University of Alberta

Time and Distance Estimation While Walking in Outdoor Environments: Effects of Route and Environmental Characteristics

by

Anthony Chaston ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Doctor of Philosophy

in

Department of Psychology

Edmonton, Alberta

Fall, 2001

0-612-69828-9

University of Alberta
Library Release Form

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Title of Thesis: Time and Distance Estimation While Walking in Outdoor Environments: Effects of Route and Environmental Characteristics

Degree: Doctor of Philosophy

Year this Degree Granted: 2001

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Date Oct 2nd/2001

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Abstract

To date, the study of distance estimation and the study of time estimation have been largely independent. Both tasks involve the judgement of environmental events, yet there has been very little crossover of data or theory. Nevertheless, psychological research on distance and time estimation have shared similar methodological approaches; both have been conducted primarily in a laboratory setting, assessing relatively short distances and times. The central goal of the research reported here is to assess how well this laboratory research applies to the understanding of time and distance estimation while traveling outdoors. In a within-subjects design, university students were taken for approximately one-kilometer walks through residential neighborhoods and forested trails. The participants were periodically asked to verbally estimate the elapsed time and distance traveled at designated intervals along the walk. The results show that the laboratory research studying distance estimation accurately predicts performance in the outdoor task. The time estimation results suggest that memory based models of temporal estimation predict performance in the task more accurately than do the attention based models. Results also suggest that perceived rate of travel may be mediated by optic flow information. I discuss these results in the context of current theories and methodologies used in the study of distance and time estimation.

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Introduction

Distance Estimation

Before discussing various models and experiments related to "distance estimation" it seems appropriate to define what is meant by this term. Distance estimation can be used to describe many different tasks, each employing a variety of cognitive processes. For example, distance estimates can be generated for distances ranging from several meters (Cohen & Weatherford, 1980) to thousands of kilometers (Thorndyke, 1981). Individuals may be asked to estimate distances from memory (Garling, Book, & Ergezen, 1982). In some situations, individuals may need to estimate distances for routes that they have personally experienced (Herman, & Klien, 1985). In other situations individuals may be estimating based on knowledge they gained from a map (McNamara, Halpin, & Hardy, 1992). The estimates themselves may be qualitative, such as " longer or shortest" (Regian, & Yadrick, 1994) or they may be quantitative, such as "950 meters or 6 inches"(Lindberg, & Garling, 1982). Although all of these of situations can involve distance estimation, they may require different degrees of perceptual, memory, and integrative processes. In the current research we are interested in examining the generalizability of distance estimates made in laboratory studies to travel in outdoor environments. As a result, in this study distance estimation refers to quantitative estimates of distance for routes that an individual has been exposed to firsthand. This type of situation is often referred to as the estimation of traversed distances.

So, what information might an individual be relying on when generating an estimate of traversed distance? Montello (1997) proposes two sources of information that are of particular interest in our research: elapsed travel time and the number of environmental features. As stated above, time, as well as distance estimation, are the central focus of this paper. As a result, a detailed discussion regarding the passage of time as a source of information will be presented in its own section below. A second source of information that has received a great deal of attention has been landmarks, clutter, obstacles, and other environmental features.

When an individual traverses a route, features of that route are learned incidentally (Cornell, Heth, & Alberts, 1994; Cornell, Heth, & Skoczylas, 1999). More specifically, the individual features and the relationships between the features can be combined to create a mental representation, or cognitive map of the route which is stored in long-term memory (Berendt & Jansen-Osmann, 1997; Sadalla & Staplin, 1980; Cohen, 1978; Lindberg & Garling, 1981, 1982). Once these features are stored they are often referred to as landmarks. Presson and Montello (1988) define a landmark as "any distinct object or feature that is noticed and remembered". So how do the landmarks in these mental representations affect estimates of distance? One hypothesis is that these features allow us to segment the route. A series of experiments by Allen and Kirasic (1985) explored this idea.

Initially, Allen and Kirasic presented participants with a slide presentation depicting a 1000 meter route, with one slide for each 20 meter interval. After the participants were familiar with the route, they were asked to view the slide show again and inform the experimenter when they felt they were beginning a "new part of the walk". The results showed that participants consistently divided the route into segments based on the environmental features shown in the slides. If a section of the route had a consistent set of features, such as "dormitory houses" or "street construction" the participants reported this section as a unique segment. In a subsequent experiment, participants estimated distances were based on these derived segments.

In the subsequent experiment by Allen and Kirasic, participants were familiarized with the same slide presentation that was described above. Once they were familiar with the route, the participants were asked to make judgments about the distances between the start of the route and locations along the route. It was found that the route segments reported in the initial study had a profound effect on the distance judgments. As an estimated section of the route crossed over more of the segments from the initial study, the length of the distance judgments increased. The effect seemed to be associated with the boundaries between the segments. For each boundary that was included in the section being estimated, there was an increase in the length of the distance judgment. The research by Allen and Kirasic suggests that segmentation is a natural part of route learning, and that there is a positive relationship between the number of distinct segments in a route and the estimate of its distance.

Route Structuring

Berendt and Jansen-Osmann (1997) defined the type of segmentation we find in the work of Allen and Kirasic as "structuring by grouping" They proposed that a route can be structured in two ways; "by grouping", or "by segmentation". Structuring by grouping occurs when an individual experiences a sequence of features along the route that are similar. The individual may then structure their mental representation of the route by defining that sequence of similar features as a unique section. In the studies by Allen and Kirasic, we saw that when individuals saw a sequence of similar features, such a "dormitory houses", they grouped them together to create a distinct segment.

Structuring by segmentation involves the use of individual landmarks to create segments. An example might be an individual who is walking through the fairly uniform residential neighborhood. Each corner along his route may be stored in his mental representation as a unique landmark. These landmarks can then be used to structure the route, by acting as the boundaries between the route segments. Both of these structuring techniques represent methods for organizing the information in our mental representation based on the environmental features that we experience along the route. We've seen from Allen and Kirasic's work that structuring by grouping can have a significant effect on distance estimation. Does structuring by segmentation produce a similar effect?

Feature Accumulation Theory

Structuring by segmentation is in many respects similar to the feature accumulation hypothesis. The feature accumulation hypothesis proposes that an estimate of route distance is positively related to the number of features or landmarks that an individual has stored in their mental representation of the route. Simply put, the more you can remember about the route, the longer you think it was. Structuring by segmentation makes the same prediction; the difference is that the landmarks in the feature accumulation hypothesis are now used as the boundaries between segments. The more landmarks you have, the more segments you have, and the more segments you have, the longer the estimate of distance will be.

The feature accumulation hypothesis was explicitly tested in several studies by Sadalla and his colleagues (Sadalla & Magel, 1980; Sadalla & Staplin, 1980; Sadalla, Staplin, & Burroughs, 1979). In these studies Sadalla and his colleagues investigated the effect of intersections and corners on estimates of route distance.

Sadalla, Staplin, and Burroughs, (1979) had participants walk an 18 meter route following a line of tape along the floor of large room. The participants encountered 15 intersections, represented by pieces of tape crossing the route. In a between-subjects manipulation, the intersections were labeled with either high-frequency or low-frequency proper names. After walking the route, the participants were required to estimate the distance of the walk and recall as many intersection labels as possible. The results showed that when high frequency labels were used, more intersections were recalled and distance estimates were relatively larger. The results suggest that increasing the number of memorable intersections increases the number of landmarks in the mental representation of the route. Consistent with the feature accumulation hypothesis, an increased number of landmarks resulted in larger estimates of traversed distance.

Sadalla and Magel (1980) performed a series of studies looking specifically at the effect of corners on distance estimates of a route. In these studies they had participants walk a 67 meter route that contained either 2 or 7 right angle corners. The route was again defined by line of tape on the floor that they had to follow. At the completion of the walk each participant was asked to estimate the route distance. The results showed that routes that contained 7 corners were estimated as longer then routes with 2 corners. Again, the results were consistent with the feature accumulation hypothesis. Presumably the corners were integrated as individual features into the mental representation of the route.

From the research described above there are two general conclusions that can be drawn. First, the number of memorable features found along a route has an effect on the estimates of route distance. Second, the relationship between features and distance estimates is positive, such that an increase in the number of landmarks or segments associated with the route increases the estimate of its distance. The effects of grouping and segmentation on distance estimates, and the effects of feature accumulation theory are similar. They both suggest that increasing the number of landmarks/segments in a mental representation of a route increases the estimate of its distance. This allows us to define a new and more general term referring to the collective influence of these processes. I will call this "route processing effort". Incorporating this definition, a more general prediction can be made: distance estimates of a traversed route will increase systematically as the mental processing or representation of the route becomes more elaborate.

Application to Current Research

The conclusions that we have been discussing are well supported by the laboratory data but an important question remains: Do the predictions from short routes in laboratory environments generalize to distance estimation in a nonlaboratory environment? It is often assumed that the methods used in the laboratory represent valid simplifications of the real world conditions. With respect to distance estimates of traversed routes, this assumption has never been explicitly tested. One way to test this is to see if the predictions generated from the laboratory experiments accurately predict performance in outdoor settings.

The laboratory setting inevitably results in route simplifications and as a result differs from the real world environments in several ways. The length of the routes used in the laboratories are relatively short. For example, the work of Sadalla and his colleagues used routes ranging from 18 to 67 meters. Alan and Kirasic found their effects of segmentation in a route that was 1000 meters in length, but it should be noted that this route was not actually traversed by the participants, it was presented as a slide show. The methodologies used in these studies employed a variety of simplifications that may deprive the route learners of cues or continuous experience of travel. A primary objective of my research was to see if these are generalizable simplifications.

If the laboratory simplifications are valid, then we expect that when individuals are estimating traversed routes in outdoor environments, manipulations of route complexity should produce the same pattern of effects as occurred in the laboratory setting. If distance estimates show a different pattern of results when we manipulate route complexity, this would suggest that the laboratory simplifications are not generalizable.

Time Estimation

Ornstein (1969) published a series of experiments demonstrating a phenomenon which he referred to as the "storage size hypothesis". In general terms this hypothesis predicts that time intervals which are "filled" with memorable stimuli will be estimated as longer than intervals that are "unfilled". In Ornstein's research, participants engaged in various tasks such as learning paired associate word lists, and abstract figures. For each task, Ornstein used different conditions where the memorability of the stimuli were manipulated. At the conclusion of the memory task he asked participants to estimate how much time had elapsed during the task. The results of the studies showed that increasing the memorability of the events during a time interval increased the estimates of its duration. This result was interpreted as a demonstration of the "store size hypothesis". Ornstein suggests that as more events are experienced during an interval an individual's memory trace or representation of that interval becomes larger. This larger memory trace results in larger time estimates. We can see from this description that the storage size hypothesis is in many respects the temporal equivalent of the "feature accumulation theory" described in the discussion of distance estimation. Both predict increases in estimation with increases in the number of events stored in memory.

Following the work of Ornstein, subsequent research called the storage size hypothesis into question. In fact Hicks, Miller, and Kinsbourne (1976) were able to demonstrate the exact opposite pattern of effects for changes in task complexity on time estimates. The critical difference in the work of Hicks *et al,* was a distinction between prospective and retrospective time estimation. In prospective time estimation an individual is informed, prior to an interval, that they will be required to estimate its duration. In retrospective time estimation an individual is only informed of the estimation task after the interval is complete. This idea that prospective or retrospective conditions could affect estimates of duration was first presented by Gilliland, Hofeld, and Eckstrand (1946). The pattern of results Ornstein reported in his work had come from retrospective time estimates. Hicks *et al*, showed the opposite pattern with prospective time estimates.

Hicks and his colleagues had participants sort playing cards as fast as possible into piles, and then estimate the duration of the sorting task. They had three sorting conditions: 1) 0-bit sorting, stack the cards in one pile, 2) 1-bit sorting, sort the cards into two piles by color (red or black). 3) 2-bit sorting, sort the cards into four piles by suite. Hicks *et al* found that when they told people in advance that they would have to estimate the duration of the sorting task (prospective estimation), increasing the difficulty of the sorting task resulted in shorter time estimates.

Since this early work, several researchers have explored prospective and retrospective time estimation in more detail. In general the pattern of data established in the studies described above has held true. Under retrospective conditions, increasing the engagement of the participant in the events of the interval increases the estimate of the duration of that interval (Poynter, 1983; Zakay, Tsal, Moses, & Shahar, 1994, Zakay, & Feldman, 1993; Gray, 1982). Under prospective conditions, increasing the engagement of the participant in the events of the interval decreases the estimate of the duration of that interval (Brown, 1985; Marshall, & Wilsoncroft, 1989; Predebon, 1996; Casini, & Macar, 1997). So, how does awareness, or lack of awareness, of the estimation task produce its effects on time estimates? Below I will discuss several models that have been developed to explain the processes that occur during each of these conditions. A good summary of these models can be found in Zakay and Block (1997).

Attention-based Time Estimation Model

Under prospective conditions, the effect found when manipulating task complexity is typically explained in terms of a limited capacity attentional system (see, Thomas & Weaver, 1975). During a prospective time estimation task, individuals are aware during the task that they will have to estimate its duration. This causes an individual to devote a portion of their attentional resources to monitoring the passage of time. The assumption is that time monitoring requires attention. If attention is diverted away from time monitoring by another task the individual is in a dual-task situation, the temporal task, and the non-temporal task. As the nontemporal task is made harder, more attention is devoted to it. The result is that less attention is available to monitor the passage of time. To understand the predictions of this model in more detail we can look at a recent incarnation of this approach, the "attentional gate model", Zakay and Block (1997). This model proposes that humans are equipped with an internal clock, which outputs "clicks" at a constant rate. These clicks are passed through an attentional gate to an accumulator. If attention is committed to the task of time monitoring, the gate is open and the clicks pass unimpeded to the accumulator. If, however, attention is committed elsewhere, the gate is closed and clicks from the internal clock are not passed to the accumulator. When an estimate is provided, the sum of the clicks in the accumulator is tabulated, and then transformed into a time value. In conditions where attention has been engaged elsewhere, the sum of the accumulator will be less than the actual elapsed time, and hence time is underestimated.

Memory-based Time Estimation Model

Under retrospective conditions, the effect found when manipulating task complexity is typically explained in terms of memory related processes (Block, 1978, 1989; Block and Reed, 1978; Poynter 1983, 1989). When an individual is engaged in a retrospective task he is assumed to be unaware that a time estimate will be required. As a result, there's no particular reason to devote attentional resources to monitoring the passage of time. At the completion of the task, when the individual is asked to generate an estimate, the information available is their memory for the events that occurred during the interval. The assumption is that as individuals are increasingly engaged in the events of an interval, they will remember more about what occurred. When they are required to generate a time estimate, the relatively larger memory store results in a relatively longer time estimate. In this form, the explanation is simply Ornstein's storage size hypothesis. More recently, researchers have investigated how the specific components of an individual's memory for an interval may affect their time estimates. What types of events get remembered in an individual's memory for an interval? Through what process do these various remembered events influence estimates of duration?

It has been suggested that individual memory events may act as temporal landmarks, and that these temporal landmarks may allow an individual to structure their memory for the interval. There are two ways that this can occur. One is by contextual change (Block, 1978, 1989), and a second is through segmentation (Poynter, 1983; Zakay, Tsal, Moses, & Shahar, 1994). Though the time estimation literature does not typically describe these as two unique processes, we will see that they are directly analogous to "structuring by grouping", and "structuring by segmentation". These two terms were previously discussed as processes that allowed individuals to structure their memory representations based on landmarks while traversing a route.

Contextual Change Theory

The theory of "contextual change", as described by Block (1978, 1989, 1997) proposes that changes in the environmental context during an interval represent key markers that allow an individual to structure their mental representation. In this framework a "context" is a set of environmental conditions that stay the same for some period of time. Contextual change occurs when those environmental conditions change in some way, signaling the beginning of a new context. These ideas can be easily illustrated. Imagine you get to work one morning and someone asks you how long as it been since you had breakfast. You might look back at your memory for that time period and remember several unique "contexts". There might have been time spent at your house before you left that constitutes one context. There was the time spent driving to work that constitutes another context. And maybe you've already been at work for some time, possibly a third context. During each context we could define certain characteristics of the environment that stayed the same. Contextual change theory predicts that as you increase the number of contextual changes during an interval, the retrospective estimate of that interval's duration will increase.

The theory of contextual change in the temporal domain is very similar to the idea of structuring by grouping described for the spatial domain. In both cases, when the environmental characteristics stay relatively consistent over space or time, our mental representation gets structured in episodic memory such that the period encompassing those characteristics is remembered as a unique spatial or temporal section. Both theories predict that as the number of these sections increases, estimates of the interval will increase.

Temporal Landmark Segmentation Theory

The second method for structuring a mental representation in a retrospective time estimation task, is "temporal landmark segmentation". Specifically, this theory argues that salient temporal landmarks allow an individual to segment their mental representation of the interval. This is the temporal equivalent to structuring by spatial segmentation.

Poynter (1983) presented a laboratory demonstration of temporal landmark segmentation. Participants listened to an audiotape which contained 30 evenly spaced words, and lasted a total of 170 seconds. Of the 30 words 27 were unrelated nouns, and the other three were the names of former United States presidents. Participants were told to try to remember the words in the list because they would be tested on them later. The participants were also told to pay particular attention to the names of any former United States presidents. Due to this last instruction, the president's names represented high priority events (HPEs). There were two conditions in the experiment; segmented, and unsegmented. In the unsegmented condition the HPEs were the first three words in the list. In the segmented condition the HPEs were in positions 10, 20, and 27. After listening to the list participants were asked, retrospectively, to estimate the duration of the list learning task. Poynter predicted that when the HPEs were spread throughout the list they would segment the participant's temporal experience of list learning. This segmentation should result in increases in retrospective time estimates of the list learning task. The time estimation data from the experiment confirmed these predictions. Poynter's experiment demonstrates a temporal example of structuring by segmentation. During the interval, unique salient features act as temporal landmarks. These temporal landmarks allow the interval to be segmented, and this increased segmentation results in longer time estimates.

Application to current research

When we look at the current research addressing time estimation, we see an important distinction between retrospective and prospective estimation conditions. It has been shown that manipulating the task complexity, or the level of engagement in the task, can increase or decrease time estimates as a function of the estimation condition. What predictions does this research provide for people estimating the time to traverse outdoor, real world walks?

In the study I will be presenting below, all the participants were explicitly informed prior to the walks that they would be required to provide time estimates. As a result, previous research involving prospective time estimation should provide good predictions. I expect that as I increase the complexity of the routes to be walked, the participant's time estimates should decrease. A limited attention model would argue that the participants will devote attentional resources to monitoring the passage of time. When the complexity of the routes is increased, attention will be diverted from monitoring time, resulting in shorter time estimates. Unfortunately, this prediction hinges on a critical assumption that may not be true in travel outdoors.

The prospective, attention-based models make valid predictions only when the nontemporal task requires extensive attentional resources. The model works on the idea that the nontemporal task requires so much attention that there's not enough left to accurately monitor the passage of time. The models have been derived from laboratory situations where the nontemporal task has intentionally been made extremely demanding. For example, in the study by Hicks *et al* the participants were instructed to sort the cards as fast as possible, and to sort as many cards as they could in the time provided.

In my research, the complexity of the routes was increased by adding more corners into the routes. The participants were not given any instructions to remember the corners, or study any particular environmental features. It seems possible that this type of complexity manipulation may not require the participants to allocate extensive attentional resources and as a result, adequate attentional resources will still be available for monitoring time. If route features are easily encoded, automatically or otherwise, time estimates should be unaffected by the manipulations of route complexity.

We can take this line of reasoning one step further. Although the complexity manipulations might not result in changing the allocation of attentional resources, features may continue to be incorporated into the memory representation of the route. The corners may be experienced as environmental features that the participants could use to segment their memories of the walks. If this is the case the memory-based retrospective models may provide a more accurate prediction of the outdoor time estimates than the attentional prospective models. This may occur even though the task was made explicitly prospective to the participants. If this were the case, we would expect that increases in route complexity should result in relatively longer time estimates. Hence, the second objective of this research is to determine which class of time estimation models best predicts time estimates in outdoor, real world settings. If time estimates decrease with increases in complexity, then attention-based models should be applied when interpreting the results. If time estimates increase with increases in complexity, then the memory-based models will be more appropriate.

Rate of travel

One of the goals of the current research was to look at the relationship between estimates of time and estimates of distance. "People often express [spatial] separation between places in temporal terms. Clocks and watches are much more widely available than our instruments for measuring distance, and provide a relatively handy way to assess the extent of travel" (Montello, 1997). Montello is making a point that everyone is familiar with: time and distance perception are strongly related. It would be of theoretical interest to understand what role temporal knowledge plays when generating a distance estimate. And, it would be equally important to understand what role spatial knowledge plays when generating the time estimate. In practice, these questions are difficult to answer. Estimates of time and distance are typically highly correlated, and are not independent measures in statistical analyses. With this in mind, the approach used in this research will be to see if there are particular sets of environmental characteristics that change the correlation between time and distance estimates. This will be done by examining the participant's perceived rate of travel as a function of route conditions. Specifically, each time estimate and its corresponding distance estimate will be combined to derive an estimate of rate. This procedure is obviously quite simple, with rate being simply the ratio of distance over time. These derived rate estimates were calculated for each participant in the study. This new set of dependent measures was then analyzed as a function of the changes in the environmental characteristics of the routes. Hence, the third objective of my research was to see if changes in the environmental characteristics of the routes affect the derived estimates of rate.

Summary

During the introduction to this paper I have presented three research objectives: First, to determine whether task simplifications used in the laboratory research on distance estimation, generalize to outdoor walks. Second, to compare prospective and retrospective models of time estimation when interpreting time estimates from outdoor walks. Third, to see if changes in the environmental characteristics of routes walked outdoors affects the derived rate estimates.

Method

Participants

The participants used in the study were 24 male and 36 female University of Alberta undergraduate students. The participants ranged in age from 17 – 47 years, with a mean age of 20.1 years. All participants were volunteers from the Department of Psychology experimental participant pool. Their voluntary participation partially fulfilled an introductory psychology course requirement. All participants stated that they were generally unfamiliar with the areas in which the experiment was conducted.

Conditions

During the experiment the participants completed two walks. Both were 960 meters in length. At various points along these walks the participants were stopped by the experimenter and asked to estimate the time and distance traveled since the last stopping point. The study was designed such that the environmental characteristics of the routes provided the different conditions for the experiment.

The first condition was termed the *route environment*. Simply put, the two routes took place in different environments. One of the walks took place in the neighborhood of Windsor Park, an urban residential neighborhood adjacent to the campus. As can be seen in Figure 1, the route began at the circle marked with an "S" and followed along the dashed line. The numbered circles represent the locations where participants were stopped and asked to generate estimates of time and distance. The second route was along a forested trail in the Edmonton river valley park. This route is shown in Figure 2, with similar labeling.

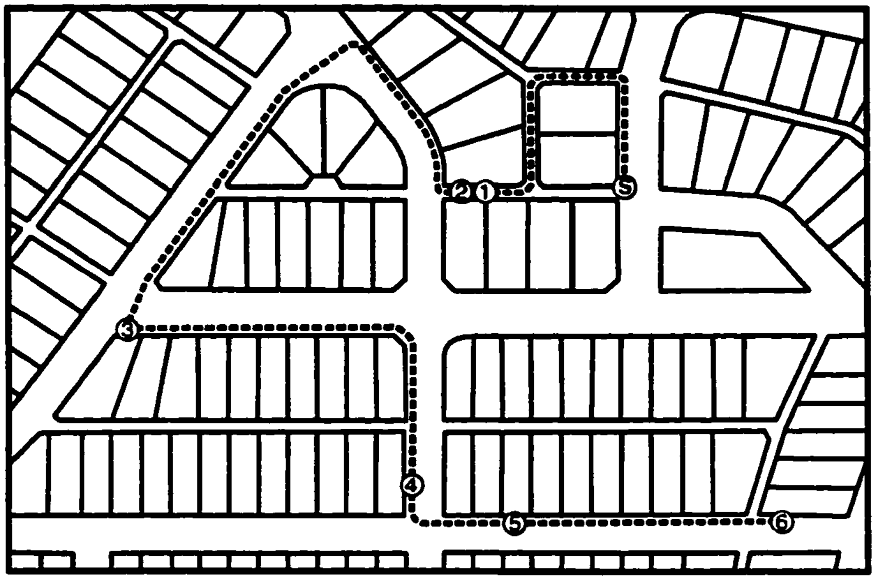

Figure 1. Map of the route in the urban residential neighborhood. The route began at the circle marked with an “S” and followed the dashed line. The numbered circles represent the locations where participants were stopped and asked to generate estimates of time and distance.

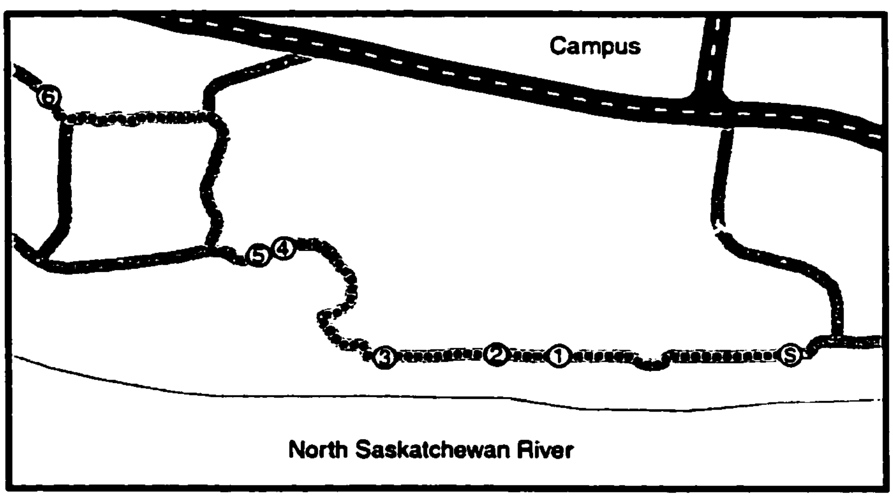

Figure 2. Map of the route along the forested trail. The route began at the circle marked with an “S” and followed the dashed line. The numbered circles represent the locations where participants were stopped and asked to generate estimates of time and distance.

These two routes differ greatly in their general appearance. The urban route was through a stately residential neighborhood, with houses positioned on landscaped lots. The neighborhood featured an established infrastructure of signage, light posts, curbs and sidewalks. The trail walk took place in a boreal forest on a gravel trail approximately two meters wide. Both sides of the trail were heavily forested with popular, spruce and aspen. The tree limbs typically extended over the trail shading the route.

A second experimental condition incorporated into the routes was; *route complexity*. A quantitative measure of route complexity was defined as the number of distinct changes in direction or corners that were encountered during travel. I will functionally define a corner as any change of direction exceeding 60 degrees in less than 10 meters of walking. When I applied this definition to the residential route, the high complexity section (between points "S" and "3") had five corners and the low complexity section, (between points "3" and "6") had two corners. The high complexity section of the residential route also contained one slow radius turn. The same pattern of complexity was sought when selecting the trail route. As defined above, the high complexity trail section (between points "3" and "6") had five corners and the simple trail section (between points "S" and "3") had two corners. The high complexity section also had many slow radius turns, whereas low complexity section was relatively straight.

It should be noted that the order of the complex and simple sections was different for the two routes. This was incorporated in an attempt counterbalance the section complexity with serial order.

The third manipulation was the *interval length*. As is shown in Figures 1 & 2, each route was divided into six intervals. For each interval the participants provided time and distance estimates. Each route section contained three intervals defined as, a short, a medium, and a long. To create the intervals the total route length, 960 meters, was dividing by 6, resulting in a mean interval length of 160 meters. Centered around this point we created six intervals which differed by 60 meters each. The intervals used were: 10, 70, 130, 190, 250, and 310 meters. 10 and 70 meters were defined as short, 130 and 190 meters were defined as a medium, and 250 and 310 meters were defined as long intervals. One of each of these interval types was assigned to each route section with constraint that the complex and simple sections of the walk differ by no more than 60 meters in length. Once assigned, the order of the intervals within each section was randomly assigned. The result was that during a complex route section, the participants estimated intervals of 190, 10, and then 310 meters. During a simple route section, the participants estimated intervals of 250, 70, and then 130 meters.

An alternative method for establishing the interval lengths would have been to use the same three intervals in each section, simplifying the design. The problem with this methodology is that participants may have been able to correctly conclude that there were only three different intervals. This knowledge would allow participants to make predictions about the upcoming endpoints of intervals that they were experiencing. As a result, this methodology was rejected.

The final design of the experiment had two routes (urban, trail), each containing two sections (simple and complex), with each section containing three intervals (short, medium, long). The result was a counterbalanced design with, *environment*, *complexity*, and *interval length*, as within-subjects factors.

All distances were measured with a surveyor's wheel. This is a one-meter circumference wheel with a rotation counter. Once established, the locations of the interval endpoints were noted in relation to existing path landmarks and memorized by the experimenter. All elapsed times were measured with a stopwatch.

Procedure

At sign-up for the study, participants were informed that the experiment involved "going outside for a walk", and as a result "participants should wear appropriate footwear and clothing". All participants were tested individually. Upon arrival at the lab, the participant's age and gender were recorded. The experimenter and the participant then left the building and proceeded to the location where each participant got an opportunity to practice distance estimation. This practice session was incorporated to provide a reasonable range in distance estimates during the experiment. The location of the practice session was the midpoint of a straight sidewalk several hundred meters in length. The participant was then told the actual distance to two objects beside the sidewalk, a lamppost that was 10 meters away and a flowerbed that was 100 meters away. The participant was then asked to look down the sidewalk in the other direction and select two objects, one 10 meters away and the other 100 meters away. The participants then received feedback only by being told which to objects were actually 10 and 100 meters away in that direction. The experimenter and the participant then proceeded to the starting point of the first experimental route. At this time, each participant was told the general location of the two experimental routes and asked if they were familiar with these areas. All participants stated that they were not.

The order of the two routes was counterbalanced between participants, to preempt *route environment* order effects. Half the participants did the residential walk first, and half did the trail walk first. When the experimenter and participant reached the starting point for the first route, the participant was asked if they were wearing a watch, and if so to put it in their pocket for the duration of the experiment. They were then read a set of instructions.

The instructions began by informing the participant that they would be completing a walk that started from this location and that they should walk beside the experimenter, who would guide them along the route. The instructions stated that the walk would be divided into several intervals, and at the end of each interval they would be asked to estimate its time and distance. When they arrived at each of these locations the experimenter would say "stop", indicating to the participant that he/she should stop walking and provide estimates of the distance traveled and time elapsed for only the interval they had just completed. Participants were asked to provide their time estimates in minutes and seconds rounded to the nearest second, and their distance estimates in meters rounded to the nearest meter. These estimates should be provided verbally, and the experimenter was to record them on a response sheet. The instructions also stated that the experimenter would be recording the actual elapsed time for each interval. The participants were then asked if they had any questions. The experimenter and the participant then proceeded through the six intervals of the first experimental route. During the walk the experimenter engaged in a small amount of light conversation with the participant. This was done to eliminate the opportunity for participants to either count their steps or count seconds.

At the completion of the first walk the participants were told that they would now be proceeding to the starting point of the second route. When they arrived at this location, the participant was informed that the instructions for the second experimental route were the same as they had used during the first route: they would complete a series of intervals along the route, and the participant would be required to provide time and distance estimates in the same manner as they had previously. The participant was then asked if they had any questions. After this route had been completed the participant was led back to the laboratory. The average time required for each participant to complete the experiment was approximately 1 hour and 45 minutes, during which time they walked approximately 5 km.

Results

To get a complete data set (n = 60), data was collected from a total of 61 participants. The data from one participant in the study was replaced due to an unforeseen incident involving a dog. It was felt that the incident resulted in a significant disruption in the experimental procedure, and as a result the participant's data set was discarded. Each participant's data contained the estimated and actual distances as well as the estimated and actual times for each of the six intervals from both the residential and trail routes.

Both the time and distance data were subjected to analyses for route order effects. Null results showed that the route order had no effect on the participant's ability to estimate time or distance. As a result, in all subsequent analysis the data were collapsed across route order.

Before presenting a detailed discussion of the effects of *route* and *complexity*, I will look specifically at *interval length*. This is because the method of analysis used will be slightly different. To allow the comparison of estimates from different length intervals, the estimates will be converted to a proportion of over or under estimation. When looking at the effects of *route* and *complexity*, I will directly analyze the estimates given in meters and seconds.

Interval Length

Distance data and time data were analyzed separately using the same procedure. The first question of interest can be stated as this: "Does the actual distance traveled during an interval affect the accuracy with which participants can estimate its distance?" For our purposes here we will define accuracy as the proportion to which people over or underestimate the actual distance. The first step in statistically addressing this question was to convert each estimate into a proportion. This was done using the formula below.

$$\text{Error Proportion} = \frac{\text{(distance estimate)} - \text{(actual distance)}}{\text{(actual distance)}}$$

These proportions give us a comparable measure of estimate accuracy for each interval. The proportional data were then subjected to a 2 (route) X 2 (complexity) X 3 (Interval) repeated measures analysis of variance. The results of this analysis show a main effect of interval length, $F\,(2,118) = 8.27$, MSe = 0.214, $p < 0.001$. The effect size = .22. This result can be seen in figure 3. The intervals that were categorized as "long" were estimated with the least accuracy, and were proportionately overestimated. Interval length did not interact with *route* or *complexity*.

This same statistical procedure was applied to the time estimates. For each interval the estimated and the actual times were converted to a proportional measure of accuracy. The data were then subjected to the same 2 X 2 X 3 repeated measures analysis of variance. This analysis showed that interval length did not effect estimation accuracy. There was no main effect of interval length nor did interval length interact with *route* or *complexity*. This analysis shows that when participants estimated walks that ranged in time from 8 sec to just over 4min, the actual duration had no systematic effect on the accuracy of participant's time estimates.

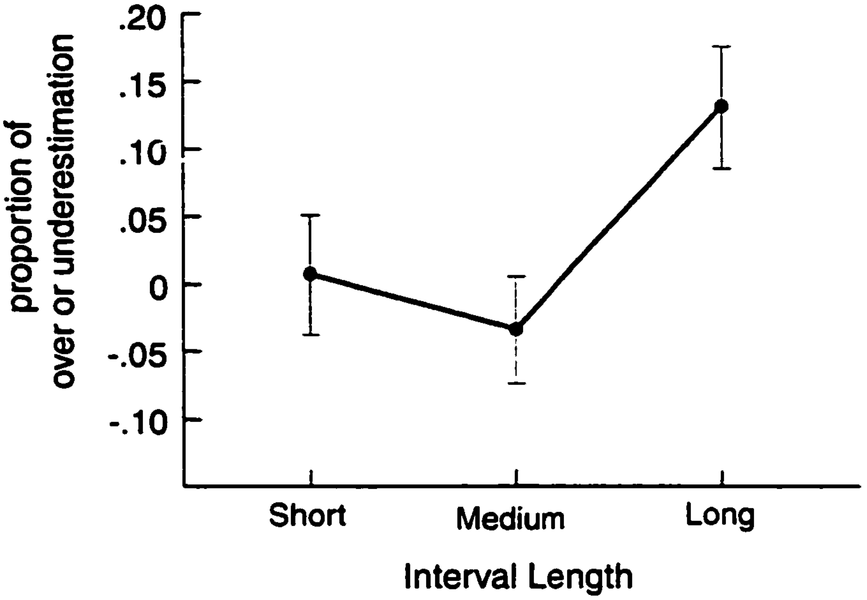

Figure 3. Graph of the group means for the proportion of over or underestimation as a function of the length of the interval (short, medium or long).

Route and Complexity

The data were collapsed across interval length for each walk segment. The method used to do this was to sum together the three intervals that made up each segment, for each participant. The result was to simplify the experiment into a 2 X 2 design, with factors of *route* and *complexity*. Table 1 shows the estimated and actual distance means and the estimated and actual time means for each of the four cells in this design.

Table 1

Means and standard errors of the estimated and actual distances, times, and rates for the four cells in the design.

	Urban Complex	Urban Simple	Trail Complex	Trail Simple
Segment Distance (m)	**510**	**450**	**510**	**450**
Actual				
Time (s) Standard Error	360.1 2.6	324.3 2.7	437.8 4.4	332.8 2.4
Rate (m/s) Standard Error	1.41 .012	1.38 .012	1.17 .014	1.36 .011
Estimated				
Distance (m) Standard Error	580.8 43.8	442.6 29.1	577.8 43.8	472.9 36.8
Time (s) Standard Error	512.6 31.1	422.3 26.4	536.0 30.4	436.2 29.3
Rate (m/s) Standard Error	1.33 .117	1.25 .085	1.30 .114	1.30 .109

To create a measure of error for analysis, I subtracted the actual value from its corresponding estimate. This was done to both the distance and the time data and I will refer to these as distance error and time error respectively.

The analysis of distance error was done by applying a 2 X 2 repeated measures analysis of variance. The group means can be seen in Figure 4, which shows the distance error as a function of the section complexity for both the urban route and the trail route. The results of the analysis showed a significant main effect of ***complexity***, $F\,(1,59) = 6.91$, MSe = 32875.14, $p < 0.02$. The effect size = .09. Participants gave significantly longer distance estimates for the high complexity route sections when compared to the low complexity sections. The analysis showed no significant main effect of ***route***, and no significant interactions.

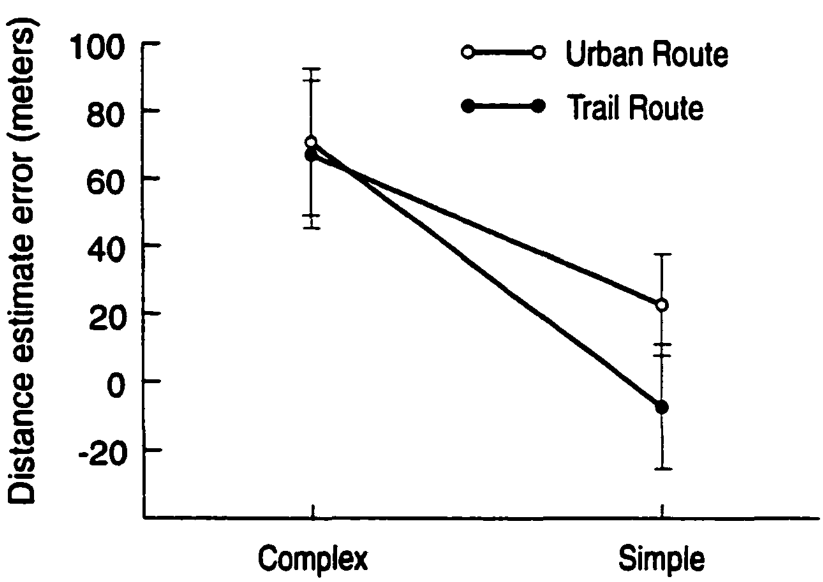

Figure 4. Graph of the group means for distance estimate error, showing the distance error as a function of the section complexity for both the urban route and the trail route.

The effect of complexity on distance estimates is consistent with our predictions. The previous research using short indoor or simulated walks showed that increases in the route complexity resulted in increases in estimated distance. The current finding suggests that this pattern holds true in outdoor walks, over longer distances. Regardless of the route environment, increased route complexity resulted in longer distance estimates.

The analysis of time error was also done with a 2 X 2 (*route* X *complexity*) repeated measures analysis of variance. The group means can be seen in Figure 5, which shows the time estimate error as a function of section complexity for both the urban route and the trail route.

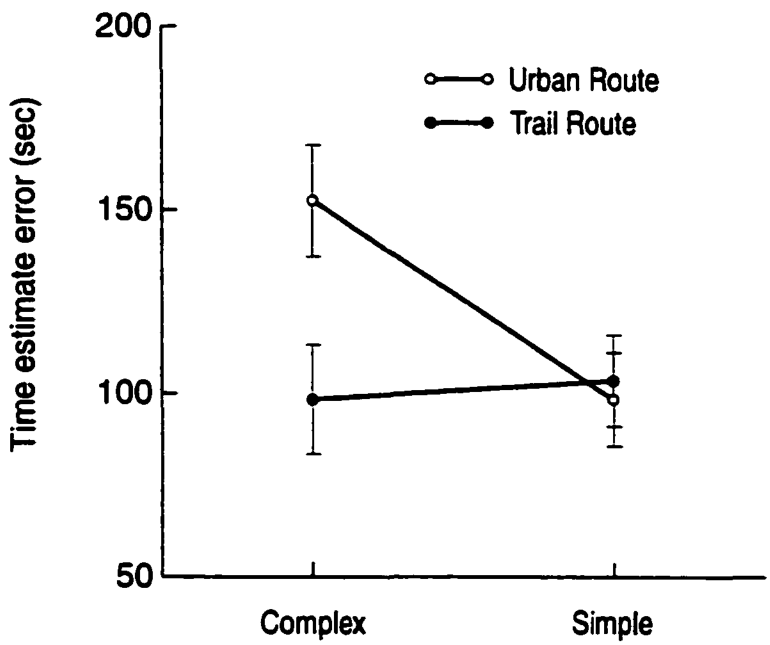

Figure 5. Graph of the group means for time estimate error, showing the time error as a function of the section complexity for both the urban route and the trail route.

The results of the analysis showed no significant main effect for either *route* or *complexity*, but a significant interaction of these two factors, $F(1,59) = 4.53$, MSe = 11786.36, $p < 0.04$. The effect size = .15. This interaction is not consistent with either the predictions from the attention-based models or the predictions from the memory-based models. Both of these models predict a main effect of *complexity* on time estimates (though in different directions). The result suggests that the effects of route complexity depend on the route environment. The means in Figure 5 suggest that complexity increased time estimates, but only in the urban environment. Estimates for the trail environment seemed to be unaffected by route complexity. I will present a potential explanation for this unexpected result in the discussion.

One other result was indicated in the time estimate error data. When the above analysis was conducted with "participant gender" included as a between subjects factor, female participants showed a marginally larger degree of overestimation when compared to males $F(1,58) = 3.73$, MSe = 152049.40, $p < 0.06$. The effect size = .04. This marginally significant effect has been included because of a recently growing interest in gender differences during environmental spatial tasks (Montello, Lovelace, Golledge, & Self, 1999).

Rate

After the distance and time data had been analyzed independently, the two dependent measures were combined to generate the estimate of rate. As stated in the introduction, one of the objectives of this experiment was to begin investigating the relationship between perceptions of distance and time during outdoor travel. Towards this goal, each participant's distance and time estimates were combined to derive an estimate of rate of travel in meters/second. This was done for each of the four cells in the previously described 2 X 2 ANOVAs. A corresponding actual rate of travel was calculated in the same way; actual distance divided by actual time. So, for each participant we had a set of estimated and actual rates, for each of the four cells in our 2 X 2 design. The estimated and actual rate cell means are shown in Table 1.

To examine the accuracy of our derived rate estimates we applied the same procedure that was used with the distance and time data. Each actual rate was subtracted from its corresponding estimated rate. These differences are referred to as the rate errors. We then applied the same analysis as before, a 2 X 2 repeated measures analysis of variance. The group means can be seen in Figure 6, which shows the rate error as a function of the section complexity for both the urban route and the trail route. The results of the analysis showed a significant main effect of *route*, $F(1,59) = 10.61$, MSe = 0.106, $p < 0.01$. The effect size = .14. Neither the main effect of *complexity*, nor the interaction of *route* and *complexity* were statistically significant. In Figure 6 the Y-axis represents the extent to which participants over or underestimated the actual rate. The value of zero represents a correct estimate, positive values represent overestimates and negative values represent underestimates.

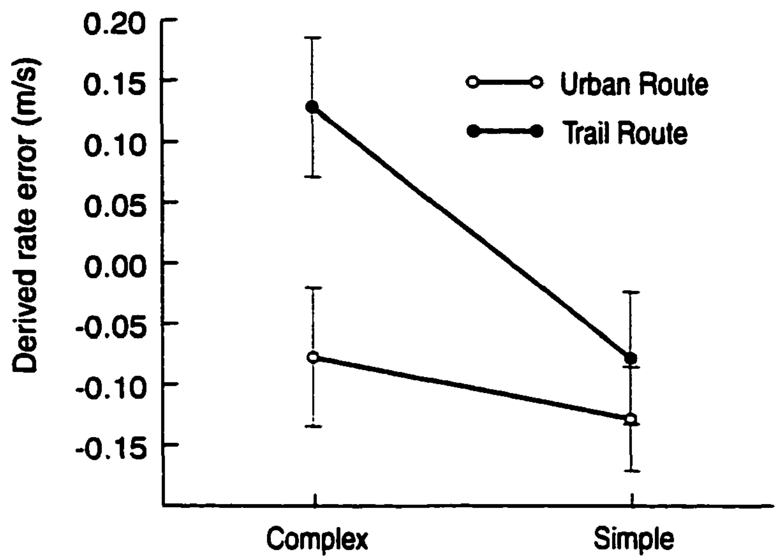

Figure 6. Graph of the group means for derived rate estimate error, showing the rate error as a function of the section complexity for both the urban route and the trail route.

We can see in Figure 6 that rate estimates are relatively higher in the trail environment than in the urban environment. This suggests that participants had the perception that they were traveling more quickly on the forested trail, relative to the urban sidewalks. This intriguing result will be addressed in the subsequent discussion.

Discussion

The data collected in this study have provided a variety of interesting results. Participant's estimates of distance revealed that longer intervals were overestimated as compared to the relatively accurate estimates for the short and medium intervals. Participant's estimates of distance also suggest that more complex routes seem longer. This is consistent with the prediction that the results from the laboratory simplifications of routes may be generalizable to outdoor performance. Analysis of the time estimates revealed that complexity increased perceived duration but only in the urban environment. Why did complexity affect temporal estimates only in this environment? What might be different between the urban-complex, and the trail-complex sections that could have caused this interaction? After combining these distance and time measures into derived estimates of rate, the data suggests that participant's perception of the rate of travel may have been different in the trail and the urban environments. Is there an environmental characteristic that differs between the urban and trail routes that could reasonably account for these differences in perceived rate? In this discussion we will see how these four results, and the questions they raise, further our understanding of how people use environmental characteristics to make judgments about outdoor travel.

Interval Length

Distance estimates for the long intervals showed significantly greater overestimation than did the estimates given for the short and medium intervals. Though this result was not predicted it is consistent with other research involving outdoor quantitative estimation. Proffitt and his colleagues consistently find a large overestimation of geographical slant when estimates are given verbally (Proffitt, Bhalla, Gossweiler, & Midgett, 1995, Proffitt, Creem, & Zosh, 2001). This finding is explained as being a result of psychophysical response compression: "Conscious overestimation of slant is adaptive and reflective of psychophysical response compression. Psychophysical response compression means that participants' response sensitivity declines with increases in the magnitude of the stimulus" (Proffitt, 2001). In their research they found that as the slant of the hill increased to an angle that would be difficult to walk, the magnitude of the overestimation increased. Proffitt and his colleagues belief that pragmatic considerations are a significant contributor to the magnitude of the estimate. This line of thinking can also provide an explanation for the interval length effect found in the current study. When the interval length reached several hundred meters, participants overestimated its length. This distance may be reaching the upper range of distances that an individual might generally walk with ease. As a result we would expect participants to experience psychophysical response compression which would decrease their estimation accuracy. Consistent with the work of Proffitt *et al*, the error is in the form of a significant overestimation. However, the argument would be more conclusive if effort of travel were scaled independently of estimates of distance traveled.

Distance Estimation

This study had three main objectives. The first was to determine if the laboratory research investigating distance estimation predicts distance estimation performance in outdoor environments. The previous research investigating distance estimation in the laboratory setting consistently found a positive relationship between distance estimates and the number of environmental features and contexts along a route. It was hypothesized that these features and contexts provided participants with methods for structuring their mental representations of the route. As the number of these structured route sections increased, so did the participant's estimates of the route's distance. We also saw that the laboratory research supporting this finding typically used routes that were simplifications of outdoor routes. Some of the simplifications included short routes and routes presented as simulations such as a slide show. An important question regarding this research addresses the generalizability of these results. Individuals that work in applied fields such as search-and-rescue and wilderness navigation are particularly interested in predicting human distance estimation in outdoor settings. Are the route simplifications in the laboratory research valid when the goal is to make predictions about distance estimation performance in the applied disciplines? The results of this study suggest that the answer to this question might be "yes".

The results showed that estimates of distance were consistently longer in the complex environments relative to the simple environments. This effect occurred in both the urban residential and forested trail environments. This result is directly consistent with the predictions made by the laboratory research.

This finding in itself is of significant importance in the future study of distance estimation. Researchers working solely in applied fields can with more confidence attempt to apply the predictions generated from laboratory research. Our data suggests that the processes of distance estimation in artificial and contrived environments may be the same as used in outdoor situations.

Time Estimation

The previous laboratory research investigating time estimation has yielded two main classes of theories used to explain estimation performance. These are the attention-based models associated with prospective time estimation, and the memory-based models associated with retrospective time estimation. The goal was to see which class of these theories best describes time estimation performance in outdoor environments.

When individuals are told prior to an interval that they will have to estimate its duration (prospective time estimation), it is argued that the amount of attention devoted to time monitoring is a critical factor in determining the magnitude of the estimate. In this situation, increasing the complexity or the engagement of the participant in the events of the interval is predicted to decrease the estimates of duration. When individuals are not informed until after the interval that they are required to estimate its duration (retrospective time estimation), it is argued that the individual's memory for the events of the interval are a critical factor in determining the magnitude of the estimate. In this situation increasing the complexity or the engagement of the participant in events of the interval is predicted to increase the estimates of duration.

In this experiment the time estimation tasks were entirely prospective. This implicates the attention-based models, but these models work on the assumption of high attentional demand that may not be present while walking along outdoor routes. The question is: do people typically use an attention-based timing system or a memory-based timing system when prospectively estimating the duration of a walk? As I will explain, the results of this study suggest that the answer is more likely a memory-based system, but the results are not entirely conclusive.

The results of the experiment showed an interaction of complexity with the route environment. It seems that increasing complexity significantly increased time estimates in the urban environment, but had no effect on the forested trail. The result from the urban environment is consistent with predictions of a memory based time estimation model. Increasing route complexity lengthened time estimates. Surprisingly, on the trail, route complexity seemed to have no effect on the magnitude of the time estimates. The differential predictions of the memory and attentional models suggest an increase or decrease in the estimates as a function of complexity, but it was not predicted that such effects would interact with the route environment.

One possible explanation for this finding may stem from the methods of route structuring discussed in the introduction. It was discussed that the memory representation for an interval can be structured by either grouping similar features (contextual change) or by segmenting between unique features (temporal landmark segmentation). The laboratory research demonstrated that both of these techniques could be employed under the right circumstances. In the design of this experiment, the method used to manipulate route complexity was to introduce more corners. Corners are route features that can be used as landmarks for segmentation. Our complexity manipulation introduced features appropriate for temporal landmark segmentation, but what if contextual change is the method used in outdoor walks when structuring mental representations for time estimates? If this were the case, increasing the number of corners should have no effect on time estimates, but increasing the changes in the context should. With this idea in mind, the routes used in the experiment were evaluated for possible contextual changes. Though the complex trail route had corners, it had little in the way of contextual change. From beginning to end, the route traveled through the same type of forest on a trail approximately the same width. In contrast, the complex urban route began on the sidewalk, traversed through a section of alleys, returned to the sidewalk, and then covered a section of grassy boulevard. It is possible that these route characteristics acted as contextual changes in the memory representations of the participants. The observed contextual changes in the complex trail and complex urban routes are consistent with time estimation within the contextual change framework. In the urban environment where contextual change appears to have been higher, time estimates were larger. In the trail environment where contextual change was lower, time estimates were smaller. Obviously this interpretation of the results is post-hoc. An interesting future study would be to explicitly test this explanation in a controlled experiment by having participants list and possibly rate environmental variations, as was done by Allen & Kirasic (1985) with a pictorial route.

The results of the time estimation data suggest that it is more likely that memory-based timing systems are employed when estimating the durations of outdoor walks. Neither of the route environments showed the signature of the attention-based models, a significant decrease in time estimates with increases in complexity. Though not conclusively, memory-based time estimation is implicated.

Rate

When the time and distance estimates were combined into derived estimates of rate, the analysis showed an interesting result. The derived rate estimates were significantly higher, relative to actual travel rate, in the trail environment than in the urban environment. The results suggest that the environmental characteristics of the forest produce a different perception of the rate of travel than does an urban environment. To explore how this might occur we can look at what characteristics of the environment are different in the urban route vs. the trail route. First, the urban environment provides much greater visibility of the route just traveled while the participants are looking back and generating their estimates. Secondly, the participants had greater visibility ahead while walking. Thirdly, different types of objects border the two routes (houses vs. trees) Fourthly, the urban environment provides a larger viewing area on the side of the trail during walking than does the trail route. Measurements showed that the average distance to the closest object exceeding 1 m in height, perpendicular to the direction of travel along the urban route was 7.1 meters, whereas it was only 1.4 meters along the trail route. This difference in the proximity of objects and what these objects were may have affected the way the route was perceived, remembered, and/or structured. For example, travelers along the trail route have restricted visibility, and thus see fewer distant landmarks. Also, as common landmarks and objects were different in the two environments and relatively closer the participants, they may have perceived that these objects passed by more quickly.

Gibson (1950, 1954) suggests one rich source of travel rate information is "optic flow". As most features in our environment are stationary, movement through the environment results in an optic flow; the movement of those features across our retina. Subsequent research has demonstrated that optic flow is a powerful determinant in our perception of self-motion. (for a summary see Lee, 1990). Research by Lee and his colleagues has demonstrated that optic flow is so powerful a source of information, it will determine our perception of self-motion even when it is inconsistent with the direction we are walking. Studies conducted by Owen (1990) specifically demonstrated that people are sensitive to changes in their own rate of travel given only optic flow information. It may be possible that the differences in object identity and proximity between the two routes resulted in different patterns of optic flow. More specifically, recent research by Chatziastros, Wallis, & Bülthoff (1999) has demonstrated that global spatial frequency of the optic flow pattern directly influences perceived rate of travel. Spatial frequency can be described as the overall texture of the environment. An environment that produces many small features in the optic flow pattern would be considered relatively high in spatial frequency. An environment that produces fewer and larger features in the optic flow pattern would be considered relatively low in spatial frequency. Chatziastros *et al* demonstrated that increases in spatial frequency result in increases in the perceived rate of travel, independent of actual velocity. It is possible that in this experiment the trail environment produced a higher pattern of spatial frequency relative to the urban environment. The leaves and twigs along the trail may produce many smaller features whereas objects such as buildings and cars found along the urban route may produce fewer and larger features. The trail environment may have produced a relatively higher spatial frequency in the optic flow pattern resulting in a relative increase in the perceived rate of travel.

Conclusions

The data collected in the study were used to address three objectives. First, the participant's estimates of distance showed a pattern that was consistent with the predictions made by the laboratory studies. This consistency suggests that the results from simplified and/or simulated routes typically used in laboratory research generalize to outdoor environments. Secondly, the participant's time estimates lend support to the idea that memory-based models, rather than attention-based models, are more appropriate for interpreting the results gathered in outdoor environments. It seems that retrospective models more accurately predict performance in outdoor environments even when the task is made explicitly prospective. Finally, analysis of the derived rate estimates suggests that the perception of travel rate may be effected by the characteristics of the route, and that the proximity and identity of objects along the route may be the source of the differences in derived rate accuracy.

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