similarly, two sides/components of bounded rationality should be taken into account while evaluating the decisions.

Just like demons, bounded rationality has two branches or sub-groups as satisficing and fast and frugal heuristics. In satisficing, people do not decide by weighing the costs and benefits, as in optimization problems, but they aim to give the most satisficing decision among the alternatives depending on the limitations imposed by the mind and environment. Therefore, limited resources are not spent on evaluating all alternatives and future outcomes.

Fast and frugal heuristics are applied when the time, knowledge, and computational power are limited. As apparent from the prefix added to "heuristics", these heuristics process the information as "fast" and their requirements for the information are "frugal" (Gigerenzer, Czerlinski, & Martignon, 2006). Just like the optimization under constraints, these heuristics have a search, stopping, and decision rule. After the explanations above, the difference of FFH from demons can be distinguished from now on. In addition to them, as Hoffrage and Relmer (2004) stated, these heuristics should be held as separated from the heuristics and biases working of Kahneman and Tversky. In these studies, heuristics are correlated with systematic errors, and their conditions for success or failure can be changed as a result of bias. On the contrary, FFH are seen as successful approaches to reaching a purpose, and they are not related to the biases.

As understood from the information above, satisficing and FFH are handled in two different categories, but there are cases in which two concepts meet in common ground like "satisficing by FFH" or "FFH that make satisficing." Decision-making in sports is one example of this situation. Since the studies in the context of bounded rationality have recently begun, classification of them as "satisficing by FFH" or "FFH that make satisficing" is not easy at this stage. However, from the studies of Bennis and Pachur (2006), we can briefly summarize the improvements in this field until now.

Sports, like basketball and volleyball, involve many throwing or catching ball activities. In dealing with dynamic environmental parameters, simple heuristics called gaze heuristics by Gigerenzer are used instead of optimization approaches. These heuristics identify their frames by addressing the issues of fixation, adjusting, and angle during the activity. Due to the dependency of navigation activity on ecological rationality, another application area of FFH is the navigation-related activities. Eccles and colleagues' studies in orienteering or Hutchins's study on Micronesian islanders and Caroline islanders reveal the simple heuristics used by navigators.

2.4. Map Reading

One of the most important abilities that an elite or experienced orienteer is map reading. Map reading task requires many cognitive skills such as previous knowledge of maps, recalling of this knowledge, that is to say, store and retrieve information from LTM to STM and working this information in STM. Moreover, there is a fruitful debate on the nature of this act. Information recalled may be visual or propositional, depending on the time span in the race. After looking at the map, one may hold information in short term memory as pictorial, but after some time, one should recall this information as in the form of proposition since the boundaries of short term memory are not enough to hold this information as it is. So a part of long term memory much likely episodic memory. These claims are valid for ordinary maps, but it may be better to take a closer look at orienteering maps.

2.4.1. Orienteering Map

Orienteering maps are drawn by applying the rules specified by IOF, and these rules are published under the names of International Specification for Orienteering Maps (ISOM) to provide standardization on the maps. These specifications may differ depending on the orienteering disciplines and formats. The orienteering map is accepted as a topographic map, but symbolizations and colors to indicate the salient features, runnability, and visibility make them different an ordinary topographic map.

Contour lines constitute the baseline for orienteering maps. As we all know from basic geographic knowledge, the same contour line indicates the same elevation. The contour line interval is 5 meters from the standardization. The gap between contours enlarges at the flat ground, and it narrows at steep grounds.

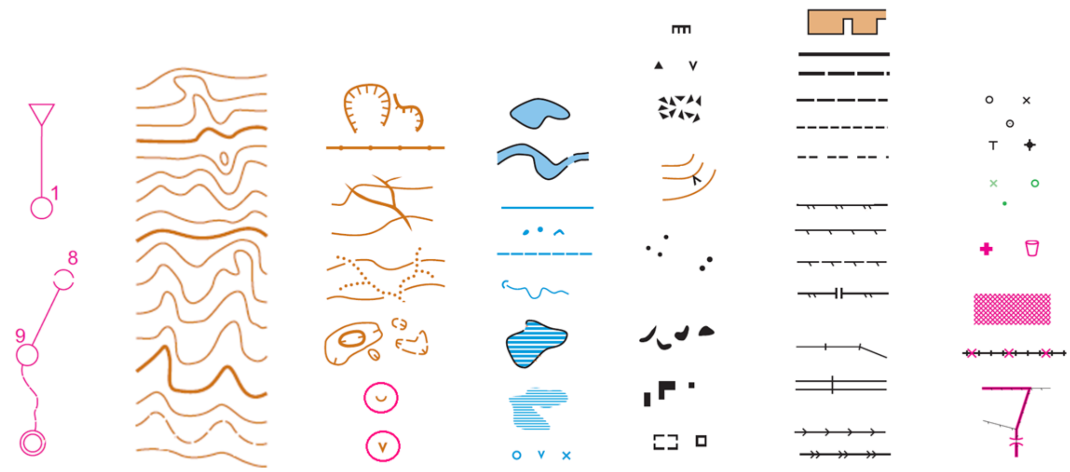

Figure 3. Layers in orienteering maps

There are seven different colors in the drawings, and at least one color code is used while drawing seven symbol categorizations, which are landforms, rock and boulders, water and marsh, vegetation, man-made features, technical symbols, and course planning symbol *(Appendix A.4. and Appendix A.5.).* As you can see in *Figure 3*, purple is used for course information, brown is used for landforms, blue is used for water-related features, green and white are used for vegetation features, yellow is used for open areas, and black and gray are used for the remaining symbols. Besides, symbols are classified as point, line, area, and text. From this classification, we can understand the nature of the features. For example, towers, boulders, and prominent large trees situated in relatively small areas so that they are informative point-like features as landmarks. Buildings, stony grounds, and marshes are scattered to large areas so that they are in area features. Distinct vegetation boundary, contour lines, roads, and paths continue through a line so that they are line features. Apart from their nature, these properties can be used while drawing a route. For example, the adjacent line features constitute easily traceable tracks, and their boundaries are a good reference by moving along a target.

The symbols and colors on the maps do not only represent a 2-D representation of a 3-D environment, but they also hold some latent meanings that affect route choices and speed. Runnability, visibility, and passability are the most important ones. First, runnability is a measure of the speed on the ground and there have been five different scales as you can see *Table 1*. The grounds like lawns, paved areas, and paths offer high speed in running because their grounds are free from obstacles like bushes and scrub, and there is no dense vegetation like tree branches or ivy that restrict the visibility. However, the runnability is gradually decreased with the increase of vegetation density, and the shades of green color, which represent vegetation features on the map, become darker to warn against this change.

Table 1. Runnability categorization for vegetation features

(Adapted from ISOM 2017)

No	Percentage	Description	Examples	Approx speed (min/km)
1	>100%	Easy running	Lawns, paved areas, paths	< 4
2	80 – 100%	Normal running speed	Rough open land, forest	< 5
3	60 – 80%	Slow running	Stony ground, undergrowth, dense vegetation	5-6:40
4	20 – 60%	Walk / Difficult to run	Very stony ground, undergrowth, dense vegetation	6:40-20
5	<20%	Fight	Extremely stony ground, very dense vegetation	> 20

Second, passability is related to intrinsic properties of the features, some features like buildings, high fences, private properties, and lakes cannot be passed over so that athletes should move around these features. Good symbology knowledge and attention to the map are necessary to make the distinction of whether a feature is passable or impassable. For example, fences are indicated with a horizontal line and the single cross line that cuts the horizontal line.

When athletes see this symbology, they understand that it is a passable fence. On the other hand, two cross-line cuts horizontal line means that this fence is impassable, and its height is higher than 1.5 meters.

In addition to the information above, maps give direction knowledge too. The arrow image is put and their sharp edge points the north. Moreover, the upper sides of the numbers indicating the visiting order of a CP are positioned to indicate the north side. By using these clues, the orientation is done by matching the north sides of maps and the compass' magnetic north direction.

2.4.2. Control Descriptions and Representations

Planning a course in orienteering requires extra symbolic knowledge. The same map can be used to plan different courses and locations of CPs in the course are described via the control description. For example, if there are 20 CPs in a course, there have been 22 rows in the control description with a start and finish points. Each cell in a row contains specific information. When we look at *Figure 4*, the purple circle shows the area that the control flag is located (see also *Appendix A.3.*), and two dots represent the stones as you may see the real appearance from the right side. On the right side of *Figure 4*, we can see the control descriptions that describe the exact location. According to *Figure 4*, the flag is on the east side of the stone located on the southeast side, and it should be 37 on the SI-station.

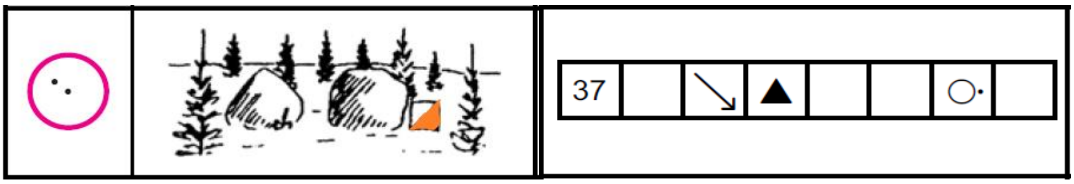

Figure 4. CP, its appearance in the real world, and control description

Jones (2015), Eccles and Arsal (2014), and Mottet and Saury (2013) state that attention is divided between the map and the environment during the movement (see *Figure 1.*). When athletes focus their attention on the map, they take the information of where a CP is located and which actions should be taken to reach that point; however, focusing the map reduces the speed and obscures the view of the environment. Hence, athletes should also give their attention to the terrain to match the representations on the map to the environment. Moreover, in ruined and rough ground surface, attention to the terrain would be inevitable. However, dividing attention results in the trade of problems. For example, if attention is spent on the map mostly, then the speed of the athletes would decrease and finishing time would elongate. In the condition that attention is spent on the terrain, athletes can cope with the environmental difficulties effectively; however, if the knowledge of where to go is lost at some point, it would cause time loss again. So, athletes should balance these two terms by regarding the environmental parameters and their domain-knowledge.

In different surfaces, athletes arrange their necessities differently. In quiet periods "where the runnability is high and the ground is even" as Eccles defines (Eccles & Arsal, 2014), athletes' attention to the environment would be less and their attention would be mostly to the map, to planning upcoming points. Through this strategy, athletes can deal more effectively with upcoming parts of the course that require more attention to the map. In Jones' notational terminology (Jones, 2015), the same situation can be expressed as: buffer zones, which are the sub-goals for upcoming legs, can be identified in addition to key features, which are the sub-goals in a leg.

During an orienteering course, attention to the map does not remain constant, and Jones (2015) describes five different contact types with the map as retrospective, reading the next step, visionary, affirmative, and detailing. In an ideal course, it is expected that athletes should consult with visionary map reading because buffer zones and key features are ready for the front leg and some decision points for the next leg. During the usage of this type of map reading, the natural sequence of the movements is less disrupted. If athletes only identify key features to reach the CP and leave to identify further decision point after the target CP, this is called as reading the next step. The drawbacks of this map-reading are to cut off the continuity and lead to sudden stops while moving at a pace and time losses based on the stops. The third type, affirmative map reading, is the relocation of athletes' current position. Athletes may come across an unexpected object while moving through their route, and they may need to confirm their current location by looking at the map. Detailing map reading may be applied after the requirement of the affirmative map because it strengthens the idea of where they are by supporting the key features with additional features. Instead of holding on a key feature, additional features are useful in the areas which are covered with similar features. However, the time losses by spending on the identification of the features should also be considered. The last type, retrospective map reading, mostly occurs in the case of an error that is made, or it might be a response to a distracting event. Athletes may not know where they are precisely, and by using the map, they compare the features in the terrain and features in the map to find clues about the places they have already passed. The time of the search is correlated with the distance from the last landmarks they had been passed.

As Richter et al. (2004) cited by Lerjen (2010), the contact time of retrospective map reading is the highest, then visionary and detailing take their place thereafter. Affirmative and reading the next step types have the shortest time; however, it does not mean that they are the most effective techniques. Reading the next step type does not involve buffer zones, and it only has key features. Lastly, visionary map reading is identified as safer, even if it requires more time.

2.5. Different Aspects of Orienteering

As mentioned in *part 1.1.,* orienteering should not just be classified as physical activity, it is more complicated than that. To be able to acquire a high-level performance, an orienteer should have the optimal balance of physical, technical, and psychological skills. Physical skills include the ability of an orienteer's bodily limitations, like the values of the max speed of an orienteer in "x" m or km, Vo2max value, or lactate level mainly. Technical skills include orienteering knowledge of an orienteer, such as the simplification of a route, the choice of right sub-goals, or the level of familiarity with symbolization. The last component, psychological skills, deal with motivation, emotion, concentration, and attention of an orienteer (Juhas, Baĉanac, & Kozoderović, 2016).

If these abilities were not optimized over a sufficient level, at least, athletes would be prone to make errors. The increase in time spent on the errors during a course causes the increase in consumption of mental effort and the decrease in physical performance. Thus, minimizing errors during a course provides a reduction in elapsed time, which is the main factor in acquiring high performance. All the skills that I mentioned are limited to the human body and mind, but inputs come from the environment also contain various parameters. Thus, interaction with the environment should be analyzed carefully. For example, the ground of terrain, runnability in the forest, significant features like an obstacle on the ground, all of them and more affect the performance in this sport.

2.6. The Relation of Technical Skills with Situatedness

Technical skills constitute basics of orienteering knowledge and ease to deal with orienteering effectively, so almost all orienteers know these strategies like fine and rough compass, simplification, attack points, thumb on the map, orienting the map, and map folding, etc.

A newcomer in this sport may not use all techniques effectively because the usages of these strategies are learned in time and then become an intrinsic behavior for an orienteer. Of course, learning all of them does not mean that someone is good at orienteering; tactical skills should support this.

Tactical skills are constituted by the realization of someone's own abilities. For instance, an orienteer who is faster in the paths would form her/his route selection strategy as containing the paths mostly, or an orienteer who is more confident of her/his map skills in the terrain would prefer to move without going away the shortest distance. You may see the relation of technical skills with situatedness by reviewing the most important technical skills below:

2.6.1. Map Folding

It is used to ease the holding of a map in hand, so the visual sight of the map is limited with target CP and a few forthcoming CPs. In this way, the probability of possible distractions based on irrelevant information is reduced to a certain degree. When the usage of this area has ended, another refolding is carried out ("Beginner Basics: Folding, Thumbing, and Orienting", n.d.).

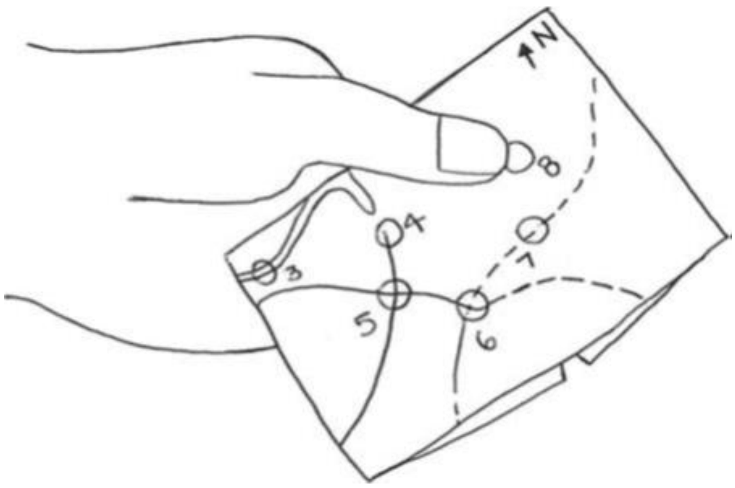

Figure 5. Folded map sample (Adapted from Eccles and Arsal (2014))

2.6.2. Thumb on Map

This technique can be seen as complementary to the map folding technique and is used to follow where you are. The position on the map is marked via the thumb, and its position is updated with the location changes so that athletes can be more precise about where they are. Also, the time loss due to the visual search on the map is minimized with the effect of pinpointing on the map. Moreover, orienteers can relocate themselves in case of possible confusion of where they are because the position of the thumb gives a clue about where they are passing.

2.6.3. Orienting the Map

It can be considered as an attempt to reduce cognitive load. Before heading to the next control point, an orienteer should realize whether any direction changes are required. If such a change is necessary, then s/he should rotate the map in addition to the rotation of her/his body. In this way, the features to be followed on the map and in the terrain are matched. Otherwise, the orienteer may go on in the wrong direction for a while because of similar features in the terrain. This simple process does not seem so essential or complicated at first glance, but most novice orienteers make mistakes in this step.

The techniques above are accomplished with the collaboration of the body, and those small bodily activities turn complex perceptual problems into manageable processes. This event can be a representable example of embodied and situated cognition paradigm since the environment changes the mind by way of body interacted. The combination of all techniques/methods makes us think about epistemic actions. An epistemic action is observed when a mental computation is difficult. To explain this concept, Kirsch and Maglio (1994) carry out a study on Tetris players to detect how they decide to place Zoids, the name of the falling block in the game, concerning time constraints. At the end of the study, experienced players prefer to use more physical movements instead of rotating the shape changes of a zoid in their heads. Similar to this situation, forming a mental representation without orienting the map is computationally difficult for the mind, and it holds the risk of the movement in the wrong direction so that orienteers prefer to deal with such a problem with physical movements.

Another contribution of these movements is to give the possibility of coping with attentional limitations for talented orienteers (Macquet, Eccles, & Barraux, 2012). During the cycles of map reading and cognizing of the environment, working memory should always be active and should be into the interaction with the long term memory, and episodic memory. However, athletes' attention is a fragile topic and related to an important psychological concern that is divided attention and dealing with simultaneous tasks. In that situation, a possible distraction is prevented via the thumb on the map.

These three skills above have a property in common. They take the help of the bodily movements to reduce the time for visual search, and they handle complex thought processes by dealing with them physically. In the study of Eccles and Arsal (2014), they analyze technical skills by grouping as behavioral and cognitive strategies. As indicated in *the decision model of orienteer (Figure 1)*, attention is distributed between the map and the terrain. So, athletes develop cognitive and behavioral strategies to cope with the limitations of attention. According to their classification, map folding and thumb on the map are evaluated as behavioral strategies because they define behavioral strategies as physical arrangements on the map to be able to reduce the time for visual search. The technique of orienting the map is not mentioned in the article; however, it is proper to take place in this grouping. Cognitive strategies spread the map reading to the time and ease the map reading by simplifying the navigation. Attack points and quiet periods, which are mentioned in map reading, are some of the cognitive strategies to overcome the difficulty of map reading mentally. The strategies below, in addition to attack points, also fall under the definition of cognitive strategies so that they can be reviewed under this term.

2.6.4. Fine and Rough Compass

While moving one CP to another, the pace of orienteers does not remain steady, and they do not read the map in the same detailed manner at each speed. When a CP is far from the location of orienteers, they prefer to move by depending on the most salient and traceable features in the map and so that they can preserve high tempo and concentration to the route at the same time. The precision in reading the map increase as orienteer approaches to the pink circled area around the CP. After that point, a detailed map reading that takes almost all shapes into account is required, and this results in a decrease of tempo and the increase of concentration (Stjerndahl & Yttergren, 2006).

2.6.5. Attack Points

It is known as one of the simplification techniques and corresponds to sub-goals in a problem-solving environment. So, most salient features in the terrain are selected and approached them one by one instead of covering all the distance at once. This technique eases to move safer, but the salient features should not be negligible in the area. While drawing a map, map makers can simplify the landform to increase the readability of the map so that the shapes that occupy more extensive areas should be preferred in this context. On the other hand, this shape can be skipped unintentionally due to the deviation in the compass or to the noticeability of the shape. As you might see from *Figure 6,* the small figure attached to the lower left part of the original map represents one of the simplified versions of this leg from an orienteer's perspective. (see also *Appendix A.7. and A.8.*)

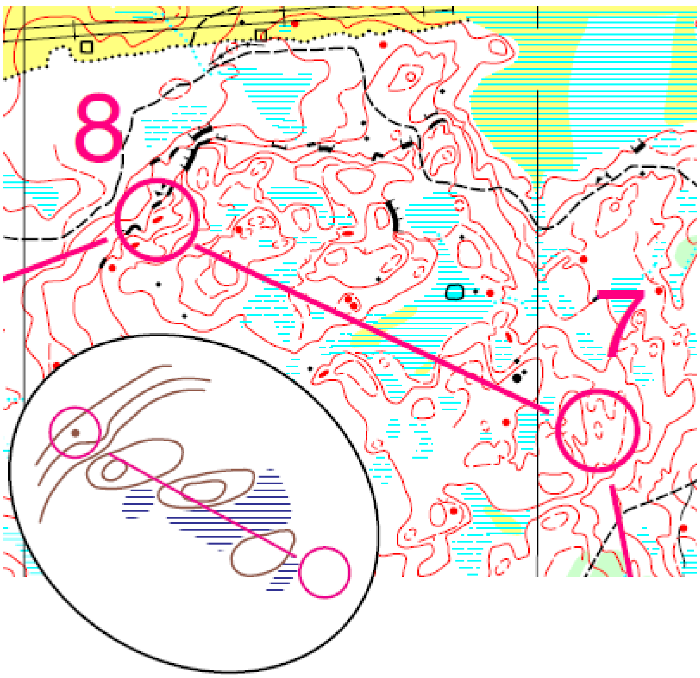

Figure 6. Simplified map sample from an athlete's point of view

(Adapted from Stjerndahl and Yttergren (2006))

2.6.6. Intentional Deviation

Sometimes moving into the terrain might be more difficult than expected, and the compasses deviate at certain degrees. At this point, an athlete may aim to arrive at the left/right of the target point after that s/he may direct towards the target since s/he knows the current location is on which side of the target. Moreover, in the terrain, when an athlete encounters the obstacles, s/he may prefer to pass the left/right side of them.

However, maintaining this random passage for a long time causes the loss of the knowledge of *"Am I which side of the target?"* To prevent this confusion, athletes may prefer to pass always the left/right of the obstacles. The situation above is also known as a type of intentional deviation, and it is related to short term memory.

2.7. Previous Studies in Decision-Making

Investigating previous studies in orienteering is helpful in terms of understanding the scope of what has been done already. Since orienteering is a sport branch, most studies are carried with the perspective of sports physiology or psychology.

Physiological studies mainly focus on understanding physical skills. The performance difference between on treadmill, which is taken as the baseline, and the actual competition are compared. These studies are not directly related to the decision-making capabilities of the athletes, but it is important considering the physical states that are effective in thinking related processes. Running with a high heart rate will cause athletes to exceed the lactate threshold of an athlete, and it will probably cause some disconnection while choosing a route and lead to making some mistakes in route selection or execution.

Studies about cognitive aspects of orienteering generally prepare a simulated environment that consists of a treadmill in front of a TV screen and orienteering simulation is run. After the first simulation is completed, various tasks are given to increase cognitive load and simulation is done again. Results are compared to test whether any significant difference exists between the decisions of orienteers. Sometimes simulation is paused, and the knowledge about map symbology, route plans, or symbols on the map and attention of athletes are tested. However, the simulation environment is just a small reflection of the real one. For instance, in reality, someone needs to look at their map frequently by balancing the movements in the environment, but deciding what to do by looking at the screen on the front is a much easier task. So, when the limitations of environmental conditions are considered, these studies remain only as an approximation to the real environment.

There also some methods to reveal the decision-making process like post-competition free recall, shadowing, think aloud, and head-mounted camera. Post-competition free recall is done after the course is completed. Athletes are expected to remember their cognitive processes that take place during the course. Questions like why a specific route is selected, which deviation occurred, or how confronted obstacles are managed, and how they reach that route are being analyzed upon these recollections. In the shadowing method, two athletes go together to each control point under one's leadership. During this time, the following athletes evaluate the decisions and moves of the leader, and this method is used as a training technique in orienteering in general. In the think-aloud method, athletes record what s/he has confronted

during the course, including the decisions s/he gave, by using an audio recorder. In the last method, as understood from the name of head-mounted, a camera is placed to the head of an athlete, and video records are taken from the perspective of the athlete. Although all techniques give valuable information about how decision-making processes take place, each of them has some drawbacks.

According to Omodei and McLennan (2011), when direct techniques are considered, it gives harm to the nature of decision-making, because decision-making is performed in complex and dynamic contexts in real-time. However, expressing the chosen route, or why this route seems rational to the athlete, interrupt the integrity of the decision-making process. Hence, post-task techniques or methods, which are ex post facto by themselves, like post-competition free recall, are preferred in some studies. In these studies, athletes talk about significant details that remain in their minds, but there may be large gaps in their expressions since the process relies on memory.

Shadowing, on the other hand, may not be a good strategy to observe the inner processes of someone else, because going together with someone may put pressure of being observed or tested with his/her orienteering knowledge upon leading orienteer and it may cause changes in his/her navigational style.

The method of the head-mounted camera provides a visual record and the possibility of watching the race repeatedly if necessary. Except for the disturbance to wear a camera and carrying it during the course, there are no visible drawbacks in this method.

In the rest of the article, free recall and head-mounted camera methods are compared to understand which one gives more satisfying results. The head-mounted camera is useful to observe possible signs of important mental events like thoughts, decisions via a visual or auditory stimulus. Besides, it is possible to reach more representative knowledge of what happened in real-time, compared to free recall.

However, having all the details of the course without considering the importance degree of processes taken place during the course does not mean that this method is superior to free-recall. Those two methods give valuable information on different coverage.

These methods and questionnaires are also being used in recent studies, mentioning from those findings would be useful to scrutinize the components of the decision-making process. In the study of Eccles et al. (2002b), the topics of what types of heuristics, “rule of thumb”, are used by experienced and novice orienteers are investigated. As conclusions, they find that while experienced orienteers’ tendency is toward to backward direction in route planning, the novice's tendency is toward to forward direction. Moreover, the factors affecting planning are indicated as “distance, amount of ascent, runnability, and the presence of obstacles” (Eccles et al., 2002a).

The common thing in these studies is not having clear coding taxonomies that reflect the decision types or mistakes. They investigate behavioral strategies in detail; however, simplifying them under some specific topics has not been done frequently yet. Before mentioning them, it would be useful to review the studies only focusing on modeling.

In the field of operations research, there are many modeling approaches which are named as orienteering problem. What they usually study under the name of orienteering is known as score orienteering, a different version of sprint. In score orienteering, the order of control points is not given, and each control point has a numeric value. Orienteers should collect the highest score within the given time. Athletes who do not comply with time limitations are disqualified or a specified point is cut from their total scores for each second or minute of delay. So, athletes should decide which CPs to visit without exceeding time constraints.

Moreover, athletes should know how far they can go at the same time by punching the highly valued CPs. These details are usually neglected in modeling, and they are much more related to how the highest point can be collected by minimizing distance. The distance between points/nodes is given and only one-time visiting is allowed in this paradigm and can be considered as the combination of Traveling Salesman Problem (TSP) and Knapsack Problem. Since this problem is NP-hard, it is not possible to solve without appealing to heuristics approaches like depth-first, bound and branch, etc. However, there are claims that it can be solved by using the ant colony algorithm, genetic algorithms, or even neural networks (Vansteenwegen & Oudheusden, 2011).

Modeling studies in OR are impressive; however, it is not sufficient to adopt them in current score orienteering. Because, in score orienteering, athletes do not care distance much, their primary aim is to maximize their score. It is not possible to reach all control points in score orienteering; hence, they have to choose a strategy for collecting the highest point. Moreover, the distance between points is linear in the OR paradigm, but in the real world, there are buildings, man-made objects and other obstacles that limit to navigate directly.

Studies above are focusing on the individual level, not an abstraction to the decision-making process. Even though many information about how orienteers make decision or planning, there have been limited resources which combine behavioral strategies with modeling platform.

Some studies, for instance, Arnet (2019), model the race context by bringing in the physical/topographical properties of the terrain together with typical velocities of athletes observed in those terrain types. A color-coded map that shows the optimal effort paths can be deducted from such maps. Such maps could be useful to model the optimal paths given the physical, physiological, and cognitive constraints relevant to orienteering. Then the predicted maps can be compared with the paths followed by the runners.

CHAPTER 3

METHODOLOGY

This study aims to investigate the parameters that affect an athlete's route choice decision during an orienteering course. During this chapter, the research design, participant selection, and data collection methods and data analysis approach will be represented.

3.1. Data Collection Procedure

Turkey Orienteering Federation (TOF) organizes orienteering races in specified time intervals. The first stage of them happened in Niksar/Tokat. From the long-distance stage of this race, GPS data of seven men, who race in the elite category, was collected via Garmin and Suunto branded watches. There are two reasons for the selection of athletes competing in the elite category. First, athletes who race in this category are aged between 21 and 35, as Bird et al. (2001) stated, there is no significant difference in the speed of orienteers between the ages of 21 and 40. Second, the course in the elite category has the highest distance and technical difficulty. So, athletes in this category have already acquired the necessary map reading skills, and their physical strength is sufficient to complete the course. This idea is supported by the knowledge that the least experienced one from the participants has done this sport for four years.

GPS watches have the latest technology, and they receive the data by using GPS satellites placed into the orbit of the Earth. To be able to collect accurate data, at least three satellites are required, and the fourth one gives the elevation related information (Malczewski, 1999). GPS receivers can obtain real-time data like longitude, latitude, and speed, so observations can be done without disrupting the integrity of the orienteering course. Hence, fluctuations in speed, heart-rate, and elevation can be monitored simultaneously.

Data acquired via GPS are very handy, but Norouzi (2013) addresses some drawbacks of using GPS by referring to Hejna (2004). Instability of signals in some areas like valleys, the shades of buildings, metal nets, and the human body may decrease the strength of satellite signals. So, there might be some deviations in the position of athletes, arising from GPS receivers. The error margin of these deviations should not be too high. At the current state of GPS technology, 10-15 meters of dislocation is acceptable. To provide a higher level of accuracy of location, which is up to 0.3 m, Cych (2006) mentions the dGPS (differential Global Position System) and its usage by attaching an extra receiver to the athletes. Also, he warns against two factors that affect the accuracy of GPS data receivers, which are the area and scale of the maps. While the error in recorded data in terms of total distance and average speed is less than 2% in the outdoors, the measures in an urban area do not give the same satisfactory results. The increase of scale from 1:5000 to 1:15000 decreases the covered area with 1 cm, so the accuracy works well in the high-scaled maps.

3.2. Design of the Study

In this study, qualitative and quantitative study designs were used to examine collected data. In the first part, GPS data of the athletes were added on the map via Route Gadget (RG) program to visualize their route selections and mistakes (see *Appendix B.14.*). The routes of the athletes were analyzed with an unstructured interview with an expert who has done this sport for nine years and is a national team member. In the interview, first, the routes of the athlete who complete the course fastest among the participants, then, all participants' routes were evaluated. This interview aims to give meaning to the behaviors of athletes and understand the effect of leg characteristics on their decisions.

In the second part, further analyses that support the qualitative study were done by using GPS data of participants. But, first of all, two raters, including the author of this study, evaluated the difficulty of legs by giving scores to make it possible to establish a relationship between the environment and the behaviors. In the scoring, some principles for evaluation were set and their details will be mentioned during this section. Then, among behavioral outcomes, some observations were made due to the changes in the speed of athletes by using descriptive statistics in SPSS. While the first analyses were focusing on the average speed changes, the focus of the second one was upon speed changes at control points. In this way, we are also able to observe the technical skills mentioned in the literature from the speed changes at waypoints. After that, a similar environment to where athletes ran was created with grids, and the unit cost allocation followed in grids was mentioned in the following sections. After that, this environment was run with one of the shortest pathfinding algorithms and its compatibility with real paths was compared to see the connection of fast and frugal heuristics. Lastly, the analyses were concluded with a regression model to demonstrate the dependency of decision-making on the environment and to reveal the effect size of parameters on the decisions.

3.3. An Overview of the Course

The course prepared for the long-distance competition consisted of 18 checkpoints and required 330 meters of elevation gain in 10.5 kilometers (see *Figure 7*), and the scale of the course map was 1/15000. Athletes completed this course within the time of 80 to 160 minutes and by elongating the distance up to 12 to 16 kilometers. Time spent on each leg can be observed in *Table 2*.

The terrain had widespread open lands, highly dense forests with the brushes on the ground and many thick and traceable paths, so runnability in open lands and paths was high and low within the forest. Athletes generally preferred the routes, including open lands and paths, as long as they did not have to pass through the forest. While the route selection was nearly the same in the legs that have a short distance, attack points and the followed routes differed as a result of the increase in the distance.

After this brief explanation, the following sub-sections were composed as a result of the qualitative analysis of the comments made by the expert to assess the performance of the athletes. The following subsections also aim to make the underlying causes of athletes' behaviors explicit in reference to practices known to expert orienteers.

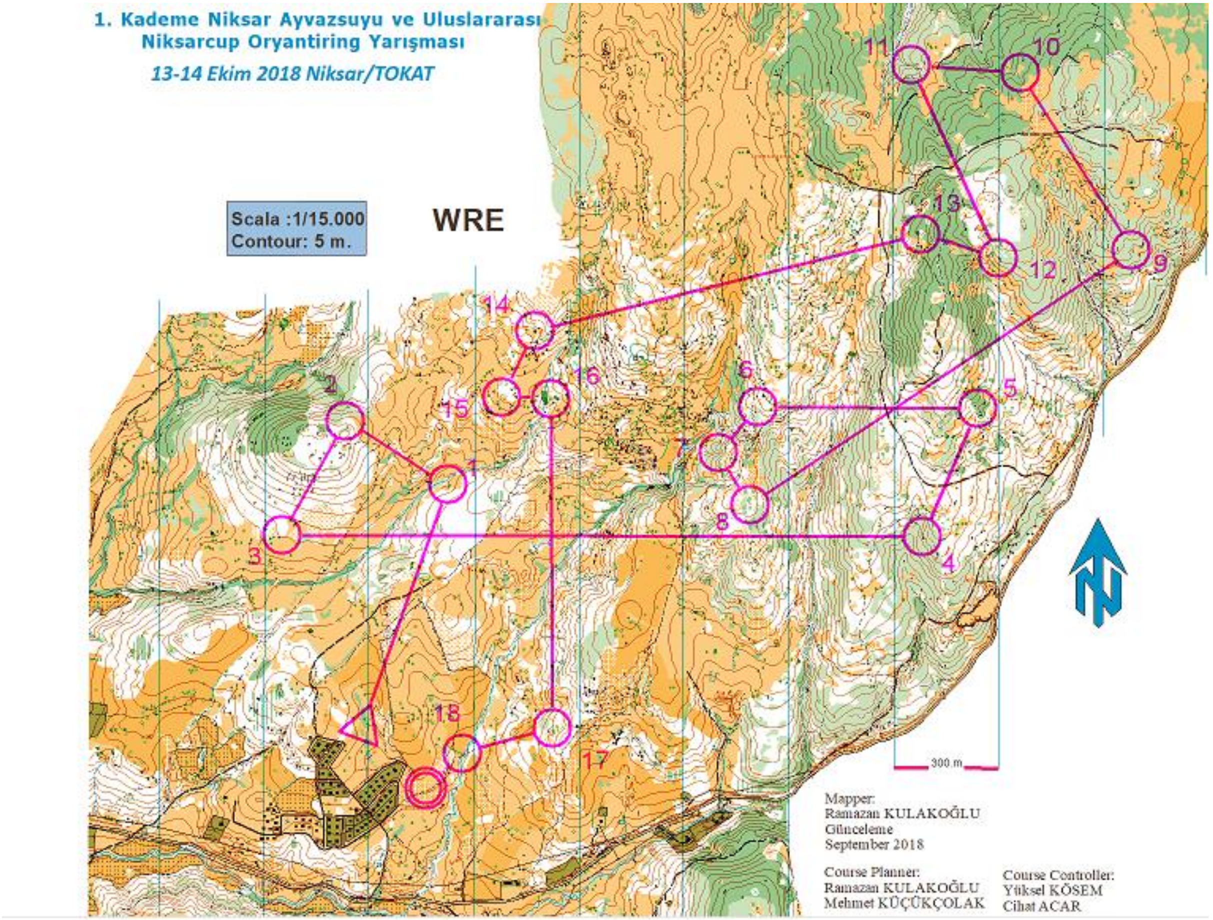

Figure 7. Niksar map

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Table 2. Split times of participants in each leg

	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Subject 6	Subject 7
Leg 1	04:25	04:42	04:52	04:48	05:17	04:31	10:24
Leg 2	02:23	02:48	02:35	02:19	02:51	02:09	03:54
Leg 3	03:11	02:43	03:12	05:11	02:50	03:57	03:55
Leg 4	15:22	14:53	16:03	15:31	19:39	17:35	25:41
Leg 5	04:15	03:26	04:05	05:32	03:57	09:29	05:19
Leg 6	05:26	05:49	07:44	10:57	07:03	09:44	10:03
Leg 7	01:10	01:04	01:28	01:12	01:11	03:07	04:24
Leg 8	01:14	01:05	01:12	01:07	03:10	02:25	02:22
Leg 9	12:13	15:26	12:36	12:23	16:14	12:35	18:46
Leg 10	04:27	03:59	04:03	05:02	04:16	04:21	06:06
Leg 11	01:56	02:00	03:13	02:07	02:33	03:36	02:50
Leg 12	05:10	04:38	05:56	05:43	05:52	13:02	08:32
Leg 13	01:51	01:56	02:03	02:15	02:04	01:47	02:34
Leg 14	09:20	07:16	08:18	09:02	09:13	10:32	30:18
Leg 15	01:01	01:07	01:10	01:20	02:21	01:45	01:30
Leg 16	00:52	01:29	01:03	00:54	00:58	01:12	01:20
Leg 17	04:47	04:50	05:55	05:28	12:16	09:19	21:49
Leg 18	01:00	01:02	01:18	01:10	01:00	01:20	01:41
Leg 19	00:32	00:34	00:36	00:36	00:29	00.39	00:31
Total Time	01:20:35	01:20:47	01:27:22	01:32:37	01:43:14	01:53:05	02:41:59

Figure 8 shows the total time spent by athletes to complete the course. Since the ranking of subjects was done based on these times, you can keep in mind that athletes who have high ranking performed poorly.

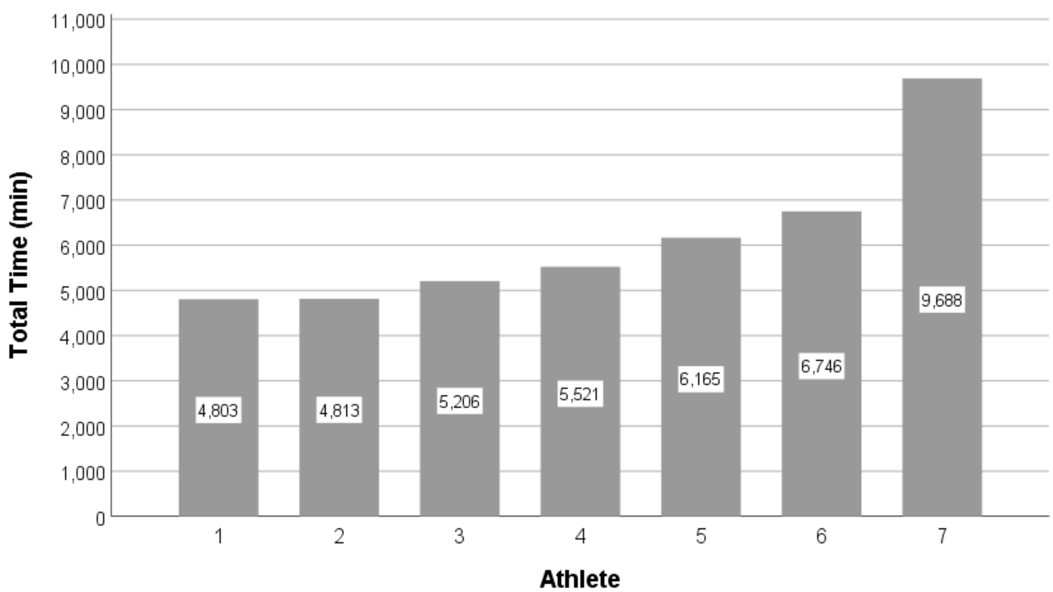

Figure 8. Total time spent by athletes during the course

3.3.1. Start to CP 1

When an athlete's start time begins to be counted, the time during the first few CPs passes with the adaptation of the athlete to the course and s/he compares the real-world condition with the representations on the map. For example, if there is a stream on the ahead of the athlete's route, the athlete is prepared to see a stream by taking reference from the map. However, s/he does not know the current condition of that feature or which features are not added by the mapper to increase the readability of the map. So, the information like whether there is any water on the stream, it is deep or steep, or there is any osier wood that would reduce the speed, remain ambiguous before the athlete comes across that shape. Hence, there is also a hidden adaptation task in these first CPs aside from just finding the CPs, and the route selections in the upcoming legs are affected by this situation.

When *Subject 1*'s route of going to the first CP was examined, you can observe the traces of the hidden adaptation task, as expressed above. *Subject 1* did not care about how much he moved away from his reference fence as long as he reached the path because this attack point was big enough to come across the left/right of that feature eventually. Even he wasted his time by going away from the fence and the elongation of the distance as a result, this divergence stayed behind the preliminary tasks like the speed arrangement and planning of the next steps in the route. Moreover, this rough arrangement did not result in a major waste of time as *Subject 1*'s split time was the best among the participants.

From the routes of other participants, different route selections were observed. Although everyone took the fence as their reference until reaching the path, afterward, the choice of attack points differentiated at some points. For example, *Subjects 2* and *4* selected the stream as the attack point after the path. However, this choice had some drawbacks, like causing too much decline because the CP was located in a higher position and climbing was required to reach the target. This selection caused time loss based on this unnecessary descent and ascent while moving on the same elevation was an option. The expert stated that such behaviors could be observed in the first CPs because athletes have prior knowledge of how much time required to focus on the map from previous experiences. Hence, until that time, they prefer to move in safer routes instead of losing time by making mistakes.

In *Subject 7*'s route, the opposite case could be observed. He tried to approach the CP by staying in a higher position, but he chose a more challenging route by comparing attack points in the below route. As a result, he could punch the CP by spending almost twice as much time as other athletes, and he got started to be tired from the first CP.

3.3.2. CP 1 to CP 2

When the characteristics of this leg were examined, the altitude of CP 2 was higher than CP 1, and CP 2 was located near the hill. Since this leg was one of the starting legs, athletes would like to preserve their strength by climbing less. *Subject 1* selected attack points as the stream, the spur,

and reentrant near to the pink line and the vegetation boundary, as you can see from *Table 3*. In this leg, *Subject 1* moved closer to the pink line since there are features that do not require moving away from this line. When the other athletes' routes are examined, their split times are close and route selections were almost the same except for their tendency to stay at the right or left of the pink line. The expert explained this situation as the natural tendency peculiar to each person and this kind of deviations can occur unintentionally. *Subjects 3* and *7* preferred to less steep incline by moving around the spur, and this is related to how they prefer to go on basically: struggle with less elevation by elongating the distance or passing steep area in a shorter distance.

In this leg, the point where you enter the forest was also important because if you enter the forest after the reentrant, instead of taking the vegetation boundary as a reference, you should think of the possible direction deviations in the forest and this leads to a more complex situation. Besides, contour lines in this area are more close to each other, so steep.

3.3.3. CP 2 to CP 3

In this leg, the altitude of CP 2 is higher than CP 3, so athletes would increase their speed with the decrease of physical pressure factors such as slope. Such legs are used to compensate for the time spent on the slowdowns or errors; however, athletes should be careful about keeping contact with the map while speeding.

Subject 1 went down from CP 2 by aiming to reach the open land located on the north-east side of CP 3. However, he made a mistake in the open land with scattered bushes/trees area that was near the open land because realizing the difference between these two areas may not be easy at high speed since athletes' perception of distance can be confused with this instant speeding. According to the expert, this mistake was also rooted in the deficiency in attack point identification. If *Subject 1* had chosen their attack points as the open land and the spur next to it, he would not make the same mistake since there was supporting feature, the spur, to give the cue about whether he was in the right location. Besides, he moved by heading to the right until the open land, he probably assumed that first open land-like area as their attack point, but if he had preferred to move close to the pink line, he might realize the open land with scattered bushes/trees from the vegetation boundary.

When other participants were analyzed, *Subject 4* still preferred to go more safely. His GPS tracking reminded a broad arc-like shape when the pink line is taken as a base. To the expert, this situation is related to the map reading level of athletes. Athletes who hesitate their map reading skills prefer to go on safer routes in case of staying behind in capturing features in the terrain and getting lost consequently. *Subject 6* preferred to move from the left side of the pink line, and this choice resulted in searching the CP 3 in the forest on the left side of the CP 3. After he saw the open area, he recovered his error by changing his direction towards the target. Even though he lost the time from this error, his split time was better than *Subject 4* because *Subject 6* almost never slowed down except a few points, and *Subject 4* made a mistake near the CP 3 despite all the efforts to go safe.

3.3.4. CP 3 to CP 4

In the long-distance legs like this, there are two options to be selected: the route that involves the paths mostly and the route from the terrain. Just like each route option, these routes have their pros and cons. The first option is preferable for those who have good physical strength because this route is planned away from the pink line and the distance to be covered is longer than the second option. On the other hand, athletes can increase their speed by spending the minimum effort to read the map, and athletes can relax their mind while identifying the routes for upcoming legs in the meanwhile. The second option is almost the opposite of the first one because this route is selected by those who are not good in physical strength, and more concentration to the map is required although this kind of route is shorter and close to the pink line.

When the route characteristics were analyzed, the area on the west side of the CP 4 is very steep. After ascending half of this area, almost the same amount of descending is required to cross over the entire area. The path at the bottom of this steep area is a better option because the elevation gain during the path is low and athletes can increase their speed instead of fighting with the dense vegetation. Before arriving at the path, there is a huge area mostly having the open lands and athletes should pass over it by considering the elevation change and the deviation from the pink line.

In *Subject 1's* route, the big valley in the middle of the leg among the other valleys seemed like one of the attack points. After that, he moved towards the point where the open land has ended, and then he followed the path to the end and continued to climb up the hill where the CP 4 was located. According to the expert, *Subject 1*'s route was mistaken because of his awayness from the pink line and the increase of the distance to be covered upon this choice. Besides, he had to climb up at some point since he could not balance the ascent and descent. When *Subject 1*'s choice was compared with *Subject 2*, they both climbed up the hill by using the same path; however, *Subject 2* stayed closer to the pink link by choosing a more successful attack point, which was the reentrant. With the help of this attack point, *Subject 2* did not have to cover much distance as *Subject 1* did. For the expert, the choice of *Subject 2* is more advantageous in terms of both the traceability of the features and the distance coverage.

In this leg, different route options exist. For example, *Subject 5*'s route is really interesting. Unlike the other athletes, he aimed to reach the road at the bottom with the thought of increasing his speed by decreasing the time spent for map reading. However, the distance to be covered was almost twice as much the distance of the pink line, so the gain from the time against the other athletes did not seem possible with this trade-off. This route was not one of the optimum routes; however, it is easy to follow and safer in terms of being connected to the path approaching the target location.

If *Subject 1*'s awayness from the pink line was ignored, it was seen that all athletes' routes united at the path start. After that point, *Subjects 3* and *4* continued their movements from the terrain instead of following the path to the end. This selection required a lot of map reading than path following, and the speed of the athletes would be lower accordingly. Although there seems to be no significant gain with this choice, the expert linked this issue to distance speed trade-off. The

athletes who are not good in physical strength assumed that they would stay behind the others if they had chosen to move from the path. Hence, they tried to compensate for their time-related disadvantageous by shortening the distance with more map reading.

3.3.5. CP 4 to CP 5

There is a big spur to be climbed all the way along to reach CP 5. In the climbing, the speed of athletes decreased automatically, and athletes would like to spend this time for another task, such as identification of attack points. According to the expert, the most traceable attack point is the re-entrants that are located on the south-east side of the target. But there is more than one reentrant in this area, so athletes should make intentional deviations by holding their compass and aiming to reach the bottom part of the reentrant. Otherwise, they may fall into error, just like *Subject 1*. This mistake did not cause a significant time loss; but, he assumed the wrong re-entrant as if the re-entrant where the CP was located. For the expert, there are possible outcomes in case of not making intentional deviation. For example, athletes may not perceive how far they are going as long as seeing the open land across the target or relocating themselves may not be easy due to the difficulty of separating the high-density green area from the forest. This condition can be clearly observed in *Subject 6*'s route. He was confused in a field near CP5 and searched the CP for a while. The expert related this error with moving a speed that surpasses the map reading, and identification of missing attack points.

When the other athletes' routes were investigated, except for *Subject 7*, all athletes had approached the target from the right side because the route on the right side required less climbing. *Subject 3*, *4*, and *5* had chosen a safer route by deviating to the right to reach the reentrant where CP was located. After that point, they climbed up to the target. In this route, recovering from an error is easier than *Subject 1*'s choice because capturing the open land in the terrain is more difficult than capturing the contour lines for those who are not good at map reading.

3.3.6. CP 5 to CP 6

In this leg, there is a deep and steep valley to be passed over. On this type of leg, the number of contour lines to be descended and how many of them to be climbed after this descent is important. If the distance shortenings do not provide any gain because of the fatigue and heart rate variability, then alternative routes are searched. In this case, the surface ground of the valley and its steepness are not preferable, so six out of seven athletes preferred to move around the valley.

When the details of *Subject 1*'s route are examined, the first choice is whether passing over the spur or moving around it by following the same contour line. According to the expert, the second option is better since athletes can speed up through the same elevation. The second choice is how the valley will be passed, by directly running through the valley or running around it. He preferred the second one again and he reached the crossing point of the paths and headed to the end of the stream and then ascend just one contour line was enough to reach the path at the other side of the stream. While approaching the path, since he knew that he eventually arrives somewhere on the path and the interval between the contour lines is wide, and then he moved diagonally to shorten the distance. The last choice is related to the entrance point to the forest. He got into the forest from the path close enough to the pink circle of the CP.

When the other athlete's routes were analyzed, the first and last choices mostly varied. However, the second choice was almost the same as mentioned above because of the importance of the choices. The effect of the second choice on the physical endurance and performance in the remaining parts of the course has a higher impact. According to the expert, the difference in *Subject 6*'s route depends on the confidence to his physical strength, and how much challenged to climb a hill.

3.3.7. CP 6 to CP 7

Control points in this leg are very close to each other. The expert stated that the optimal route is going through the pink line. In the case of this option, the path intersection and the second reentrant after the intersection are the attack points, respectively. When the routes were analyzed, there was no one applied this route, and athletes preferred safer routes. Because the expert's route requires good map reading skills, athletes could not take the risk to deviate into the forest, and the requirement to relax their minds in the middle of the course might surpass the gain from distance shortening.

The athletes preferred to make a small deviation from the pink line to see the path and then they entered the terrain by changing their direction. Except for *Subject 6* and *Subject 7*, all athletes' split time is around 1 minute.

As mentioned in the previous leg, *Subject 6* selected his route by going down and up into the valley and this choice led to the mistake in this leg. Maybe it is because of the increase in his heart rate and heart rates' effect on thinking. On the other hand, *Subject* 7 moved through the path in the middle of the leg instead of passing over it and he recovered his mistake after seeing the open land at the right side of the path.

3.3.8. CP 7 to CP 8

For this leg, the expert specified the difficulty of moving through by following the pink line; however, the lack of route options compelled athletes to select the pink line as their reference. Moreover, she told the possible attack points and preventive points in case of going far beyond the target. According to that, athletes should pass from the path in the middle, then from the point of where the path turns, they should arrange their orientation with the help of the compass to reach the open land with the brushes/trees. After that point, athletes can find the target between the low-visibility forests. Besides, the point where the CP is located is plain so if you find yourself in a spur or reentrant, this means that you left the target behind.

When *Subject 1*'s routes were analyzed in this context, the attack point before punching the CP 8 was not obvious, and a very small amount of deviation was available so that this error might have occurred unintentionally. *Subjects 5* and *6*'s movement to the right resulted in the mistake and their split time is almost twice as much to athletes who have the best time.

3.3.9. CP 8 to CP 9

This leg is the second long-distance leg after the leg in between CP 3 and CP 4, and this leg has different route choices, just like the previous long leg. The big valley, while going to CP 6, was on the route once more. When *Subject 1* was analyzed, he preferred to go back and use the same path for arriving at CP 6. According to the expert, in such cases, athletes may prefer to go back from the route that had already passed before because of the familiarity with the terrain. This familiarity brings some advantages such that the probability of making a mistake and the requirement for map reading decreases, and athletes relax their minds during this time interval.

After he passed over this well-known area, he continued to move on the path for a while. At some point, he crossed the terrain diagonally to shorten the distance, and he reached a forward point of the same path. The expert did not think that this move would provide gain from the time because such cross cuttings are generally done when climbing up. In our case, the athlete made this move while descending. After he came to the intersection of three paths, he started to climb towards the target from the middle path, and he picked the open land as his attack points and the reentrant at the left side as a preventive feature to avoid possible deviations. *Subject 1* reached the around of the pink circle, but the location of where he entered the forest is important because of the dense vegetation at the around of the CP 9. So, his last attack point was probably the stones near the pink circle. If his last attack point had been the open land, which is far from almost 200 to 300 meters to the target, he might not have gone directly to the target.

When the other routes analyzed, there are two routes apart from *Subject 1*'s selection. These two routes involve some common parts with *Subject 1*'s route. In the first one, *Subjects 3, 4, 5* and *7* selected to go back from the path that had already passed; however, they continued to follow this path instead of crossing the stream and they approach the target from its above. In the second one, *Subject 2* went down to the stream and followed it until arriving at the intersection of the thin path and the stream and he finally reached the thick path that is used by *Subject 1* also. In this route-athlete matching, *Subject 6* stays out of these matches because he preferred to come up with the path by moving through the deep and steep valley instead of moving around it. Except for this difference, the routes of *Subject 6* and *Subject 1* is almost the same.

When the split times were examined, *Subject 1*'s split time was the best and the route that was selected by most of the athletes seems more advantageous based upon split time. One of the remarkable points in these routes can be done with the comparison of *Subject 1* and *Subject 2*. Until this CP, the total time of *Subject 2* was 1.5 minutes better than *Subject 1;* however, he was not only close up this gap but also took the lead from *Subject 2* again.

The expert related the difference of route selection with the planning of the next steps and perception of athletes. Because athletes prefer to take advantage of the seen-before terrain. If they plan their routes upon this strategy, it is highly possible to pay no attention to other possibilities. On the other hand, athletes who have not made a plan previously select the first route that attracts their attention.

3.3.10. CP 9 to CP 10

In this leg, half of the course had already completed and the effects of fatigue on the body and mind possibly started to show more effect after this leg. In the first stage, *Subject 1* tried to reach the thick path in the middle of the leg. The expert said that reaching exactly to that point on the path is crucial for the leg. Until reaching the path, he first came to the open land by passing over the green-colored forest, and then he reached the ancillary path that intersects the main path by moving the open land and a part of the green-colored forest again. After the thick main path, he followed the open land on the other side and got into the forest to reach a small open area where the CP was located.

When the split-times were analyzed, *Subject 1* stayed behind the most athletes. For the expert, climbing up to the hill until the thick path in the middle was the reason for time lost by *Subject 1*. His slowdown in the green-colored forest might also contribute to staying behind other athletes. The route choices of some athletes were similar to *Subject 1* in general, but their attack points had minor variabilities.

Apart from this route, there was also another route proposed by the expert, and this route applied by *Subject 3* to a large extent. I would not mention the details; but, these two routes differentiated in terms of the elevation change to the thick path. The first route required to ascend at least five contour lines, on the other hand, after climbing two contour lines, running through the same contour line was enough for the second route. The difference in the climb might affect the athletes less than we thought, but if there were the woman that ran this leg, their tendency could be similar to the expert's proposal. When we looked at *Subject 7*, he fell for a fallacy based upon the miscounting of similar features in the terrain. He should get into the forest from the second open land that remains on the left side after passing the vegetation boundary, but he turned to the left from the first one.

3.3.11. CP 10 to CP 11

In this leg, there were two paths at the left and right side of the pink line, the round of the paths was surrounded mostly by high dense vegetation. Hence, athletes made their route choices between these paths. The path at the right side was shorter since the starting point in this leg is CP 10 and the distance to the path at the left side was a little bit far, and it involves a bit of exposure to the dense forest. This might have been effective in five out of seven athletes' choosing the path on the right side. When the split times of *Subject 1* and *Subject 2* who both showed similar performances in previous legs were compared, neither routes are superior to the other significantly since the difference is only four seconds.

3.3.12. CP 11 to CP 12

The altitude of CP 12 is higher than CP 11, so climbing was the hardest challenge for the athletes at that leg. *Subject 1* used to the open land at the left side to reach the vague path in the reentrant. Then he moved through to the thick path in the middle of the leg. After this point, the steepness of the terrain diminished, and the speed of him increased after a short period, probably necessary to stabilize his heart rate after climbing five contour lines. The vegetation boundary and the flat reentrant at the right side are the significant features to follow, but his deviation to the left side prevented the athlete tracing of them and almost caused an error. He got rid of this possibility due to his sense of the slope change because the terrain beyond the CP was steeper. When the other athletes' routes were investigated, out of *Subject 5*, they all preferred to follow the same. *Subject 5* jumped to the open area after the end of the vague path, and he reached the thick path from there. The expert evaluated this move was risky because of the deviation in the forest. Besides, he had to go far from the pink line just like *Subject 1*. The mistakes mentioned so far do not generate a huge difference in the arrival time to the CP and the difference in *Subject 7*'s split-time against the others arose from the speed. On the other hand, *Subject 6* made a mistake in the pink circle when he was so close to the target, and he lost a lot of time to recover it. The details of this mistake and the effect on the next CP explained below.

3.3.13. CP 12 to CP 13

This leg did not have many alternatives and all competitors made similar choices except for moving on the right or left side of the pink line. You can see attack points of *Subject 1* from *Table 3* and other athletes made similar route choices except for *Subject 6*. As I mentioned in the previous leg, *Subject 6* used the advantage of seeing CP 13 before and having the best split time in this leg is an indicator of this situation. He made a mistake while going to the CP 12 and he recovered from this mistake by going to CP 13 before punching CP 12. The reason why he made such a move cannot be inferred from the route; however, athletes sometimes use this tactic when they do not find their target for a long time, moving forward and finding the next CP provides both to update their location and to change their perspectives instead of searching the same area all the time.

3.3.14. CP 13 to CP 14

This leg is also one of the long distanced legs and there are two hills and valleys to be passed over. Athletes should deal with which options are proper for them: being close to the pink line but making many ups and downs or following the same elevation by elongating the distance. When *Subject 1*'s route was studied, he preferred to move from the path. During the path, he had to climb. Climbing would be required in any case, but taking this climbing with minimum fatigue is the crucial point. The choice of *Subject 1* until this point is evaluated as a good option because consecutive ups and downs are more exhausting than taking this range in one piece. He continued to move in a flatter area after that point. According to the expert, *Subject 1*'s route is one of the optimal routes if he did not move too far away from the pink line. This choice resulted in some confusion and slowing at the border of the map because of staying at the outside of the map boundaries. The same mistake can be observed from *Subject 7*'s route. For the expert, the errors of these athletes were associated with allocated time for map reading and traveling because the features on their routes give the possibility of speeding for those who selected the bottom route with more map readings. Hence, their minds get confused when they arrived at a point that requires more map reading.

In this leg, there are two more route options. Four out of seven athletes preferred to move by drawing S lines around the pink line to climb less by following the same contour lines. This route seems more advantageous when split times of the competitors compared because *Subject 1* stayed behind the most competitors while he was generally in the front in other legs. *Subject 2* followed a much different route than others. He followed a similar route with the four athletes by following the same contour lines to a point. Then, after that point, he chose to move from the bottom instead of drawing S lines around the pink line.

3.3.15. CP 14 to CP 15

This leg is also one of the short-distance legs. According to the expert, following the vegetation boundary that is formed by the white-colored forest and open land is one of the best routes. After following this boundary, changing the orientation from where the open land enters into the white-colored forest would be the second step to reach the target.

From the athletes' routes, they selected almost the same route proposed by the expert, and their speed was high since the movement was on the open land mostly. *Subjects 5* and *6*'s routes were slightly different. *Subject 5* followed the boundary to the middle, and then he preferred to pass on the left side of the boundary; this preference caused exposure to the terrain that is less runnable and resulted in a decline in his speed in these less runnable areas can be seen in the RG. His second mistake around the target caused additional time loss, and he could punch the target twice as much time than others. *Subject 6* approached the target by deviating to the left more than necessary, and his awayness from the pink line caused him to lose time just like *Subject 5*.

3.3.16. CP 15 to CP 16

This leg is one of the short-distance and speedy legs and there are very distinct features like the stream and dark green area to prevent going beyond the CP. So, *Subject 1* identified his attack points as the pink line and the significant green vegetation, respectively. *Subject 2* had shifted a little bit from the pink line, and he made a small mistake. The expert related this with the identification of insufficient attack points. Because *Subject 2* aimed to reach the stream only, neglecting the green area.

3.3.17. CP 16 to CP 17

This leg was the final long-distance leg before finishing the course. From the route of *Subject 1*, it is seen that his route was close to the pink line, so the existence of many significant features going all along the pink line was effective in staying close. There was a stream in the middle of the leg and all athletes should cross over it somehow, but the location of where *Subject 1* would be on the stream was important. He approached the stream by taking the reentrant covered by the greens and the big boulders on both sides of the stream as references effectively. After that, he went on by following the same contour line until he saw the little spur and the open land a little ahead and he took the target by approaching from above. When the other athletes' routes were examined, *Subjects 3 and 4* used the same route with *Subject 1,* and others preferred to move by depending on more apparent and big features. According to the expert, the route described above requires more map reading. On the other hand, those who preferred to spend less time on map reading selected the alternative route.

Subject 5, *6*, and *7* made a mistake around the CP, the causes of their mistakes are different, but the common thing in mistakes for the expert was that they gave their attention to the travel and their connection with the map was broken. In the last controls, athletes may display such behaviors because their minds can relax with the thought of "*I almost finished*." Based on these psychological causes and the fatigue accumulated during the course, athletes can identify insufficient attack points, and they continue their moves without associating symbols in maps with environmental features.

3.3.18. CP 17 to CP 18

In this leg, athletes held their compass to arrange their orientation then they ran down until the stream without going away from the pink line. There was no significant mistake for this leg.

3.3.19. CP 18 to Finish

After the last CP, the path is marked with the tape up to the finishing point. This application is similar to the marking at the starting point; however, this time, athletes do not need to give their attention to the map so that they can focus on the travel. When the split times in this CP were analyzed, their values changed from 29 seconds to 39 seconds in around 150 meters. This difference arose from their ability to sprint and the remaining endurance level of the athletes.

3.3.20. Summary Table for the Routes of Subject 1

In the below, you can see a summary table describing the attack points, consideration about the route, and mistakes made from the perspective of *Subject 1*. Even if this table does not describe behaviors of all athletes, it gives an insight into properties affecting choices and possible mistakes in case of not applying the identified sub-goals to reach the target.

Overall, reference setting, distance arrangement, maintaining map contact, elevation change, and terrain features are matter in the planning of a route. You can find some of the properties mentioned from *Figure 1*, but elevation change and terrain feature can be perceived as the unspecified sub-categories of “attention to terrain”. When we inquired about whether these factors can be used to build a model; environment-dependent parameters like distance, elevation change and terrain features are all we have because other factors are not proper to make an abstraction due to their high correlation with personal differences.

Table 3. Attack points of *Subject 1* and points to be considered during the legs

	Attack Points in the Route	Considerations about the Route	Mistakes
Leg 1	Reach the path, move on the path by taking the fence as a reference, enter the terrain, move by following the same contour line, search the CP where the contour lines bend	Direction-setting and speed arrangements Contour line to be followed after entering the forest, stay above on the stream to preserve the elevation	✓ Elongation of the distance
Leg 2	Go down to the stream, continue from the pink line by regarding the spur and re-entrant respectively, go into the forest by referencing the vegetation boundary	Direction deviations in the forest, the gap between contour lines (steep in the forest / flat in the open land), the point where you enter the forest	-
Leg 3	Go down the hill, reach the open land located on the north-east side of the CP	-	✓ Instant speed increase ✓ Few attack point identifications
Leg 4	Reach the big valley at the middle of the route, move to the end of the open land where the path begins, move on the path, reach the hill	The tradeoff between distance and elevation change, minimum ascent/descent, avoid the steep and dense vegetated area	✓ Elongation of the distance

Table 3. Continued

Leg 5	Climb the spur and reach the path, move through the re-entrants near the CP	Make intentional deviation to avoid confusion by similar features	✓ Distance elongation ✓ Not balancing ups and downs
Leg 6	Move around the spur, reach the path, head towards the end of the stream, climb up the path and move on it, get into the forest from the closest point of the CP	Avoid unnecessary ascent/descent, keep the speed constant	-
Leg 7	Reach the path intersection, change your orientation and pass from the open land	The level of mental effort spent	-
Leg 8	Reach the turning point of the path, hold the compass towards the CP	Identify preventive features in case of leaving behind the CP	-
Leg 9	Reach the path used in arriving at CP6, move on the path until reaching the stream ending, go across the stream bend, and climb to the path, move on the path until three path intersection, select the middle one, pass the forest and see the stones, and move in the same direction by being aware of the CP stay on the right side	Take advantage of the familiar area, select the right point to approach the CP	-

Table 3. Continued

Leg 10	Move on the open land on the right side of the pink line, reach the path, pass over the open land by referencing the vegetation boundary, enter the forest	Physical strength required when climbing the hill to reach the path	✓ Elongation of distance ✓ Entering the densely vegetated forest
Leg 11	Reach the path that stays on the north side, move on it, and pass over the open land	Preservation of the speed	-
Leg 12	Move on the open land on the left side of the CP11, reach the path by climbing the reentrant, continue to move forward by taking vegetation boundary as a reference	Attack point selection after reaching the path	✓ Difficulty in capturing the attack points ✓ Deviation to the east side of the CP
Leg 13	Pass over the re-entrant, reach the crossing paths, keep going to move on the path that is parallel to the moving direction	-	-
Leg 14	Reach the crossing point of the paths and move for a while on the path, move on the open land, change orientation after the stream	Route selection that keeps the speed balanced Climb first, then proceed flatter areas or take consecutive ups and downs	✓ Too much awayness from the pink line ✓ Go beyond the map boundary

Table 3. Continued

Leg 15	Move on the open land by referencing vegetation boundary on the west side, go into the forest where vegetation boundary is bending	-	-
Leg 16	Hold the compass by aiming to reach the dark green area, run in the direction of the compass	Do not go far beyond the stream	-
Leg 17	Reach the stream in the middle of the leg, see the big boulders located on both sides of the stream, follow the same contour line, change direction after seeing little spur and open land	More map reading by staying close to the pink line or choosing large objects as attack points to decrease the dependency on map reading Do not lose contact with the map	-
Leg 18	Adjust your direction from the compass, run down the stream	Do not stay away from the pink line	-
Leg 19	-	-	-

3.4. Classification of Terrain Features

In this part, data acquired by GPS was interpreted. Before starting that analysis, first of all, the environment that athletes exposed were investigated because we assume that their decision is highly dependent on it, and this can be thought of as a first step to acquire the reasons underlying the route selection of athletes and to make the role of environmental constraints visible.

First, leg difficulty levels were scored by two raters. For the evaluation, a seven-point Likert-scale was used. In this scale, "1" represents the lowest difficulty, and arriving at that CPs should not cause any trouble at all for an athlete. Two raters agreed on the fundamental principles stated below to provide consistency in the scoring.

1) If paths reach the nearby of a control point: *1 point*
2) If contour lines are very dense,

   Traceability of landforms is challenging, so the guidance of attack points is low, and

   High dependency to the compass, almost 50% of the distance requires the usage of a compass: *4 points or above*
3) Technical requirements to find the CP: *+/-1 point*

When the scores of raters were analyzed (*see Appendix B.2.*), leg 4, 9, and 14 have the highest values, so it seems they are the most challenging legs to be followed. The scores of leg 13 and 17 are one step behind of the most challenging legs. The common property of these five legs, except leg 13, is the similarity of their top view distance. The high score of leg 13 probably depends on the intensity of vegetation features along the route. From the remaining thirteen legs, at least one value of five legs is at or above the average difficulty level, and the values of eight of them are under the average difficulty level of four.

In the end, these scores were processed in SPSS to gain an idea about the reliability of this study's author. As you can see from *Appendix B.3.*, the value of *Krippendorff's Alpha* in the inter-rater reliability test is 0.84, which is above the minimum required level of 0.7.

3.4.1. Variability Measures in the Legs

Analyses in this part were performed to reveal the behavior changes of athletes in each leg. *Figure 9* shows the average time spent by athletes in each leg. The means in the graph are not enough to generalize results due to the small sample size; however, the error bars on the means might lead us to gain an idea about the way athletes reacted to the difficulties involved with each leg.

It is very natural to expect that athletes' performance, so time-spent on a leg, to be more variable in a difficult leg than an easy one, because such legs require more time for planning and a high level of physical endurance.

From *Figure 9*, we can see that leg 4, 9, 14, and 17 are the highest valued means due to the length of their distance and the error bars of these legs are prominent in leg 14 and leg 17, indicating high variability among the athletes. On the other hand, leg 4 and 9 have an error bar at a moderate length.

After that, you can see that leg 1, 4, 5, 6, 7, 9, and 12 are similar in the length of error bars. Since leg distances are on a different scale, we could not directly interpret them. For example, leg 7 is one of the shortest distanced legs in the course, and it scored under average difficulty level, so having a quick completion time is under expectations, but even small-time differences may cause higher variability in such legs. In this case, the disproportion on the length of error bars to its distance is arising from the mistakes of *Subject 7* and a similar condition can be observed in leg 1 due to the errors of *Subject 6*. From the aforementioned legs above, scores of legs, except leg 1 and 7, are at average or above in all others. From the remaining legs, except leg 13, all of them have rates of average or below as difficulty.

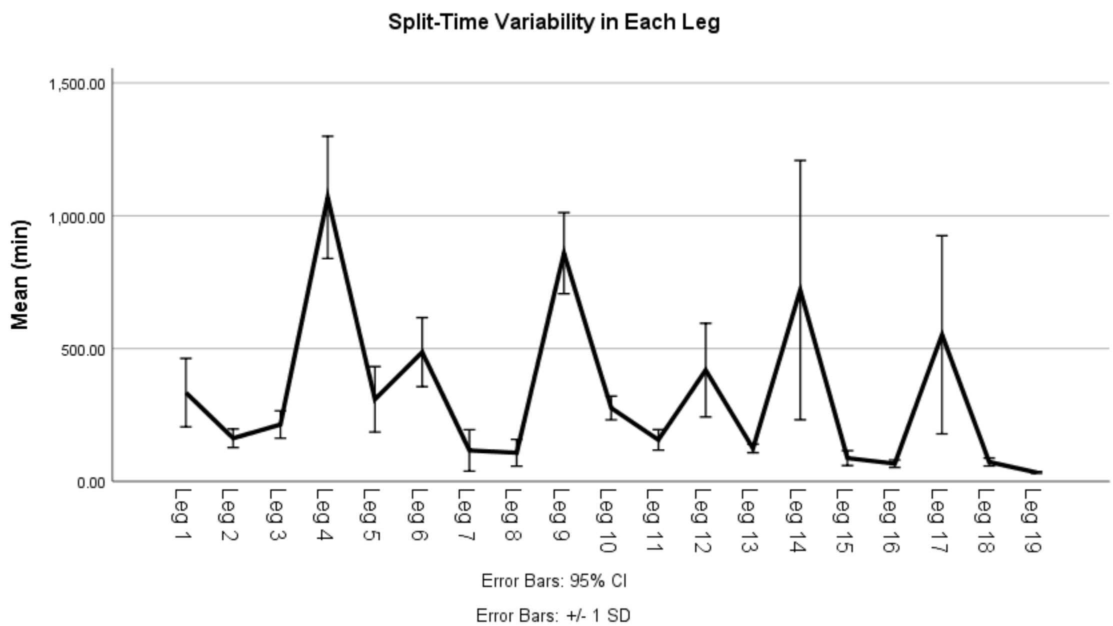

Figure 9. Average time spent on each leg with standard deviation error bars

Overall, *Figure 9* has shown, except for a few legs like leg 4, 9, and 13, leg difficulty scores are compatible with the behaviors of athletes. After this observation, the effect of distance on variability was tried to be eliminated by dividing split-times to bird eyes' distance of legs and *Figure 10* was obtained as a result. In this graph, similar to the above chart, commenting about short legs may not be proper due to sample size. However, we can make some comments about the source of time variability in the long legs.

As you can see, leg 4, 9, 14 have an average length in error bars, but the error bar of leg 17 has longer than others; nevertheless, all of them are not significant in their variability. So, we can say that the time variability of long distanced legs is much more dependent on the distance and the accumulation of performance differences of athletes.

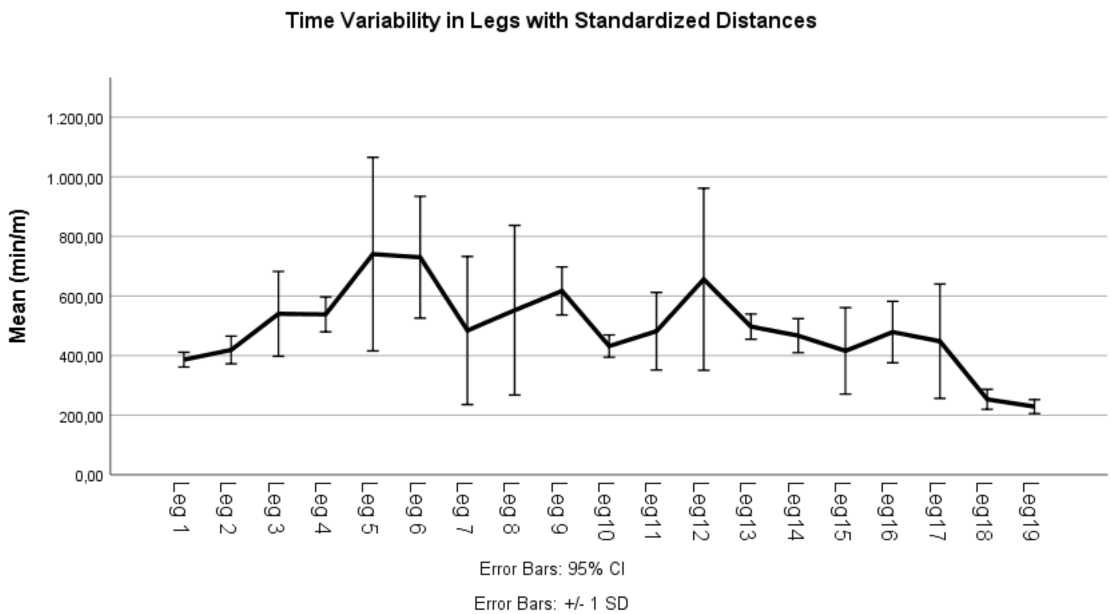

Figure 10. Standardized average time spent on each leg with standard deviation error bars

In the previous figures, a holistic overview related to leg performances was exhibited, but with *Figure 11,* the behaviors of subjects can be observed individually. For example, almost in all legs, the performance of *Subject 7* stay behind the others, but his mistake in leg 14 is the most remarkable one. Additionally, leg 1, 4, and 17 are the contributing legs to that condition. Since three of them out of four are long distanced legs, one can easily say that *Subject 7* is not good at in this kind of legs.

After *Subject 7's* performance, *Subject 6*'s performance is also different from others, but his distinctness is not apparent except for leg 12, and the reason for it was stated in the Qualitative Analysis for legs. Although the performances of other athletes do not overlap, they have very close performances in almost all legs, except that leg 4, 6, 9 and 17 and three of these four legs are long-distanced legs as stated before.

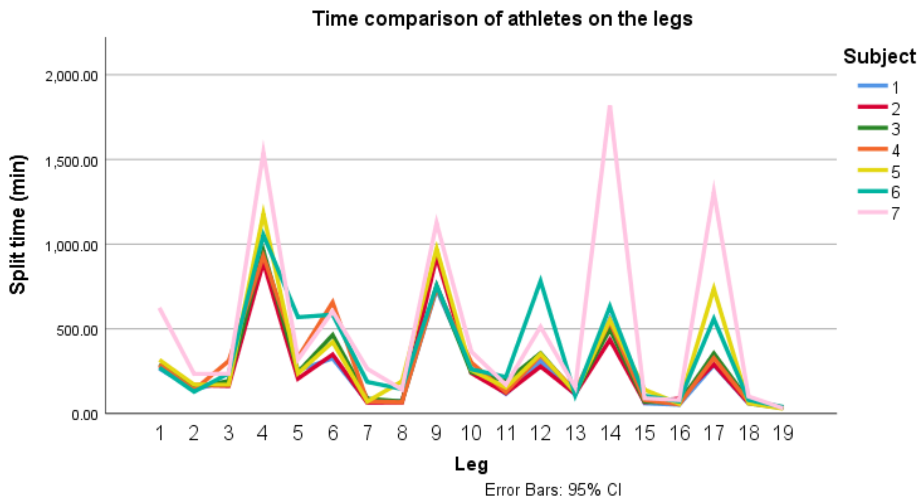

Figure 11. Time spent on each leg by the subjects

3.4.2. Monitoring Behavior Changes Near to Control Points

In the previous part, the behaviors of athletes have studied holistically and individually, but we can observe how challenging to go a CP and then to plan the steps of a CP by looking at before and after behaviors from a CP. Because these points are the most significant ones to observe the adaptation of athletes to new necessities of the next leg, like a direction change or a strategy. Moreover, the success of athletes to identify buffer zones can be understood by their speed changes because the increase in cognitive load decreases the speed of athletes.

By regarding these points, first, the speed changes of athletes at CPs were observed via the graphs in between *Appendix B.4.* and *Appendix B.10.* The speed of all athletes slowed down at these points because rules of this sport compel athletes to demonstrate such behavior, and preparation for new targets occur mostly around these points. Although there are many decision points along the legs due to attack points, the control point is the most prominent and indisputable decision point and observing the behaviors at these points reinforced our observations about the difficulty of legs.

First, the average speed of each athlete was calculated without exceeding 30 seconds before and after the CP and the speed at CP was takes as base point to make a comparison. We assumed that almost 30 seconds before a CP might inform about the visibility of CP or how easy to punch the CP. On the other hand, nearly 30 seconds after a CP might inform about athletes' preparedness for future actions, so whether they thought about any steps for the upcoming leg before punching the target.

When we look at *Figure 12,* the speed values at control points is the lowest one in almost all legs. Leg 4, 9, and 13 are the counterexamples because of overlapping speed amounts at three observation points. Then, we can observe varying dominance at average speeds before and after 30 seconds from the CP. While the speed values of pre-30 are higher than the values of post-30 in between leg 4 and leg 11, the situation is reversed afterward, and the values of post-30 have higher values for the next legs. Also, the instant decrease of the post-30 value in leg 19 is related to not having such a value because leg 19 is the finish.

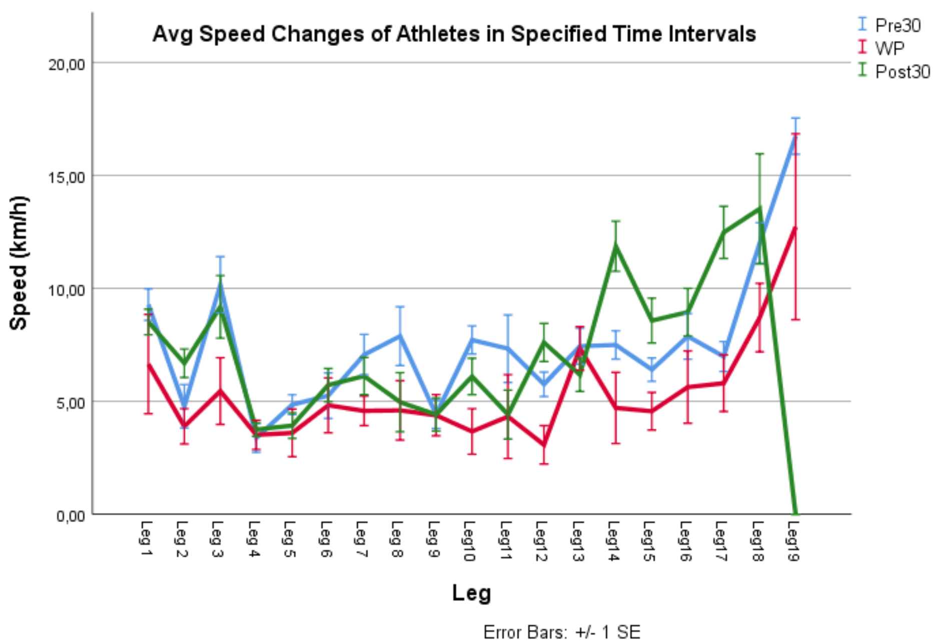

Figure 12. Average speed changes of athletes, 30 seconds before and after the CP and at the CP

When we look at some more details of *Figure 12*, average speed values at leg 4, 9, and 13 are equal. Although there can be many reasons to conclude like that, the things that come to my mind are: From leg 3 to leg 4 and leg 8 to leg 9 are long-distanced legs since athletes spent most of their time by dealing with the difficulties through the leg, there might not spare time to plan the next leg and the other common thing on these legs, they should climb after punching the CP. Thus, these two situations may have been effective in equalizing speeds. On the other hand, leg 13 has a different condition, the around of the target is surrounded by highly-dense vegetation so that getting rid of that environment was probably not possible in 30 seconds and having a long leg after the 13th leg may have contributed to the equalization.

In the last few legs, average post-30 speeds are faster than both average pre-30 speeds of corresponding leg number in post-30 and the overall average speed quantity in the graph. Although this kind of high averages speeds in post-30 can also be observed in the first legs, the speed values of these legs are lower than in the last legs, but they are more proportioned in terms of their pre and post speed values. The highness in first legs can be related to the adaptation to the course because athletes may not be aware that they are at the start of a long-distance course, and they may have had some difficulties to balance their power as can be seen from the variability in pre-30 speed fluctuations or the first legs might not have been difficult to reach. However, this condition had changed after the first long-distance leg, and close pre and post values had continued up to leg 13. After that, average post-30 speeds are getting better than previous post values, and this condition can be associated with the desire of athletes to improve their performance towards the end of the course and, most likely, the decline in elevation after 14th leg as seen from the figures in *section 3.5.2*.

3.5. The Stages of Model Building

The map information in an orienteering course constitutes the spatial part of the decision-making processes, and evaluating the given decisions apart from the spatial information is not possible. As stated by Malczewski (1999), geographical information and the preference of decision-makers are the main components in the spatial decision-making processes, and the decisions vary depending on the prioritization of the criteria based upon preferences of decision-makers and outcomes of the decisions.

In the geographic information system, data are stored in two types as raster and vector. Vector data is out of scope in this context because the vector data model is preferred for socioeconomic applications, on the other hand, the raster data model is preferred in environmental applications (Malczewski, 1999). As you can see the *Figure 13*, raster data is stored in the pixels/cells, which are the smallest unit, and each pixel has a value to represent information such as temperature, vegetation, and their data types can be positive/negative integer or floating-point.

After the information above, you can find the steps being followed to bring the current spatial data to a similar environment where athletes run and then modeling approach are as follows:

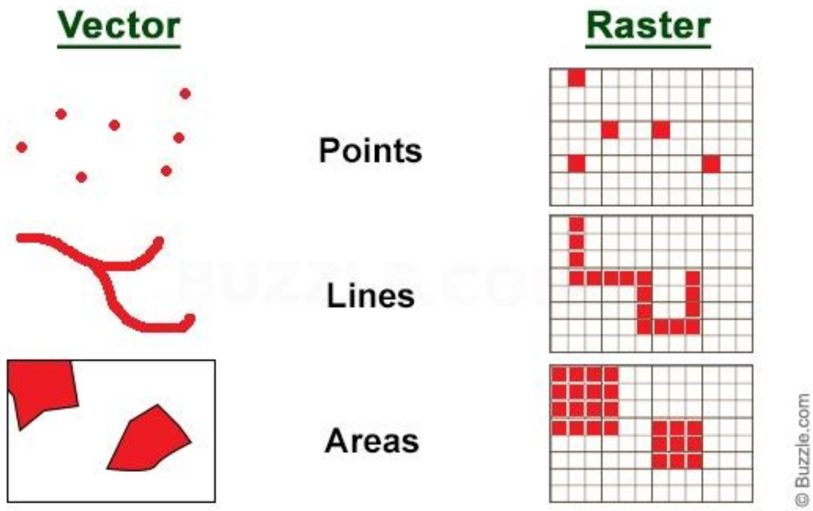

Figure 13. Raster and vector data representations (Joseph, 2012)

1) Convert digital map representation of Niksar to processable format (vector → raster)
    a. Export landform features to shapefiles in the OCAD
    b. Import area and line features to ArcGIS
    c. Convert line and area features to raster data
2) Transfer raster data to Excel as matrices
3) Reclassify raster data on the scale of five
4) Bring matrices into a suitable format to be processable as graphs
    a. Convert matrices to adjacency matrices
5) Run the shortest path algorithm, so the Dijkstra Algorithm

The general structure is indicated above, but some details should be added to fill the gaps in the process flow. As stated in *Step 1*, the digital map representation of Niksar was not suitable to be processed in its current format so that, at first, the landform features in the map should be converted to raster data in the ArcGIS. So, landform features were exported according to types of features in the OCAD because the format of shapefile, which is one of the suitable forms to be processed by ArcGIS, can be exported in this way.

From these three types of area, line and point features on the map, area and line features were added to ArcGIS, but point features, on the other hand, were not exported because they occupy a small area, so their impact on the model output is insignificant. Upon the completion of *Step 1* and *2*, geographic information came to the appropriate format.

The second component, preferences of deciders, in the spatial decision-making process starts in the following step, *Step 3,* and this step requires developing approaches to how athletes behave in a spatial arrangement. Luckily, this problem was solved by the information in *Table 1*. This table illustrates the limits of speed and runnability level upon the terrain features. As shown in the table, a scale of five was created and the symbols of vegetation features were matched accordingly (see *Appendix B.11*).

Step 4 includes the set-ups to run the algorithm. The critical thing in this step is the reconstruction of cost matrices to adjacency matrices. In the adjacency matrix, while the cost of visiting a neighboring cell is equal to the cost of the neighbor value cell, the cost of visiting the cross cells was calculated by multiplying the cost by 1.4. Thus, the shortest path algorithm works according to the parameters of the distance and ground surface.

3.5.1. Results of Shortest Path Algorithm

In this section, the results of the Dijkstra algorithm, which is one of the pathfinding algorithms, and their compatibility with the reality were interpreted. Before starting to examine them, I would like to express why the Dijkstra algorithm was used in the calculations. Because it gives the shortest paths by allowing movements in all directions as long as not encountering an obstacle and also allowing weight assignment. Drawbacks of this algorithm can be stated as a high number of iterations and the inability to use negative weights, but the matrices we worked on were not too big so that not using A* would not be considered as a problem. Regarding the issue of negative weights, there is no negatively weighted grid in the matrices.

Table 4. Comparison of the routes of the shortest path algorithm with the real performances

Legs	Route Comparison
Leg 1	The entry point of the model to the terrain stays on the upper side of where target located but in reality, athletes need a more apparent reference point to approach the target
Leg 2	Similar route but athletes did not prefer the path around the target
Leg 3	Similar but athletes avoid sharp turns as much as possible and they prefer the smooth orientation
Leg 4	The first parts are similar after that, route choices differentiate a lot
Leg 5	Similar route
Leg 6	The parts requiring to move on the path are similar, but since elevation change is not a variable in the model, these parts in the terrain are skipped naturally so that a route is drawn by neglecting this change
Leg 7	The approaching point to the target is different
Leg 8	Similar route
Leg 9	The paths in the terrain may not be significant all the time and easy to find/see so that the recommendation of the shortest route is not preferable in this respect, but remaining parts that include the path following is consistent with the behaviors of some athletes

Table 4. Continued

Leg 10	Even if the route from the model is not compatible with the preference of most athletes, the expert's view and *Subject 6'* choice is towards it
Leg 11	The only difference is the entry point to the target
Leg 12	None of the athletes selected it, but first parts are the same with expert' recommendation, then the route differentiates
Leg 13	Similar route
Leg 14	There are three alternative routes in this leg as a result of athletes' choice, but none of them is overlapping with the outcome of the model. However, as the expert stated that those who prefer the route above stayed away a lot from the pink line and the model' route is like a representation of this recommendation
Leg 15	Similar route
Leg 16	Similar route
Leg 17	The route from the model is too dependent on the path, and it causes unnecessary awayness from the pink line. On the other hand, in reality, athletes had benefited from other significant and closer features like stream
Leg 18	As in the model' route, going directly and turning 90 degrees is not preferable in reality, but for this target, this can be neglected

Table 4 offers a comparison of athletes' behaviors and the paths from the model. As indicated in the table, most routes are similar to the route in the model except long routes. However, there are some distinctions between the model and athletes' behavior in short legs, especially when approaching targets. As seen in *Appendix B.15.*, the route from start to leg 1 represents such a situation. The real route and the route from the shortest path algorithm are differentiated towards the end because of the necessity of relying on a reference point of humans or animals.

In the long distances, routes are quite different, as you can see from *Appendix B.17.* The legs from 14 to 18 also involve the shortest paths, and these routes are close to each other, but the remaining areas where the gap of two routes increases represent one of the long-distance legs, and the same thing can be observed on the leg 13 to 14.

There are many reasons for such differentiation in long legs. For example, the primary consideration of the model is finding the least costly routes in a short distance, on the other hand, human beings make their selections by thinking about the reduction of cognitive loads, so their choices are in a direction to provide this relaxation.

Besides, having no elevation change information in the model foster this differentiation in long distances. Even if elevation change is not in our model, we could say that in the routes having not much reliance on elevation change, terrain features and distance are proper parameters to predict route selection of athletes if the reference issue can be ignored for now.

After these qualitative observations, you can see the terrain costs of subjects and optimal paths from *Table 5*. These cost values were calculated by taking the sum of the grid costs where the routes are going through so that, in the long routes, terrain cost values are higher than other legs. In a few data points, you can see the values that are lower than optimal value because the grid size (cell size of raster size) of terrain features and the data points coming from GPS receivers are not in equal proportion (see *Appendix B.18.*) and in the course of placing of these subjects' data on terrain surface matrices in Excel, there can be some minor deviations due to the remarking of GPS points manually.

Table 5. Terrain costs of subjects and shortest path algorithm according to cost allocation

	S1	S2	S3	S4	S5	S6	S7	Optimal
Leg 1	106	112	104	120	99	100	108	100
Leg 2	52	61	54	53	49	61	54	48
Leg 3	63	60	66	116	62	64	68	54
Leg 4	334	332	314	339	398	341	356	273
Leg 5	65	66	69	84	64	116	73	62
Leg 6	121	110	118	164	123	142	127	89
Leg 7	23	23	20	24	24	28	37	20
Leg 8	34	36	32	34	68	60	40	33
Leg 9	232	250	248	271	264	211	250	184
Leg 10	99	99	85	108	101	91	112	84
Leg 11	49	52	49	47	60	50	50	44
Leg 12	106	103	103	113	106	201	105	84
Leg 13	39	37	40	41	45	47	42	36
Leg 14	229	202	186	211	197	190	331	190
Leg 15	36	34	34	32	46	41	34	32
Leg 16	26	28	24	24	24	24	26	24
Leg 17	166	152	162	162	226	193	189	128
Leg 18	44	44	44	44	44	44	48	43

Figure 14 summarizes the cost of each athlete's total path in reference to the baseline cost of 1528 units derived from the shortest path algorithm. Overall the deviation of the higher-performing athletes was smaller as compared to others.

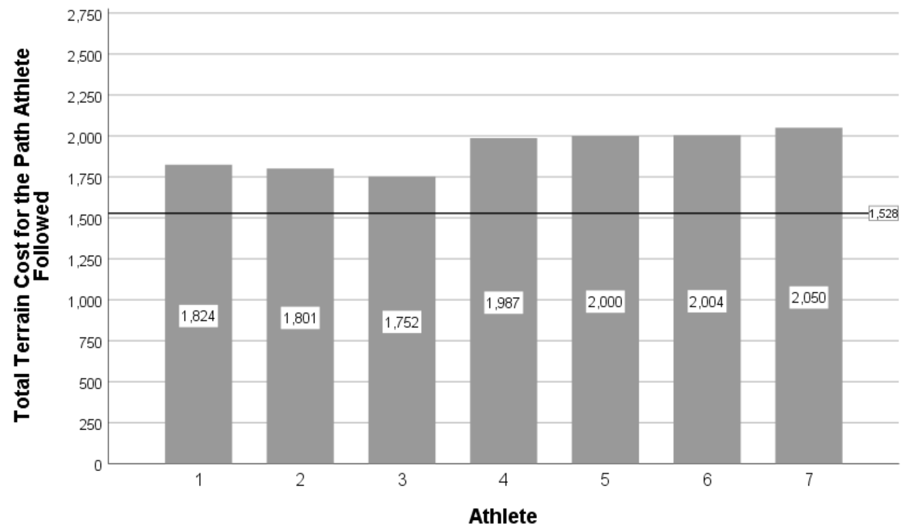

Figure 14. Total terrain cost of athletes relative to the total cost of the optimum path

From *Figure 15,* you can see clearly how terrain costs are distributed through the legs and which subjects stay out of the range of boxplots. With a closer look, those who consist of the outlier points are usually the ones except for the top three performance holders because as mentioned in the qualitative analysis these participants elongated their distance due to their route preferences or mistakes, and at some points, their physical endurance should probably be not sufficient to compensate for their mistakes by accelerating.

The only exceptional case is in leg 9 because, in all legs, outlier data points are having higher values than the limits of boxplots. From the split time of this leg, we can see that the performance of *Subject 6* is one of the best, but there is not significantly different than the other good ones. In a way, other athletes made a sacrifice from the terrain cost by optimizing the other parameters.

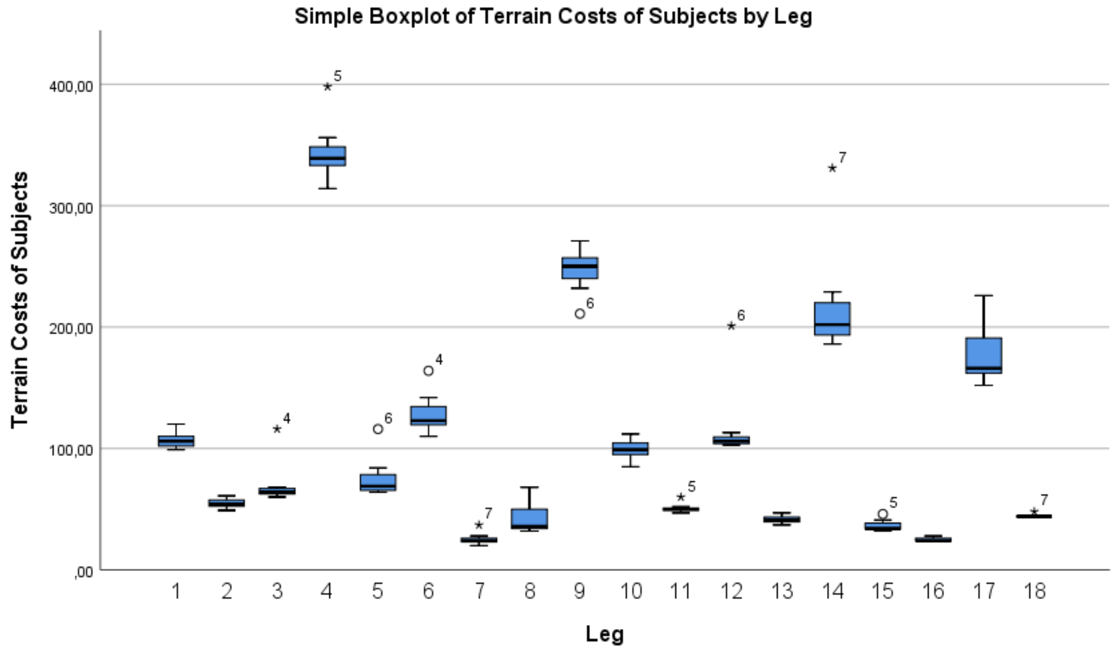

Figure 15. Terrain costs of subjects depending on the routes chosen

Figure 16 shows the cost differences observed at each leg for all athletes together. The athletes deviated from the optimal path predicted by SPA the most at legs 4, 6, 9, 12, 14 and 17.

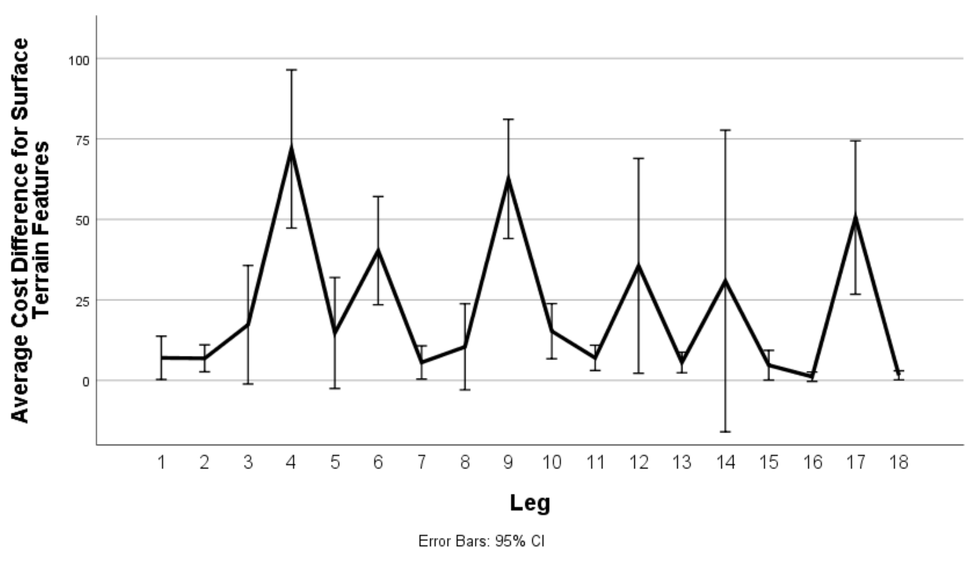

Figure 16. Average cost difference for surface terrain features in legs

Figure 17 shows the deviation between the SPA and each individual athlete across all the legs. Athletes who were in the lower ranks tended to deviate the most from the optimal path predicted by SPA (e.g. athletes 5-7 at leg 4, 4-6 at leg 6, 4-5-7 at leg 9, 6 at leg 12, 7-6 at leg 14 and 5-6-7 at leg 17).

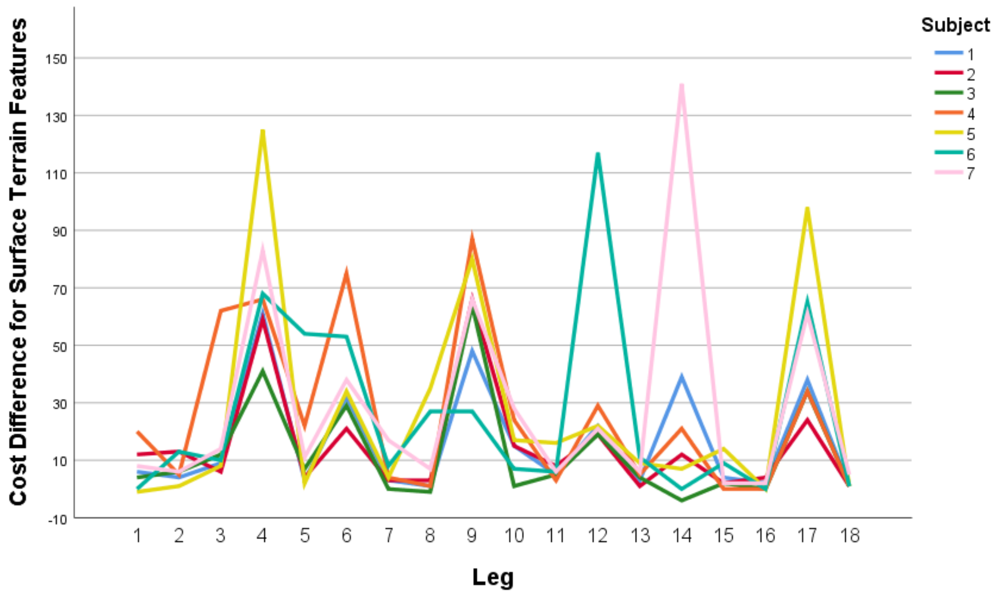

Figure 17. The deviation amounts of athletes in legs

Even if terrain costs can provide valuable information to a certain degree, they can be scarce in terms of having no information about how far apart is the optimal routes and the chosen routes, so the figure below was drawn with the hope of filling this gap.

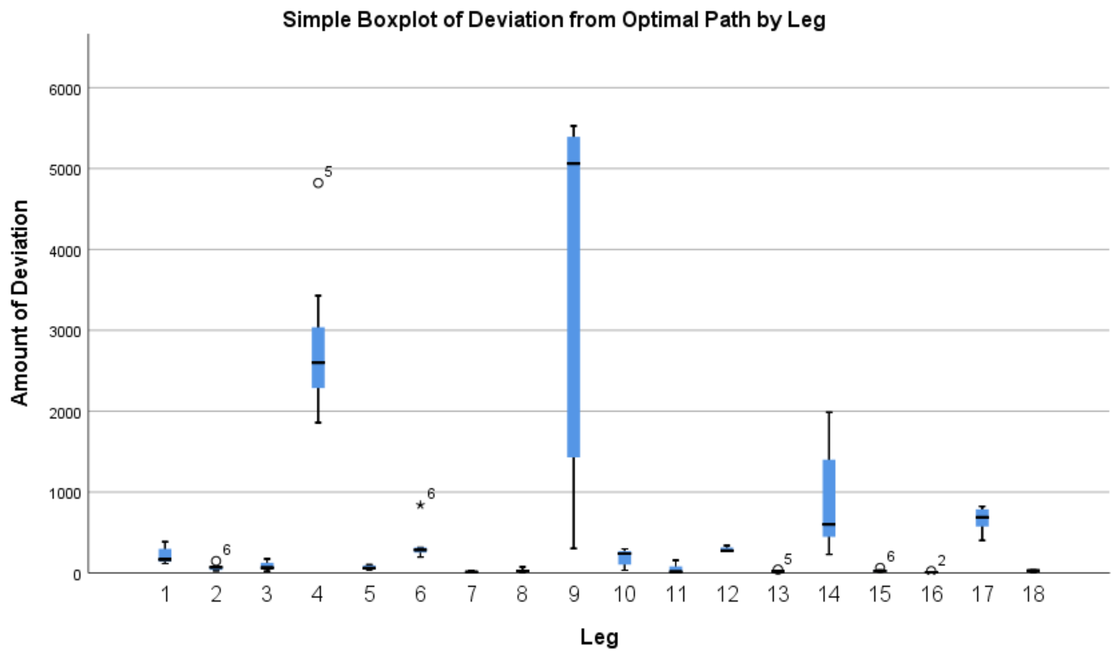

Figure 18. The amount of deviation of subjects from optimal routes

From *Figure 18*, you can see that most of the deviations are on long legs. This is highly probable because the deviation amount may not be helpful on the routes with more options like long-distance legs. In the other legs, deviation amounts seem minor, but high deviation amounts on long legs might be masking of our assessment, so, in these legs, sticking to a case by case observation as in *Table 4* can give us a more meaningful evaluation.

Before giving a complete analysis of the topics discussed so far, let's look at the speed values of athletes. *Figure 19* represents the average speed of athletes on the course. The speed of athletes usually decreases as the ranking of subjects increases.

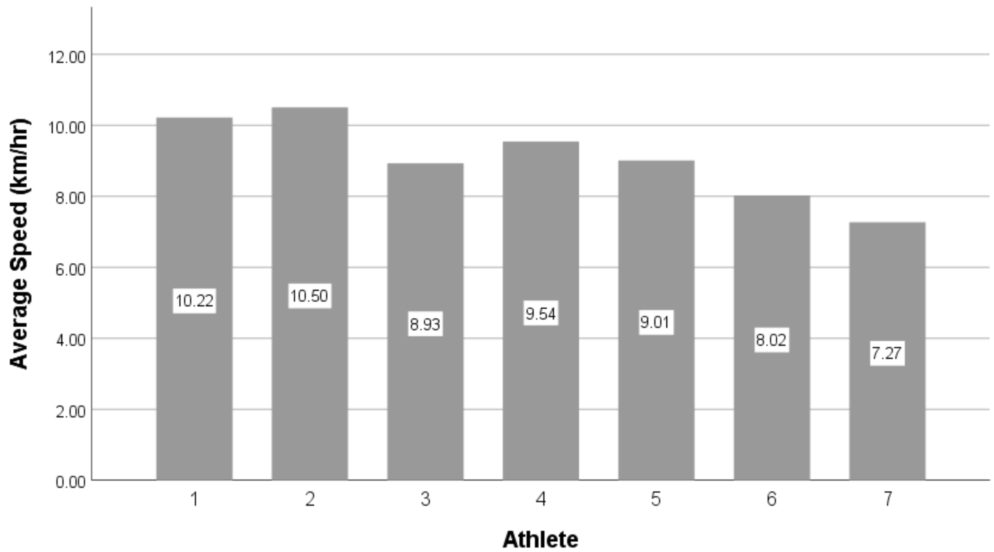

Figure 19. Average speed of athletes during the course

Table 6 shows how subjects' performance overall according to the paths by SPA. The terrain cost difference of the first three ranked athletes is lower than the others, and the same thing is valid for the total distance covered by them. On the other hand, deviation amounts present a completely different picture. *Subject 6* is the least deviation one, but his disadvantaged situation in other variables like terrain cost or distance cause to fall far behind most athletes. Besides, we know from the qualitative analyses that Subject 6's tendency to make route selections without considering elevation a lot, and you can see it detailed in the next section that covers the elevation.

In terms of distance and the cost differences, Subject 3 seems the candidate for being the top performer, until looking at his deviation amount. His awayness from the optimal route might be one the reason to take in third place, and another metric, his speed (*Figure 19*), might cause to happen this end.

In the end, the values of the highest-ranked one were investigated, he is not the best in all indicators, but it seems that he knows how to stay in reasonable limits in all of them, which led him to the top among others.

Table 6. Summary Table of subjects' performances to the optimal path in the legs

Subjects	Completion Time (hr)	Distance (km)	Total Optimal Terrain Cost	Total Terrain Cost of Subjects	Cost Difference (Subj-Opt)	Deviation from Optimal Path
1	01:20:35	13.30	1528	1824	296	8732
2	01:20:47	13.50	1528	1801	273	7044
3	01:27:22	12.89	1528	1752	224	9692
4	01:32:37	14.01	1528	1987	459	9991
5	01:43:14	15.25	1528	2000	472	12735
6	01:53:05	14.32	1528	2004	476	5875
7	02:41:59	16.12	1528	2050	522	11442

3.5.2. Elevation

Elevation is another key physical constraint contributing to the decisions made by the athletes, as described in the qualitative analysis section. Based on the route taken by each athlete, the average elevation and the elevation change that occurred during the corresponding leg were computed.

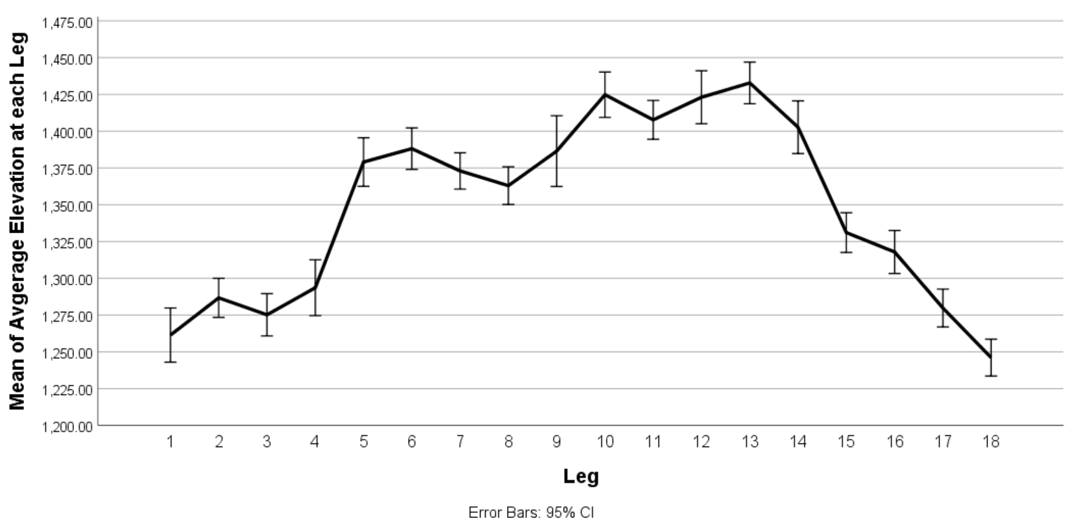

Figure 20. Average altitude and exposed elevation change and during the course

Figure 20 shows the mean elevation for the paths taken by the athletes during each leg. The steep increase following the 4th leg and the decrease following the 14th leg highlights the uphill and downhill stages of the overall circuit.

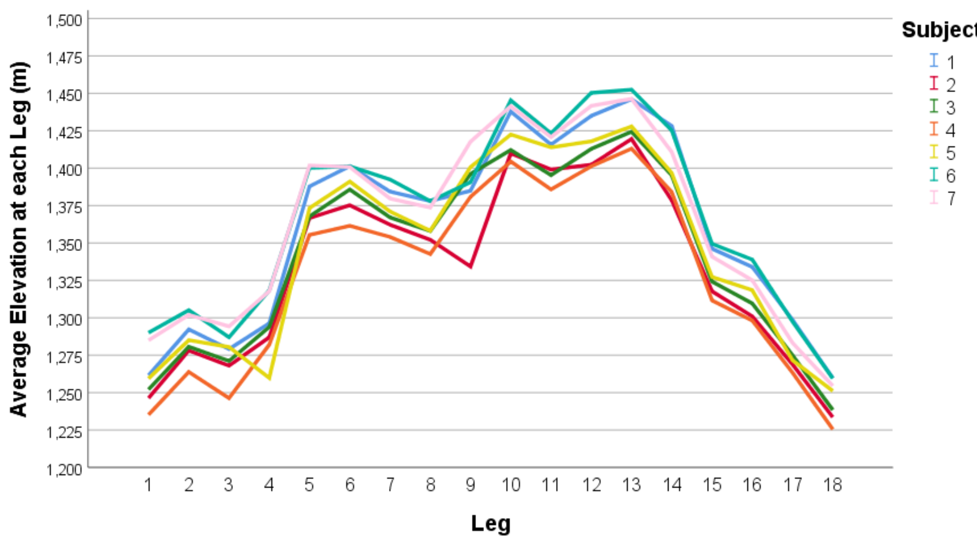

Figure 21. Average elevation taken by each athlete

Figure 21 shows the mean elevation observed at each leg for each individual athlete. In most of the legs, the average elevation taken by athletes has a similar pattern, and intervals between elevations extend in parallel. However, around leg 8 and leg 9, parallelism among elevation lines has disrupted because of too much decline in the elevation of *Subjects 2* and *4*, and then they had to climb more than others.

Figure 22 shows the average speed of athletes on the legs, and this figure has a positive correlation with the elevation change. For example, after the 4th leg where elevation inclines, the average speed of athletes starts to decrease, and average speed is below the speed at first four legs up to leg 15, which is the first leg after elevation decline.

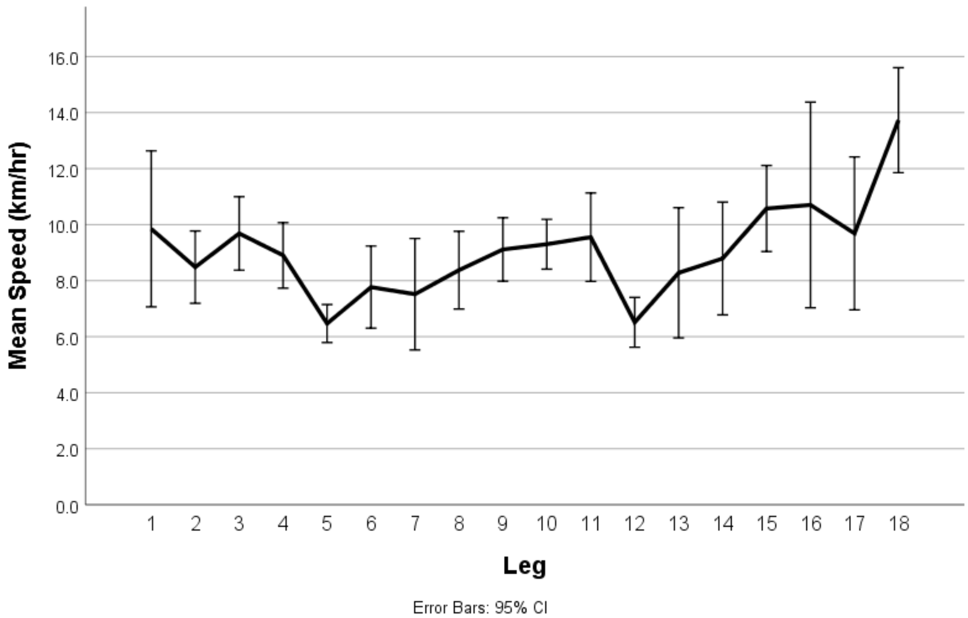

Figure 22. Average speed of athletes on the legs

The variability of athletes' speed during the course can be observed in *Figure 23*. Despite the constant changes in the speeds, some athletes' speed is more visible than others. For example, the speed values of *Subject 6* are very unstable; the average speed of *Subject 7* is lower than others except for leg 16, and *Subject 2* elevated his speed from a relatively low amount to almost peak after leg 12.

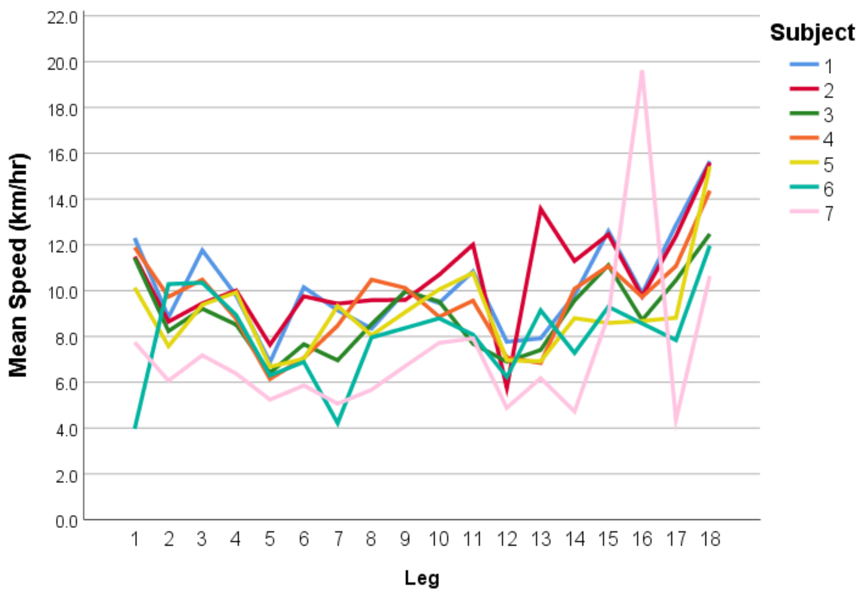

Figure 23. Speed changes of athletes on the legs

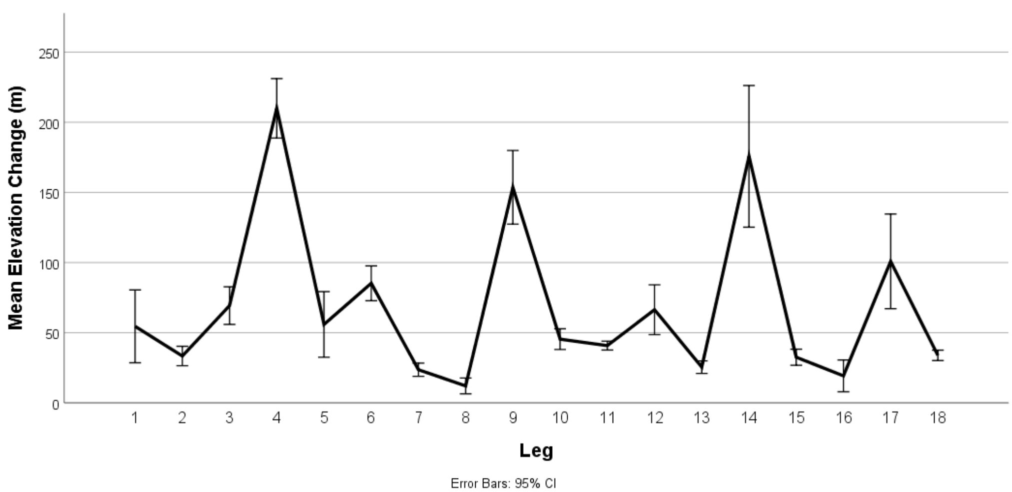

Figure 24. Average elevation change according to the route chosen

The elevation change associated with the path taken by the athletes were also computed for each leg. *Figure 24* shows the mean elevation change experienced by each athlete at each leg based on their route choices. Legs 4, 9, and 14 stand out among the other legs where the elevation change is the highest.

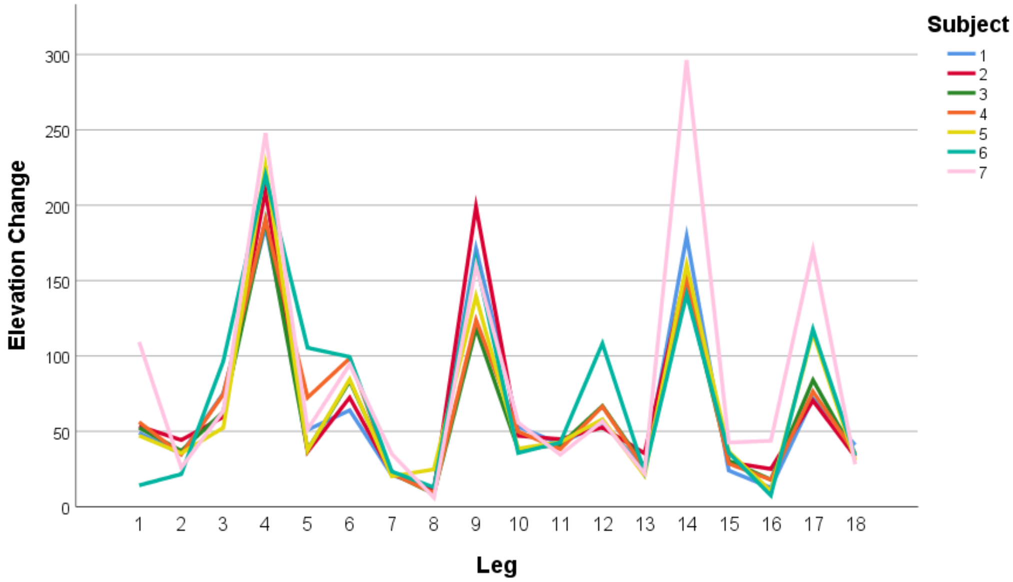

Figure 25. Elevation change of each athlete according to the route chosen

Figure 25 shows the elevation change observed for each athlete during each leg. *Subject 7* can be classified as the athlete who made the highest elevation changes and *Subject 6* is the follower after *Subject 7*. Leg 9 is the only exception where someone with the most climbs out of *Subject 6* or *7*.

3.6. Regression Model

A multiple regression analysis of the aforementioned variables was carried out in an effort to explore those factors that most significantly contributed to the total circuit completion time. *Table 7* below shows the Pearson correlation coefficients observed among all variables considered for the regression model. With the exception of average elevation, all variables have a medium-to-high correlation with the main outcome variable time.

Table 7. Pearson correlation coefficients among environment-related variables

	Time	Average Elevation	Elevation Change	Distance	Terrain Cost Subject	Cost Difference	Speed
Time	—						
Average Elevation	0.07	—					
Elevation Change	0.93 ***	-0.01	—				
Distance	0.93 ***	-0.03	0.92 ***	—			
Terrain Cost Subject	0.92 ***	-0.02	0.90 ***	0.98 ***	—		
Cost Difference	0.85 ***	0.04	0.77 ***	0.82 ***	0.82 ***	—	
Speed	-0.31 ***	-0.44 ***	-0.12	-0.08	-0.12	-0.21 *	—

* $p < .05$, ** $p < .01$, *** $p < .001$

The regression model, including all possible predictors, accounted for 95% of the total variability in time. The ANOVA test suggested that this model is a significantly better fit as compared to the baseline model, $F(6, 119)=383.66$, $p<.001$. The regression coefficients are listed in *Table 8* below.

Table 8. Coefficients of the regression model

						Collinearity Statistics	
Model	**Unstandardized**	**Standard Error**	**Standardized**	**t**	**p**	**Tolerance**	**VIF**
(Intercept)	345.711	176.542		1.958	0.053		
Average Elevation	-0.080	0.119	-0.015	-0.670	0.504	0.798	1.253
Elevation Change	2.832	0.352	0.507	8.045	< .001	0.104	9.584
Distance	0.228	0.053	0.485	4.335	< .001	0.033	30.277
Terrain Cost Subject	-0.882	0.405	-0.237	-2.179	0.031	0.035	28.525
Cost Difference	2.546	0.434	0.219	5.863	< .001	0.297	3.366
Speed	-25.674	3.172	-0.194	-8.094	< .001	0.724	1.381

The regression results suggest that Elevation Change, $t(119)=8.05$, $p<.001$, Distance, $t(119)=4.34$, $p<.001$, Terrain Cost, $t(119)=-2.18$, $p<.05$, Cost Difference, $t(119)=5.86$, $p<.001$ and Speed, $t(119)=-8.09$, $p<.001$ are significant predictors. Average elevation did not turn out to be a significant predictor, $t(119)=-0.67$, $p>.05$.

However, high variance inflation scores and small tolerance values for Distance and Terrain Cost variables suggest that there are multicollinearity issues in the data set, possibly masking the real impact of some of the variables. This is due to the strong correlations among the predictors distance, elevation change, terrain cost and cost difference, which are likely to bring multicollinearity issues for the regression model. *Table 9* below shows that distance and terrain cost, and the elevation change and terrain cost load together on the same dimension.

Table 9. Collinearity analysis among predictors

Collinearity Diagnostics

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions: intercept	Average Elevation	Elevation Change	Distance	Terrain Cost Subject	Cost Difference	Speed
	1	5.854	1.000	0.000	0.000	0.001	0.000	0.000	0.004	0.001
	2	0.912	2.534	0.000	0.000	0.003	0.001	0.001	0.044	0.012
	3	0.150	6.252	0.000	0.000	0.051	0.008	0.006	0.798	0.000
	4	0.048	10.988	0.003	0.007	0.049	0.008	0.000	0.034	0.613
	5	0.027	14.668	0.000	0.001	0.892	0.083	0.111	0.118	0.080
	6	0.008	27.074	0.000	0.001	0.003	0.898	0.878	0.002	0.033
	7	7.808e -4	86.585	0.995	0.991	0.000	0.001	0.003	0.000	0.261

The cost of the terrain traveled by the athlete naturally increases with the distance since the total cost is additively computed for each cell in the path. The correlation slightly decreases when the cost is subtracted from the path computed by the shortest path algorithm. Moreover, increasing the distance also increases the likelihood of elevation change due to the mountainous region where the race was organized. Due to such dependencies violating the independence assumption of linear regression, distance and terrain cost for the subject's path were not included in the final model.

A multiple regression model where the Time was the outcome and Average Elevation, Mean Elevation Change, Cost Difference and Speed were the predictors accounted for 94% of the variability in Time. The ANOVA test suggested that the regression model was significantly better than the baseline model based on mean Time, $F(4, 125)=485.48$, $p<.001$. The regression coefficients are summarized in *Table 10* below.

Table 10. Coefficients of the regression model

						Collinearity Statistics	
Model	**Unstandardized**	**Standard Error**	**Standardized**	**t**	**p**	**Tolerance**	**VIF**
(Intercept)	317.612	190.647		1.666	0.098		
Average Elevation	-0.083	0.129	-0.016	-0.643	0.521	0.799	1.251
Elevation Change	3.880	0.192	0.694	20.193	< .001	0.410	2.439
Cost Difference	3.305	0.407	0.284	8.125	< .001	0.396	2.522
Speed	-22.376	3.349	-0.169	-6.682	< .001	0.761	1.315

The regression results suggest that Elevation Change, $t(120)=20.19$, $p<.001$, Cost Difference, $t(120)=8.13$, $p<.001$ and Speed, $t(120)=-6.68$, $p<.001$ are significant predictors. Average elevation did not turn out to be a significant predictor, $t(120)=-0.63$, $p>.05$.

However, when the collinearity diagnostics table in *Table 10* is investigated, elevation change and cost difference were found to load on the same dimension, which is an important sign of multicollinearity and is due to the high degree of linear relationship among the two predictors.

Since the terrain cost captures aspects of elevation change as well, and it constitutes the main elements of the cost model developed as part of this thesis, a second regression model including only the Cost Difference and Speed as predictors were considered. Speed is included in the model as it could potentially explain part of the variability in Time due to the athletes' differences in terms of their stamina. This model accounted for 74% of the variability in Time. The ANOVA test suggested that the regression model was significantly better than the baseline model based on mean Time, $F(2, 123)=177.64$, $p<.001$. The regression coefficients are summarized in *Table 11* below.

Table 11. Coefficients of the regression model

						Collinearity Statistics	
Model	**Unstandardized**	**Standard Error**	**Standardized**	**t**	**p**	**Tolerance**	**VIF**
(Intercept)	287.801	61.959		4.645	< .001		
Cost Difference	9.590	0.545	0.825	17.588	< .001	0.951	1.051
Speed	-16.996	6.219	-0.128	-2.733	0.007	0.951	1.051

The regression results suggest that Cost Difference, $t(120)=17.59$, $p<.001$ and Speed, $t(120)=-2.73$, $p<.01$ are significant predictors. There are no signs on multicollinearity as both variables load on distinct dimensions, as indicated in *Table 12* below.

Table 12. Collinearity diagnostics table of performance predictors

				Variance Proportions		
Model	**Dimension**	**Eigenvalue**	**Condition Index**	**Intercept**	**Cost Difference**	**Speed**
	1	2.428	1.000	0.009	0.060	0.010
	2	0.541	2.118	0.009	0.830	0.020
	3	0.032	8.770	0.981	0.109	0.970

The regression model suggests that one standard deviation increase in cost corresponds to a 0.83 standard deviation of increase in Time. Similarly, a standard deviation increase in speed corresponds to a 0.13 standard deviation decrease in Time.

CHAPTER 4

DISCUSSION AND CONCLUSION

Along with the research conducted in this study, the dependency on terrain features in athletes' route selections has been clarified a little more. The analyses during the research were designed to answer the research questions. In the first study, the purpose of qualitative analysis was to investigate how athletes coping with this complex task and which strategies applied by them to provide calibration between two different representations: map and environment. As a consequence of this analysis, we noticed that in the first parts of the race, athletes spent some of their time with adaptation to terrain in addition to the reaching targets and those who are not successful in this made mistakes at first control as can be seen from Boga (1997)'s classification. After that, we acquired the difference in thinking and setting a strategy in legs with different distances. For example, in the long distances, the choices of athletes were separated more than one route, in the other types of legs, attack points, sub-goals, were different most of the time. Lastly, we understood that the increase in psychological pressure on athletes while approaching the last legs caused them to make more mistakes.

The second study aimed to complete some missing parts that did not exist in qualitative analysis and support the qualitative analysis with the illustrations. From these graphs, we observed that there was more variability in time in long-distance legs, and the differences in average speeds could inform us about the strategies that we mentioned *Figure 1* applied by athletes and similar to qualitative analysis, the speed changes can be handled in three sections as the first/last few legs and other legs out of these two. Besides, we concluded that leg distances and the areas that require climbing and are surrounded by high-dense vegetation have in negative correlation with the average speeds. Athletes' speeds before or after control points decrease in case of encountering one of the situations mentioned, but the reasons under these speed reductions are different. While area related boundaries compel bodily limitations; on the other hand, the increase of leg distances requires more time for planning; in other words, it needs more mental computation as we mentioned previously in research questions.

Up to this point, strategy related parts in the first and second research questions have been answered with these two studies, but we have not mentioned which parameters can be used to model and obtain similar paths in reality. When we reviewed all the collected information, the variables coming with spatial data is the most plausible ones for starting the modeling. The things outside of spatial information involve individual differences such as navigational or mental rotation abilities, or some physical arrangements to adjust the orientation, and including them to the model did not seem possible for us. In the end, we ran one of the pathfinding algorithms by taking terrain surface cost, which was obtained via the runnability measures, and distance as parameters. Then, we acquired the shortest paths according to our cost allocation, but we could not manage to add elevation change for the reasons to be mentioned soon.

When we look at the outputs of the shortest path algorithm, they are very similar in short or middle distance legs, but quite different in long-distance legs. The differences in route selection of athletes become apparent at these legs if you look at the choices in the whole course. We indicated two possible reasons causing this differentiation: no inclusion of elevation changes to the model and athletes' need for a reduction in cognitive load. While the effect of the elevation change on the outcomes is explicit, a further explanation is needed for the cognitive load part. As mentioned in qualitative analysis, long-distance takes time and spending this time by planning other routes and without any additional fatigue in mind is really important in terms of preserving strength in the remaining parts of the course.

Now, we should talk a little bit about the weaknesses of our model because there are many crucial points to be considered to develop this model. For example, reference points of athletes, calibration time to adapt the representation of map and environment, situatedness, could be subjects of the models in future studies. Also, the scores given to landform features may have different values on different legs. For example, if there are many similar features during the leg, athletes may aim to reach significant features in this leg.

Moreover, one of the missing parameters in the model is the elevation, so that model fails to reflect the areas having many elevation changes. At the first stage, the spatial analyst tool of the ArcGIS program was considered as suitable to process spatial information on the Niksar map. However, there have been some difficulties arising from the quality of spatial data and the model constructed on ArcGIS. First, the forests are represented with white color, but since the mapper drew all the features on a white-colored base layer, these points were perceived by the program as empty. So, the models constructed with this base resulted in the paths formed by going around the empty data fields. Moreover, in cases where the source and destination point located in these areas, the model gave an error in the middle of the processing time on each attempt.

Furthermore, one of the tools in the program does not work as expected. In our case, line and area features were transferred as separate layers, and these were reunited after the reclassification made. However, the output layer did not result as we supposed because this tool overlooked some data points because of the inappropriateness cell size of this layer. Also, the costs of the two features were added in overlapping regions of line and area features. On the contrary, in these areas, we wanted to see the cost of line features as the united layer' cost and area cost should not be added.

Despite the many missing points of ArcGIS, this program is advantageous in terms of responding to the expectations of multiple criteria of decision-makers. For instance, if we have DEM data in our hands, we could take advantage of this property with the condition of knowing the weight of this variable (elevation) in the decision.

Apart from these general observations about the program and outcomes of the model, we made some analytical assessments by using terrain surface costs, deviations from the optimum routes. According to terrain surface costs, the costs of long-distance routes were higher than the shortest ones, and the cost difference between shortest paths and the real ones were higher as expected, but we only could reach limited information by evaluating these costs. As you might remember from the qualitative analyses, the awayness from the pink line was mentioned a lot by supposing that these differentiations would elongate the distance, and this would reflect on the performance badly. Similar to this point of view, we calculated the deviation amounts from the shortest paths. In the end, we figured out that the athlete who had the smallest values in terrain cost, distance, or deviation was not the winner of the course. On the contrary, the one who had the balance of all variables, in word words, made the optimization better had obtained the best time.

Also, we have obtained new parameters like terrain costs and cost difference to be used in the regression model other than distance and speed. After that, the parameter that is the most mentioned in the analyses but not in the model, elevation, were analyzed and its positive correlation with the speed was demonstrated with the graphs.

In the regression model, six predictors were involved at first. First, the correlations of these predictors with time were presented, and two regression models involving different parameters were run before reaching the final result because the multicollinearity issue among terrain surface costs, distance, and elevation change prevented the independence assumption. From the remaining three predictors out of six, it was concluded average elevation was not significant, so speed and cost difference was the most suitable candidates to predict the time. Even if their assumption power was not high as the previously conducted regression models, we concluded that they are the most reasonable estimators.

After these long-lasting statement of final analyses, it is useful to indicate to what extent we managed to answer the last research question. In embodied cognition, there are several assumptions concerning the interaction of the mind with the body and the functionality of the body, which is not as a sensory input but also as a constraint shaping our thoughts. Our observations are not focusing on that side of these paradigms since we made analyses by using bodily constraints like speed. However, from the analyses, you might gain some insight into the similarity of "*body as regulator*" (Wilson et al., 2017). According to this view, cognition is dependent on time and space and constant updates are required to provide the adaptation to the environment. Throughout the course, athletes try to overcome the struggles exposed by the environment by changing their direction or calculating their map reading ability towards the upcoming conditions, or taking precautions to the possibility of getting lost. Even if we try to relate all of them as inputs coming from the sensory, fatigue level accumulating in the body over time affects our thinking and causes us to make mistakes or to live some hesitation moments. Hence, while the constraints occurring our body has control in our thinking, how the impact of embodied cognition in this sport can be ignored.

Starting to speak about the constraints is a good point to open the topic of bounded rationality. As proper to Simon's point of view, route selections are a combination of what we have already known and what the environment forces us to which actions.

From the body perspective, expertise in using a compass, map reading level, and physical capacity shapes our decisions. So, we could not say that someone who does not use the compass properly can determine whether s/he is on the right stream out of many similar ones or we do not expect the same route choices to be followed by an expert and a novice. Thus, this is why we stress there is no optimal route, maybe except for elite athletes, and everyone performs in their own limitations. Besides, the condition of the environment, such as the type of surface ground or vegetation density, shapes the given decisions. You can imagine this by thinking of what would be your speed limits on a running track or a marsh. So, denying the importance of body and environment interaction is not possible for me depending on the assertions above.

After the embodied cognition paradigm and Simon's bounded rationality validations, our expectation from the results of the pathfinding algorithm was to answer whether orienteers take advantage of fast and frugal heuristics in route selection. Our approach in the model is very similar to the perspective of optimization under constraints because we behaved as if all costs and benefits are already known. From the results mentioned above, we can conclude that our little model is good support for explaining how athletes gave near-optimal decisions in such a dynamic and uncertain environment. Except for the situated cognition, we explained all the stated paradigms in the last research question and the explanation of why we could not mention from this paradigm is in the next section. About the factors affecting decision making, the regression model put the final point to this issue. As you can see from the regression analysis, one of the predictors of time is related to the body and the other comes from the environment. So, you can think about the relation of these paradigms with the sport of orienteering one more time by looking at the regression models in addition to the path results.

4.1. Suggestions for Further Studies

To model such a complex phenomenon in just a few experimental paradigms is not possible of course, but refining these problems as testable variables in behavioral studies and modeling of these studies with more complex tools may be proposed for further research in this area.

The least-cost path model in the ArcGIS Spatial Analyst Tool can be used with a proper spatial data set to observe the effect of elevation change along with terrain features in route selections so that more precise observations can be done how deciders' choices related to fast and frugal heuristics.

This study can be enriched by placing eye-tracking glasses or head-mounted cameras to athletes during the course. In this way, athletes' strategies such as the time interval between looking at map and environment or how much time spent while looking at a map can be monitored, and it can be questioned whether these times are an indicator of being a novice or experienced in this sport. Apart from that, in the last research question, the relation of orienteering with situated cognition can be explained with the help of recordings showing the calibration of the environment with the map or direction settings moments, etc.

As we mentioned before, orienteering requires many cognitive abilities together with physical capacity. There are many interesting research areas related to more abstract concepts like attention, divided attention, short term memory, long term memory, planning, etc.

The research methods in the literature have some strong and weak sides in investigating this complex phenomenon. We mentioned the drawbacks of each of them previously.

The modeling approach may overcome some of those problems by hypothetically manipulating some real behavioral variables to a considerable extent. Of course, this requires more sophisticated modeling tools than we used here. For instance, hardly observable mental processes like the transformation of two-dimensional information in maps to three-dimensional information and behavior in a real race can be modeled with more complex modeling approaches. The memory part of the problem is also interesting. Athletes should read the map correctly in short term memory, hold this information in a relatively long period and hence use long term memory as well as short term memory or at least episodic memory. And apparently experienced athletes have the chance to learn all these racing factors more than novices and hence they develop different decision-making strategies by accumulating the learning experience.

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APPENDICES

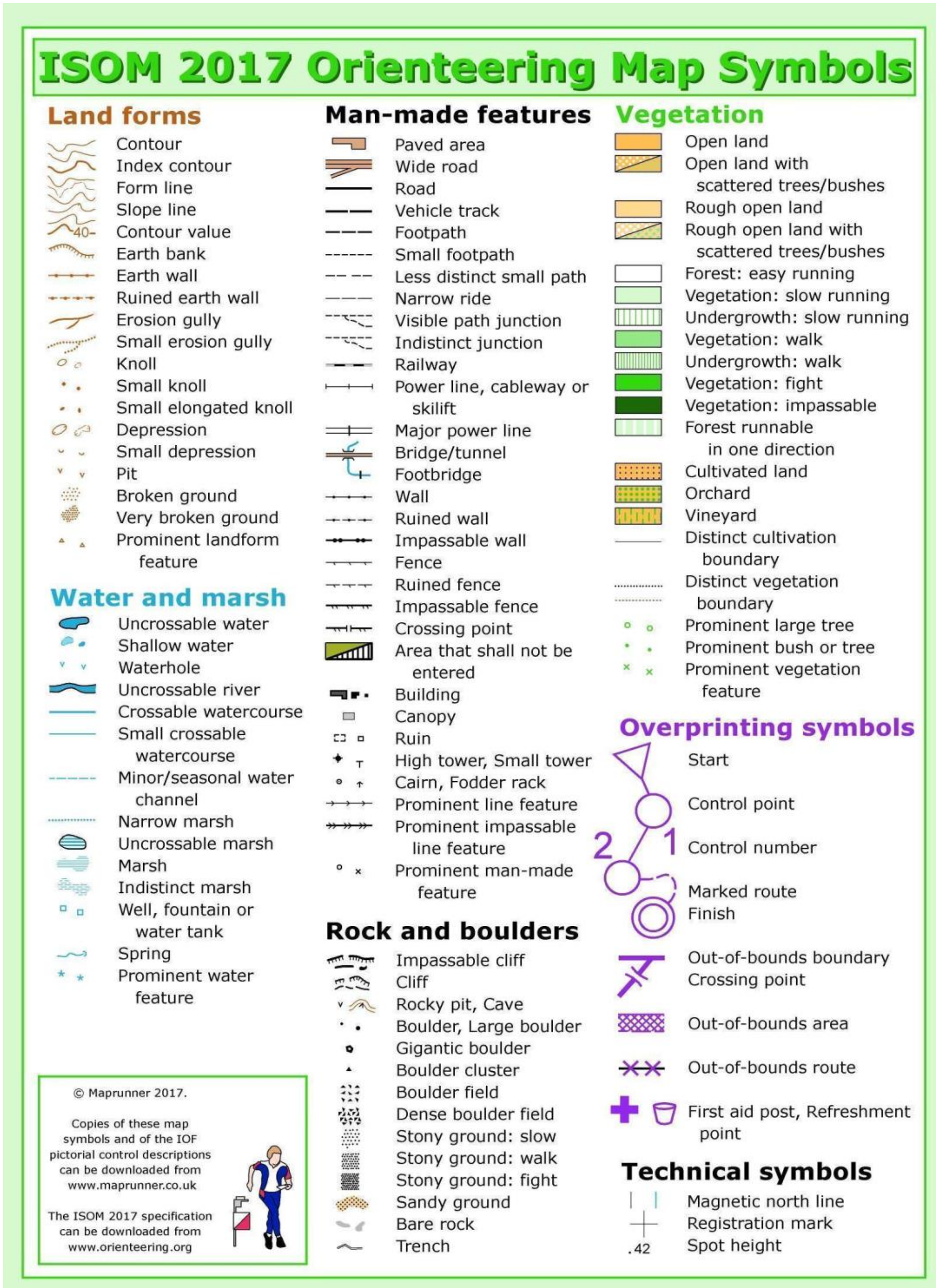
APPENDIX A

Appendix A.1. An example of how SportIDENT Card placed into SportIDENT Station

Appendix A.2. Compass

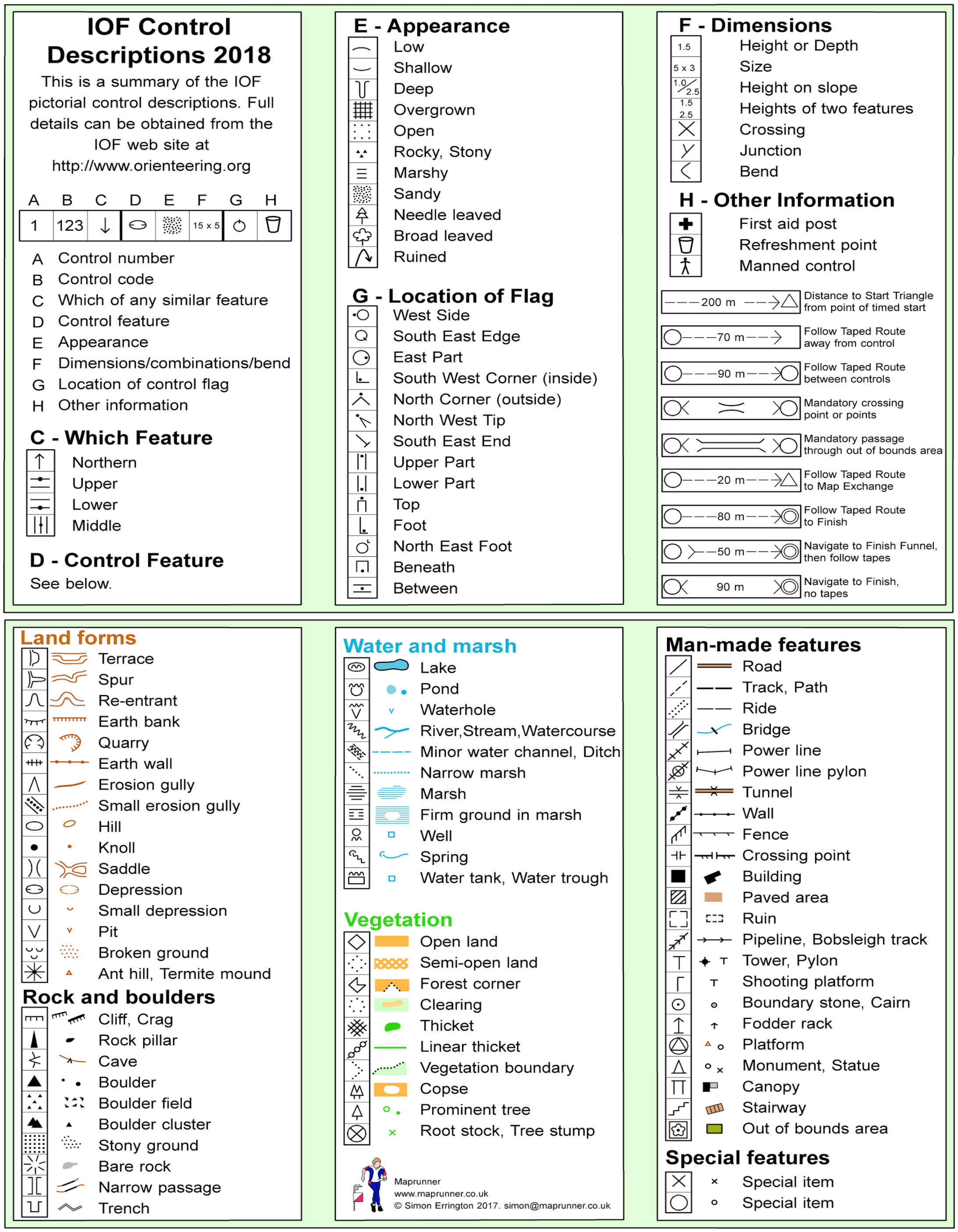
Appendix A.3. A sample for a flag at control point

Appendix A.4. Orienteering Legend prepared by ISOM in 2017

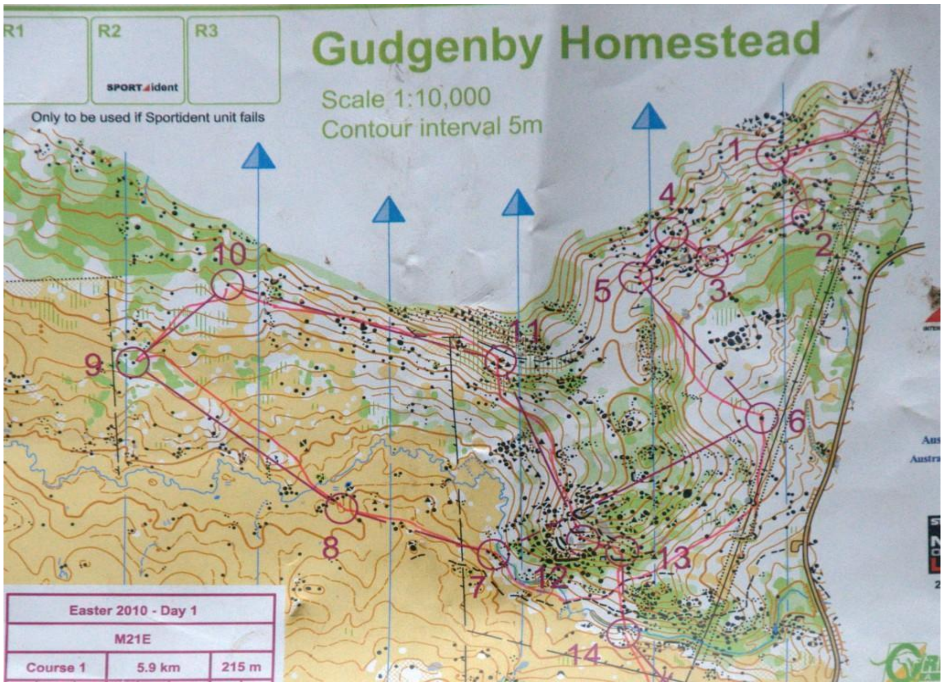


Appendix A.5. Sprint Orienteering Legend prepared by ISOM in 2017

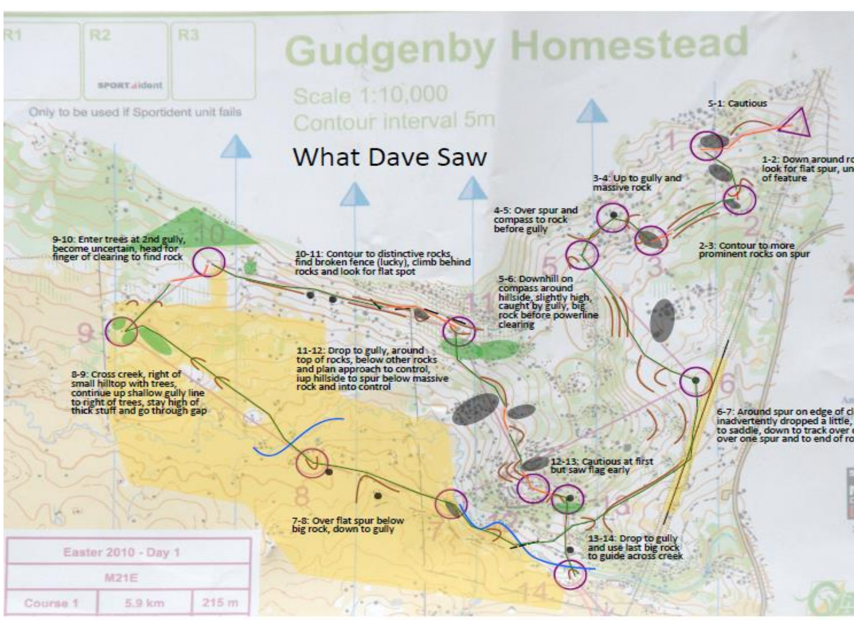
Appendix A.6. Symbology of Control Descriptions



Appendix A.7. Terrain map sample with the route drawings



Appendix A.8. An example of how an orienteer see the map after simplification



APPENDIX B

Appendix B.1. Cumulative times of participants in each leg

	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Subject 6	Subject 7
Leg 1	04:25	04:42	04:52	04:48	05:17	04:31	10:24
Leg 2	06:48	07:30	07:27	07:07	08:08	06:40	14:18
Leg 3	09:59	10:13	10:39	12:18	10:58	10:37	18:13
Leg 4	25:21	25:06	26:42	27:49	30:37	28:12	43:54
Leg 5	29:36	28:32	30:47	33:21	34:34	37:41	49:13
Leg 6	35:02	34:21	38:31	44:18	41:37	47:25	59:16
Leg 7	36:12	35:25	39:59	45:30	42:48	50:32	01:03:40
Leg 8	37:26	36:30	41:11	46:37	45:58	52:57	01:06:02
Leg 9	49:39	51:56	53:47	59:00	01:02:12	01:05:32	01:24:48
Leg 10	54:06	55:55	57:50	01:04:02	01:06:28	01:09:53	01:30:54
Leg 11	56:02	57:55	01:01:03	01:06:09	01:09:01	01.13:29	01:33:44
Leg 12	01:01:12	01:02:33	01:06:59	01:11:52	01:14:53	01:26:31	01:42:16
Leg 13	01:03:03	01:04:29	01:09:02	01:14:07	01:16:57	01:28:18	01:44:50
Leg 14	01:12:23	01:11:45	01:17:20	01:23:09	01:26:10	01:38:50	02:15:08
Leg 15	01:13:24	01:12:52	01:18:30	01:24:29	01:28:31	01:40:35	02:16:38
Leg 16	01:14:16	01:14:21	01:19:33	01:25:23	01:29:29	01:41:47	02:17:58
Leg 17	01:19:03	01:19:11	01:25:28	01:30:51	01:41:45	01:51:06	02.39:47
Leg 18	01:20:03	01:20:13	01:26:46	01:32:01	01:42:45	01:52:26	02:41:28
Leg 19	01:20:35	01:20:47	01:27:22	01:32:37	01:43:14	01:53:05	02:41:59

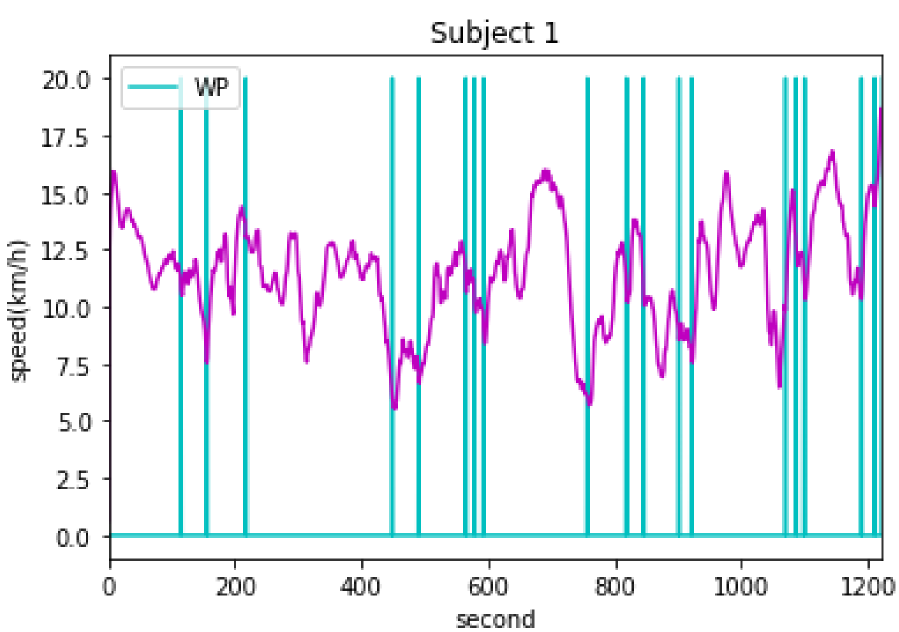
Appendix B.2. The rater's scores on the difficulty of legs

Leg Numbers	Expert_Scores	Inter_Rater_Scores
Leg1	3	2
Leg2	2	3
Leg3	3	3
Leg4	7	6
Leg5	5	5
Leg6	4	4
Leg7	2	3
Leg8	3	4
Leg9	7	7
Leg10	4	3
Leg11	3	1
Leg12	5	4
Leg13	6	5
Leg14	6	7
Leg15	2	2
Leg16	3	2
Leg17	5	6
Leg18	2	1
Finish	NA	NA

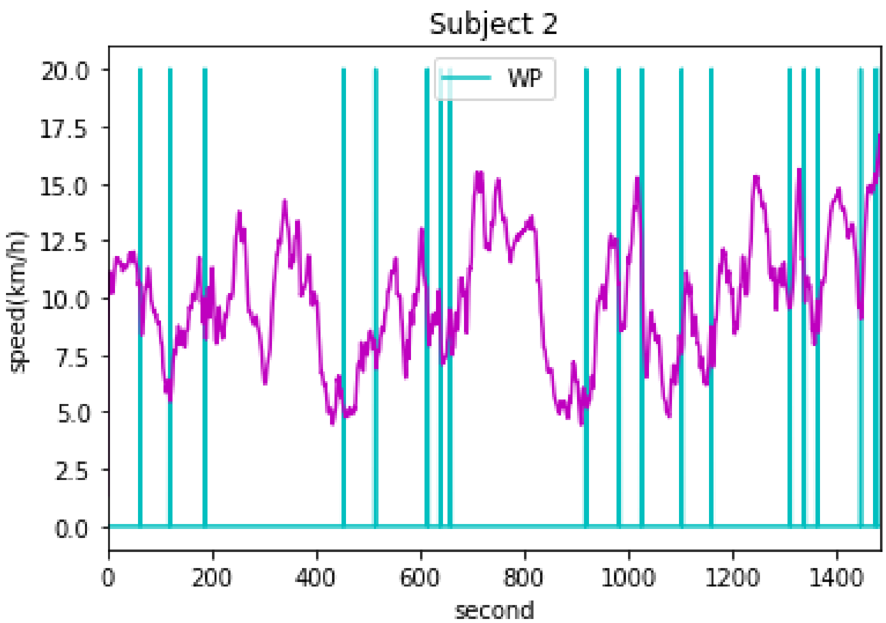
Appendix B.3. Inter-rater reliability test result on leg difficulty

```
Krippendorff's Alpha Reliability Estimate

             Alpha    LL95%CI    UL95%CI      Units   Observrs      Pairs
Ordinal      ,8379      ,7490      ,9119    18,0000     2,0000    18,0000

Probability (q) of failure to achieve an alpha of at least alphamin:
   alphamin          q
      ,9000      ,9459
      ,8000      ,1775
      ,7000      ,0024
      ,6700      ,0006
      ,6000      ,0000
      ,5000      ,0000

Number of bootstrap samples:
  10000
```

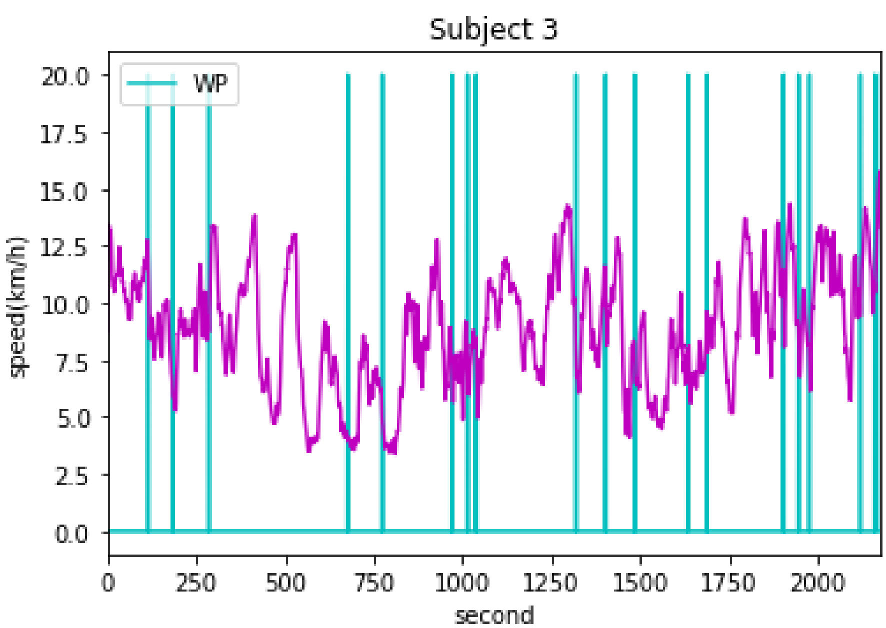
Appendix B.4. Speed changes of Subject 1 in CPs



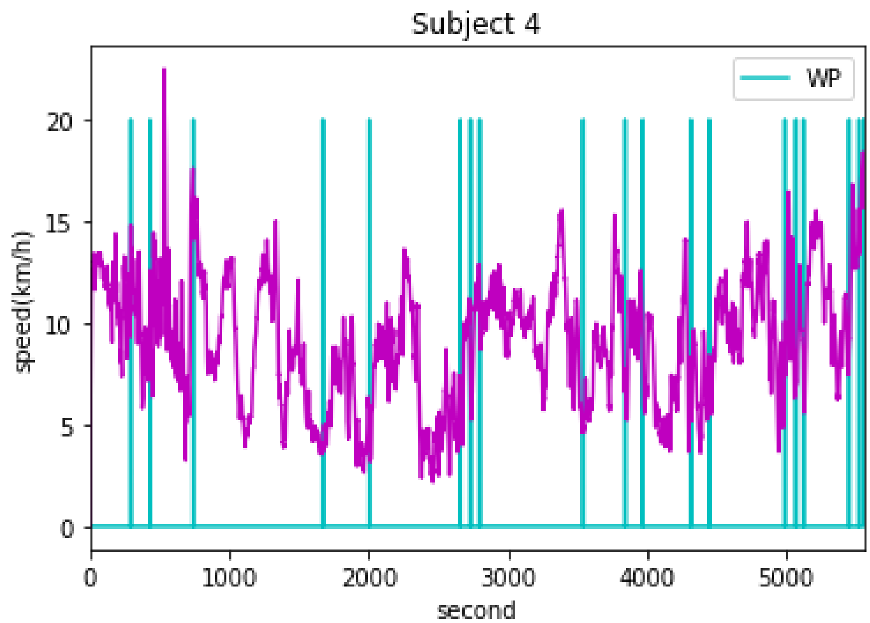
Appendix B.5. Speed changes of Subject 2 in CPs



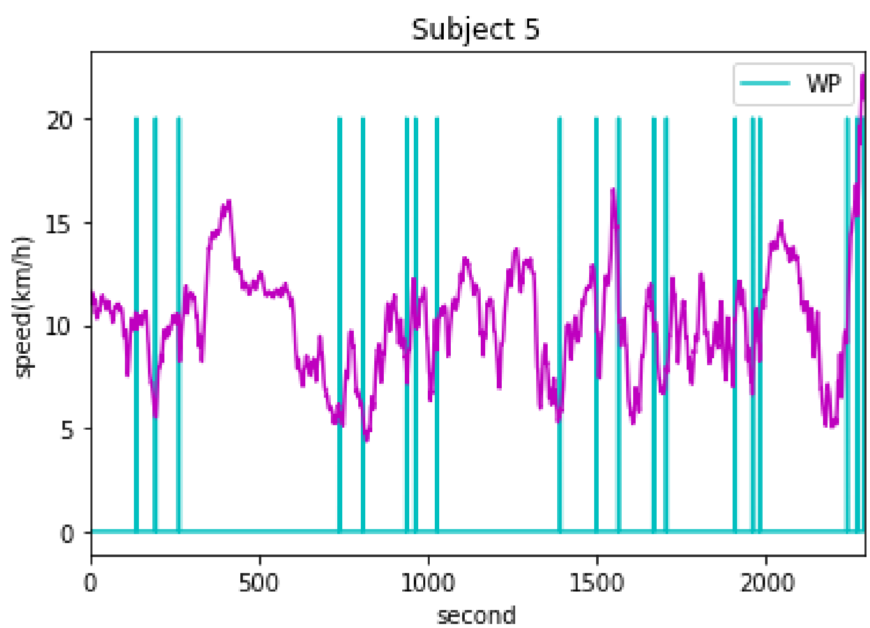
Appendix B.6. Speed changes of Subject 3 in CPs



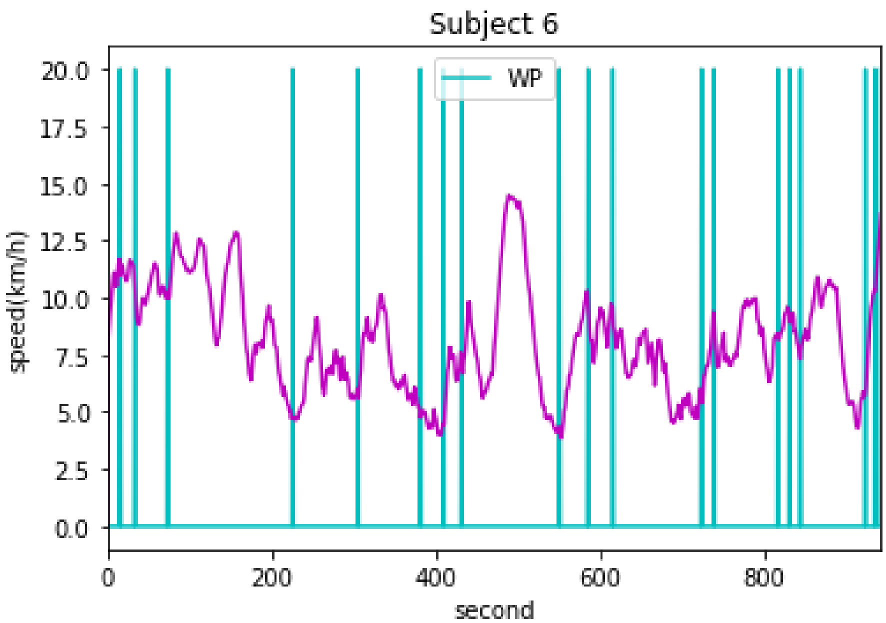
Appendix B.7. Speed changes of Subject 4 in CPs



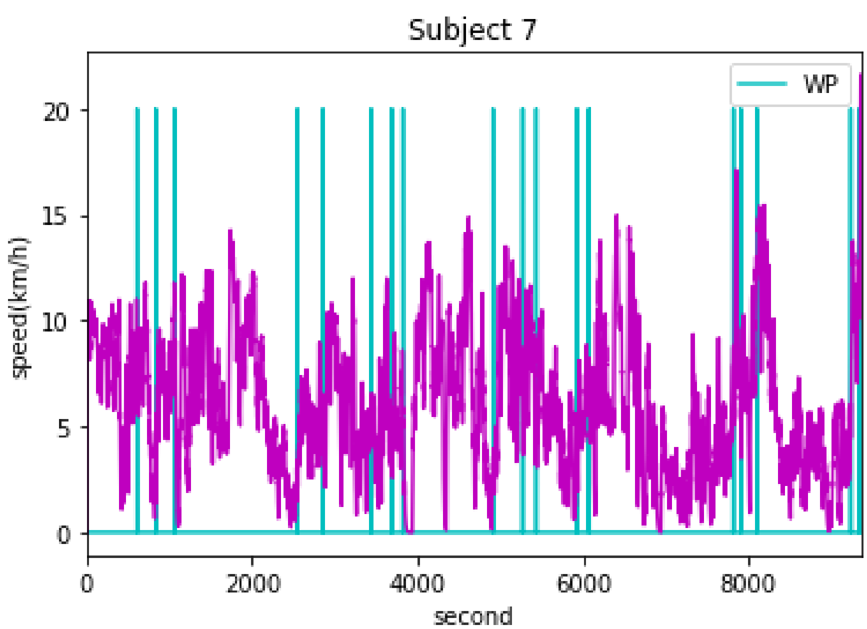
Appendix B.8. Speed changes of Subject 5 in CPs



Appendix B.9. Speed changes of Subject 6 in CPs



Appendix B.10. Speed changes of Subject 7 in CPs



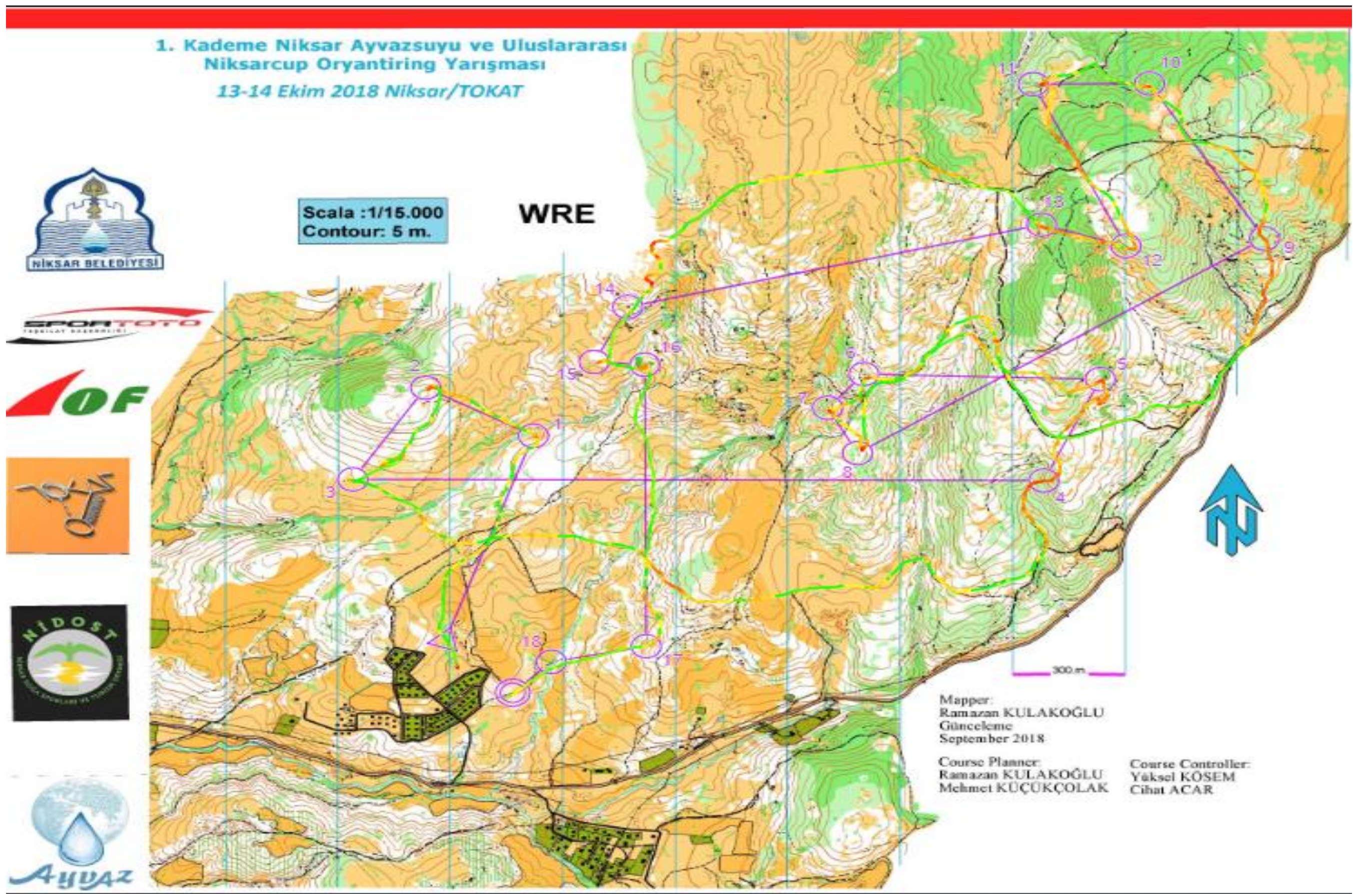
Appendix B.11. Assigned values to landforms features in legs

Type	Symbol	Definition	Value
Area Features	212	Bare Rock	3
	401	Open Land	2
	402	Open land with scattered trees	2
	403	Rough open land	2
	404	Rough open land with scattered trees	2
	405	Forest	2
	406	Vegetation: slow running	3
	407	Undergrowth slow running	3
	408	Forest: difficult to run	3
	409	Undergrowth difficult to run	3
	410	Vegetation: fight	4
	201	Impassable cliff	5
	306	Crossable small waterhouse	2
	307	Minor water channel	2
	308	Narrow marsh	2
Line Features	414	Distinct cultivation boundary	2
	503	Minor road	1
	504	Road	1
	505	Vehicle track	1
	506	Footpath	1
	507	Small footpath	1
	508	Less distinct small path	1
	508,001	Path	1
	524	High fence	5

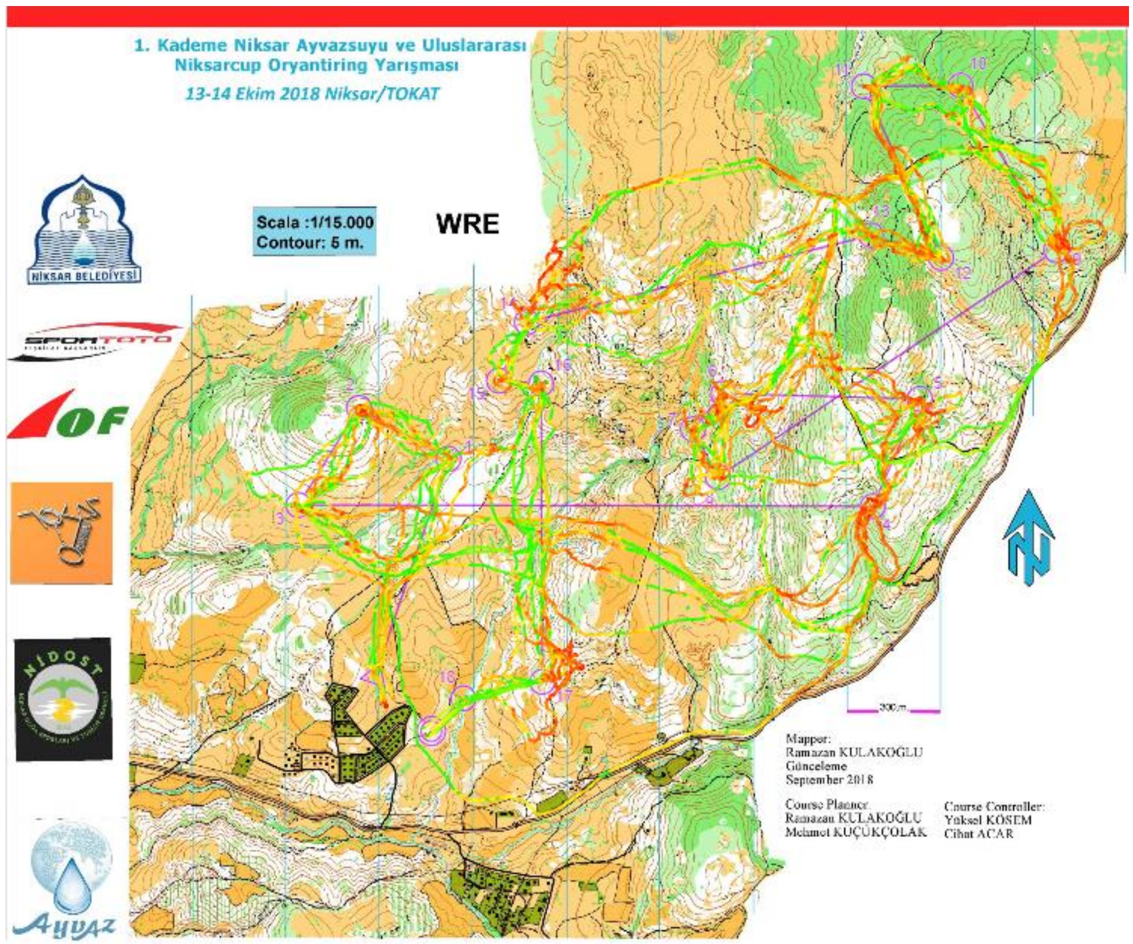
Appendix B.12. Leg-feature matrix to represent which values are in which legs

Symbol	Definition	S-Leg1	Leg1-2-3	Leg3-4	Leg4-5-6-7-8	Leg8-9	Leg9-10	Leg10-11	Leg11-12-13	Leg13-14	Leg14-15-16-17-18
212	Bare Rock			x							x
401	Open Land	x		x	x	x	x			x	x
402	Open land with scattered trees	x	x	x	x	x	x		x	x	x
403	Rough open land	x	x	x	x	x	x	x	x	x	x
404	Rough open land with scattered trees	x	x	x	x	x	x		x	x	x
405	Forest	x	x	x	x	x	x	x	x	x	x
406	Vegetation: slow running	x	x	x	x	x	x	x	x	x	x
407	Undergrowth slow running			x		x					x
408	Forest: difficult to run	x	x	x	x	x	x	x	x	x	x
409	Undergrowth difficult to run	x	x	x		x					x
410	Vegetation: fight	x	x	x	x	x	x		x	x	x
201	Impassable cliff					x					
306	Crossable small waterhouse			x							x
307	Minor water channel	x	x	x	x	x	x	x	x	x	x
308	Narrow marsh		x	x		x	x			x	x
414	Distinct cultivation boundary										
503	Minor road					x	x				
504	Road										
505	Vehicle track			x	x	x	x		x	x	
506	Footpath	x	x	x	x	x	x	x	x	x	
507	Small footpath	x	x	x	x	x	x	x	x	x	x
508	Less distinct small path	x	x	x	x	x	x	x	x	x	
508,001	Path	x	x	x	x	x	x	x	x	x	x
524	High fence			x							x

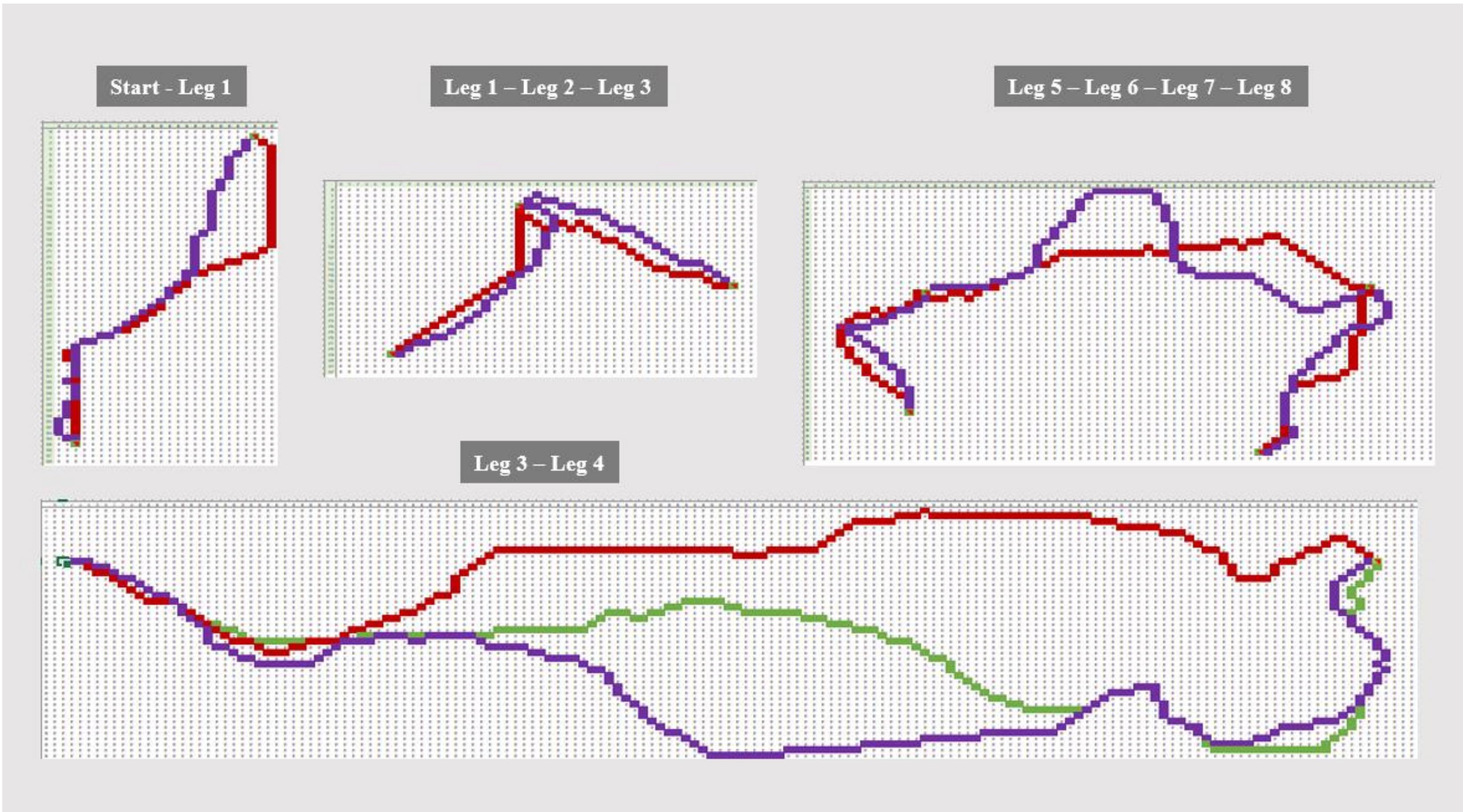
Appendix B.13. Routes of *Subject 1*



Appendix B.14. Routes of all participants

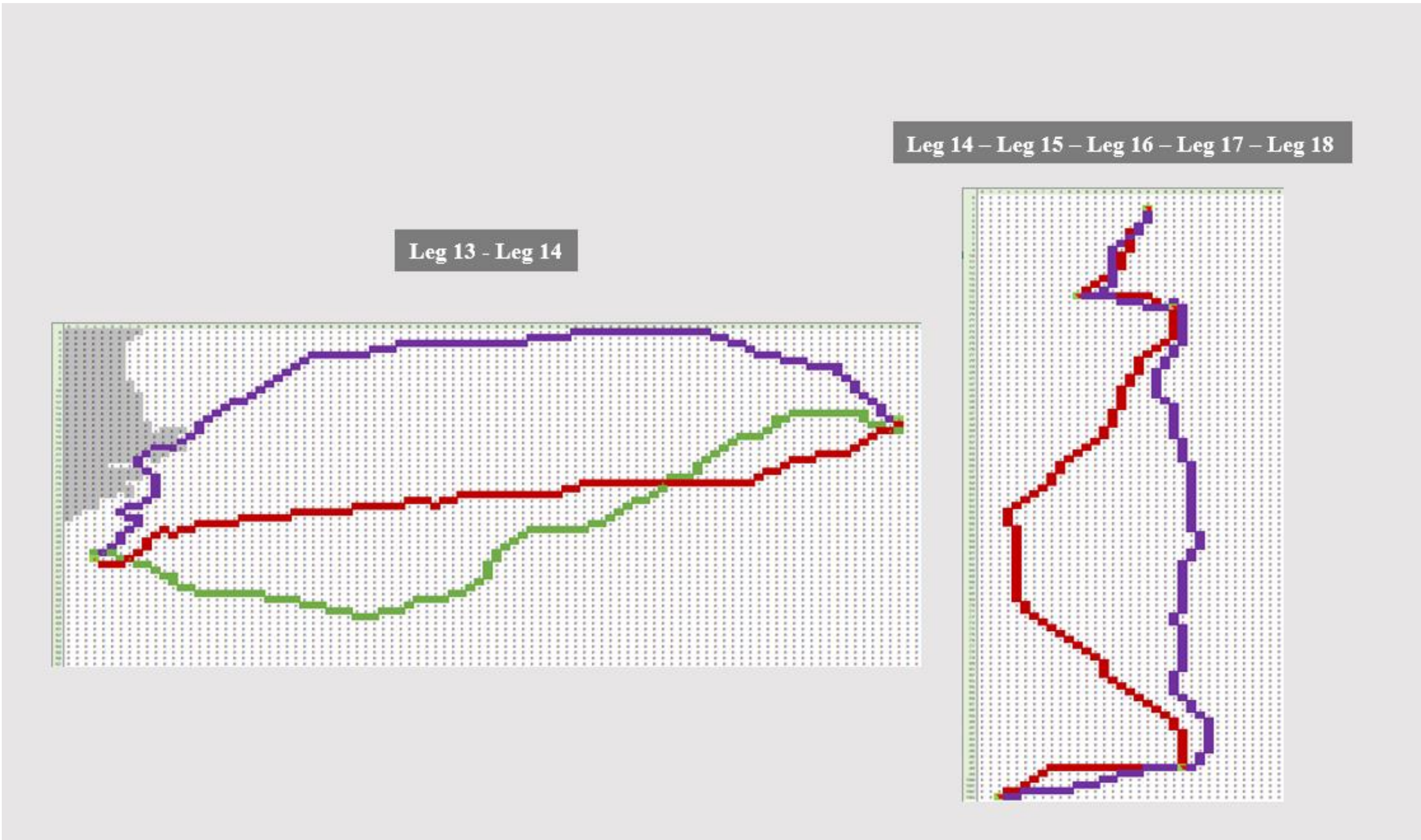


Appendix B.15. Comparison of the SPA routes with the real ones (red: the SPA, purple: Subject 1, green: Subject 2)

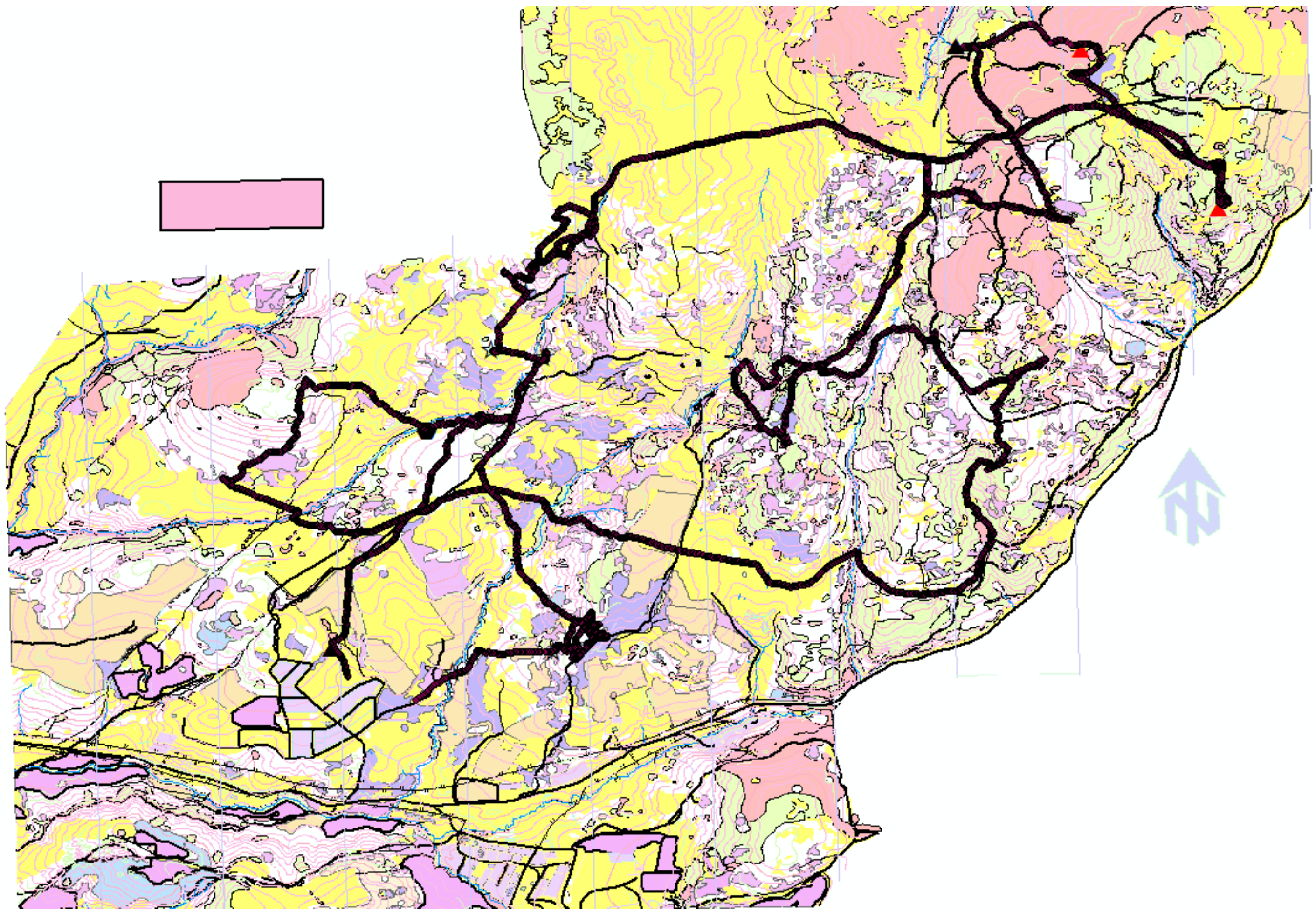


Appendix B.16. Comparison of the SPA routes with the real ones (red: the SPA, purple: Subject 1, green: Subject 2)

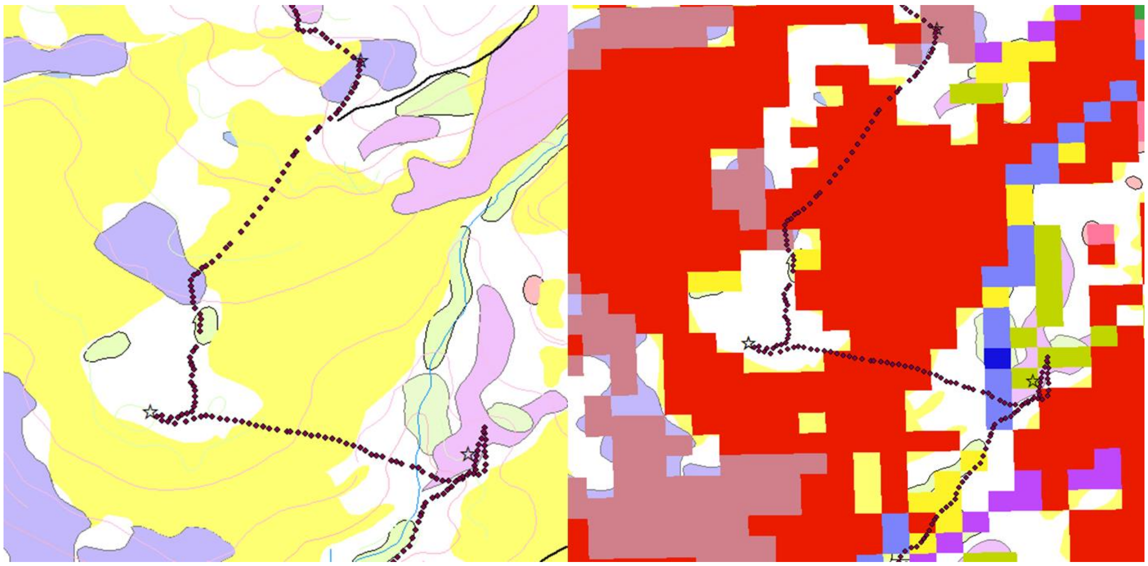
Appendix B.17. Comparison of the SPA routes with the real ones (red: the SPA, purple: Subject 1, green: Subject 2)



Appendix B.18. Niksar map screenshot with GPS data on it from ArcGIS



Appendix B.18. Line and area features (left) and reshaping version of the same area as raster data (right)



APPENDIX C

Appendix C.1. Ethics Permit from METU

UYGULAMALI ETİK ARAŞTIRMA MERKEZİ
APPLIED ETHICS RESEARCH CENTER

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21 AĞUSTOS 2019

Konu: Değerlendirme Sonucu

Gönderen: ODTÜ İnsan Araştırmaları Etik Kurulu (İAEK)

İlgi: İnsan Araştırmaları Etik Kurulu Başvurusu

Sayın Dr.Öğretim Üyesi Murat Perit ÇAKIR

Danışmanlığını yaptığınız **Tuğçe GÖLGELİ'nin "Oryantiringde Rota Planlaması Yaparken Karar Verme Sürecinin İncelenmesi"** başlıklı araştırması İnsan Araştırmaları Etik Kurulu tarafından uygun görülmüş ve **319 ODTÜ 2019** protokol numarası ile onaylanmıştır.

Saygılarımızla bilgilerinize sunarız.

Prof. Dr. Tülin GENÇÖZ

Başkan

Prof. Dr. Tolga CAN

Üye

İZİNLİ
Doç.Dr. Pınar KAYGAN

Üye

Dr. Öğr. Üyesi Ali Emre TURGUT

Üye

Dr. Öğr. Üyesi Şerife SEVİNÇ

Üye

Dr. Öğr. Üyesi Müge GÜNDÜZ

Üye

Dr. Öğr. Üyesi Süreyya Özcan KABASAKAL

Üye