INFLUENCE OF MOTIVATION ON WAYFINDING

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This research explores the role of affect in the domain of human wayfinding by asking if increased motivation will alter the performance across various routes of increasing complexity. Participants were asked to perform certain navigation tasks within an indoor Virtual Reality (VR) environment under either motivated and not-motivated instructions. After being taught to navigate along simple and complex routes, participants were tested on both the previously learned routes and new routes that could be implicitly derived from the prior spatial knowledge. Finally, participants were tested on their ability to follow schematized instructions to explore familiar and unfamiliar areas in the VR environment. Performance of the various spatial tasks across the motivated and control groups indicated that motivation improved performance in all but the most complex conditions. Results of the empirical study were used to create a theoretical model that accounts for the influence of affect on the access of route knowledge. Results of the research suggest the importance of including past knowledge and affect of the traveler as components of future wayfinding systems.

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PREFACE

I would like to thank each and every member of my thesis committee for all the help, guidance, advice and scientific insights provided to me through the early and later stages of my work. I would like to thank Dr. Michael Lewis, Dr. Peter Brusilovsky, Dr. Hassan Karimi and Dr. Marek Druzdzel, for supporting me through various stages of my life at the School of Information Sciences (SIS). A special thanks to Dr. Alexander Klippel for his continuous support and encouragement that began during our very first interaction and continues to this day. A special thanks also to the Spatial Cognition community for their support and recognition of my work at various conferences across the globe. I thank all my friends and colleagues at the University of Pittsburgh for their continuous encouragement, support and feedback. I would also like to extend my gratitude to the entire SIS community for their constant support through the years. Finally, I would like to thank my family and my advisor Prof. Stephen C. Hirtle, without whom none of this would have been possible—I dedicate this work to them.

1.0 INTRODUCTION

Imagine a scenario where you are on a leisurely stroll through a familiar neighborhood park. Imagine a second scenario, where you are trying to find your way through an unfamiliar airport, and you are running late to catch your flight. The wayfinding tasks represented in these two scenarios are performed under varying conditions. The parameters of these conditions include motivation, time constraints, and familiarity. This research attempts to explore the performance of wayfinding tasks of varying degrees of familiarity and route complexity, which are performed under varying task conditions. Furthermore, this research explores the effectiveness of presenting schematized route directions, which are based on the prior knowledge of a wayfinder, under constrained and non-constrained conditions.

1.1 ISSUES

1.1.1 Spatial Familiarity and Route Directions

A common problem in spatial domains is that of giving and following route directions to get from one place to another. Over the past several decades, there has been a considerable amount of research conducted on the nature and quality of route directions. While there are many instances where wayfinding tasks take place in a region that is completely familiar or unfamiliar, Srinivas and Hirtle (2007) considered situations where wayfinding tasks take place in a partially familiar environment that is composed of a familiar portion and an unfamiliar portion along a single route. It is a common occurrence that wayfinder's sometimes travel from a region of familiarity to a region of unfamiliarity, or vice versa, from an unfamiliar region to a familiar region. An example would be a wayfinder's first time visit to a neighboring town (the unfamiliar region) from her residential neighborhood (the familiar region), or returning home (the familiar region) having been driven by colleagues to a restaurant in an unfamiliar neighborhood (the unfamiliar region). In their work, Srinivas and Hirtle consider this case of a partially familiar route. They introduced the concept of schematization of routes descriptions based on prior knowledge of a wayfinder, and present a formalization that models routes of this nature with empirical evidence to support participant's preferences for this knowledge based schematization. The evidence they presented suggests that participants preferred route descriptions that were schematized on the basis of the individual wayfinder's prior knowledge in that familiar regions were only described briefly, while unfamiliar regions were described in detail.

This dissertation extends on the concept of a partially familiar route to include the possible influence of affect on the differential access to route knowledge by means of an empirical study. I use the term affect, in a broad sense, which describes internal states such as moods, motivation, anxiety, emotion and related feeling states (Barrett & Russell, 1999; Russell, 1980; Smith & Kosslyn, 2007). Results of the empirical study are used to create a theoretical model that accounts for the influence of affect on the access of route knowledge. Results of the empirical study and the extensions to the theory of partially familiar routes have implications for the design of future wayfinding systems.

1.1.2 Role of Affect in Wayfinding

Human wayfinding tasks involve complex information processing and decision making that usually involves access to acquired or deduced spatial knowledge (Golledge, 1999; Medyckyj-Scott & Blades, 1992). Human cognition, in general, and spatial knowledge, in particular, is an important factor that may determine the design and presentation of cognitively adequate maps or route directions. However, recent studies have also shown that affect influences human cognition (Smith & Kosslyn, 2006).

Emotion, as a primary component of affect, has been shown to affect our rational thinking, information processing, memory, reasoning, judgment and decision making (Damasio, 1995; Forgas, 2000; Smith & Kosslyn, 2006). Given that our cognitive abilities are influenced by affect, it is interesting to investigate the possible influence that affect may have on wayfinding tasks. Motivation was used as an example of an affective state (the notion of motivation as an affective state is consistent with the circumplex model of affect as described by Barrett and Russell (1999; Russell, 1980). In the empirical study, spatial tasks and experimental conditions were designed to analyze interactions between motivated and not-motivated tasks—across routes that were learned previously, and new or deduced routes.

Results from this experiment, and recent results from related studies (Brunyé, Mahoney, Augustyn, & Taylor, 2009), justify an expansion on the theory of *Knowledge Routes* as introduced by Srinivas and Hirtle (2007) to incorporate an affective component. The theory introduced as part of this dissertation, considers spatial knowledge as a factor of an individual's 'state of mind' i.e., affect, prior knowledge, time and attention; as opposed to the individual's prior knowledge alone.

This work can serve as a basis for future design of GPS and navigation systems that take affect and wayfinding into account. For instance, future GPS systems may direct users through routes based on the user's prior spatial knowledge and current affective state. Such a hypothetical system especially gains importance as recent work by artist and teacher Chiristian Nold, on 'Bio Mapping,' has shown that participants find certain areas of cities more stressful than others (Staedter, 2006). Results of this work and related research indicate that under motivated driving conditions or under high arousal states, longer less complex routes might be optimal. Recent advancements in physiological sensing and estimation of drivers stress level are important practical developments that will facilitate this process (Healey & Picard, 2005; Lin, Leng, Yang, & Cai, 2007). The "smart wheel" developed by Lin and colleagues enables the sensing of physiological metrics that will allow vehicles to interpret drivers affective state. Given these recent advances in detecting and inferring stress levels, this research will likely gain more importance in the near future.

1.2 ORGANIZATION OF THE THESIS

The thesis is organized as follows. The background to the literature and details of related work is provided in Section 2.0 The experiment design is presented in Section 3.0 The results are presented in Section 4.0 an extension to a theory is presented in Section 5.0 and the discussion is presented in Section 6.0

2.0 BACKGROUND AND RELATED WORK

This chapter begins with a summary of the interdisciplinary field of spatial cognition in Section 2.1. This is followed by a summary of the research carried out in the area of affect and cognition in Section 2.2. A detailed review of the work in the field of affect and spatial cognition is given in Section 2.2.1 Section 2.3 begins with a detailed review of adaptive wayfinding systems. The knowledge route theory is reviewed in Section 2.4. Finally, Section 2.5 lists various related wayfinding studies conducted in virtual environments.

2.1 SPATIAL COGNITION

Over the last few decades, there has been a considerable amount of work in the interdisciplinary field of spatial cognition. Contributions to the field are made by psycholinguists (Klein, 1982, 1983; Talmy, 1975; Wunderlich & Reinelt), geographers, psychologists, and computer scientists (Agrawala & Stolte, 2001; Allen, 1997; Daniel & Denis, 1998; Fontaine & Denis, 1999 ; Golledge, 1999; Hirtle & Hudson, 1991; Klippel, 2003a; Mark, Freksa, Hirtle, Lloyd, & Tversky, 1999; Raubal, Egenhofer, Pfoser, & Tryfona, 1997; Streeter, Vitello, & Wonsiewicz, 1985; Tom & Denis, 2003; Tversky & Lee, 1999). Spatial cognition is the field that is concerned with how humans think about space. The scale of the space in question can range from a few feet—a desktop space, to a few miles or more—a city or country. A great amount of work in spatial cognition deals with the issue of wayfinding. Wayfinding studies typically occur in a small scale space (e.g., inside of a building), medium scale space (e.g., college campus) or large scale space (e.g., a neighborhood) (Freundschuh & Egenhofer, 1997). Wayfinding studies analyze human's wayfinding behavior and ability. Wayfinding studies have shown that wayfinding tasks involve complex cognitive processes that involve access to acquired or deduced spatial knowledge (Golledge, Dougherty, & Bell, 1995; Golledge & Spector, 1978; Hirtle & Hudson, 1991).

Given the complexities of wayfinding tasks, the nature of wayfinding studies is varied. Wayfinding studies may look at the wayfinder's navigation behavior in familiar or unfamiliar environments (Streeter et al., 1985), the study of route directions (Denis, Pazzaglia, Cornoldi, & Bertolo, 1999; Fontaine & Denis, 1999), a wayfinder's acquisition of spatial knowledge (Golledge, 1992), a wayfinder's conceptualization and internal representations of space (Mark et al., 1999; Tversky, 1993), a wayfinder's interaction with navigation aids (Krüger et al., 2004; Streeter et al., 1985) and the importance of landmarks (Raubal & Winter, 2002; Sorrows & Hirtle, 1999; Tom & Denis, 2003).

A large amount of research in the field of spatial cognition deals with the study of wayfinding through unfamiliar environments. Wayfinder's are usually provided with navigation aids, or some information (or description) of the environment prior to travel. The wayfinder's navigation behavior is recorded and analyzed. These empirical studies help us learn about a wayfinder's navigation behavior in unfamiliar environments. For example, Streeter and colleagues provided participants with three kinds of navigation aids and analyzed participants wayfinding behavior through unfamiliar environments (Streeter et al., 1985). Results of their work help us learn about wayfinding behavior in unfamiliar environments and also have implications for the design of navigation aids.

Studies have also dealt with wayfinder's familiarity with an environment. Here, a wayfinder is typically asked to describe a familiar space or describe travel through a familiar space. The descriptions gathered through the studies are analyzed and provide important information about human's conceptualization and cognition of space. The work on descriptions and depictions by Tversky and Lee (1999) serve as an example of such a study. Here, participants were asked to describe known routes using either verbal descriptions or pictorial depictions. Analysis of participant's responses revealed a common underlying semantics and structure for route maps and route directions.

A considerable amount of work of this nature is done in the study of route directions. While some studies required participants to travel an unfamiliar environment with the use of route directions prepared by the experimenter (Allen, 2000; Daniel & Denis, 1998; Denis et al., 1999; Streeter et al., 1985), other studies required participants to prepare route directions to describe travel through familiar environments (Fontaine & Denis, 1999 ; Mark & Gould, 1992; Tversky & Lee, 1999). These directions were analyzed by the experimenters on various measures. The kinds of environments for such studies also varied from familiar or unfamiliar environments (Lovelace, Hegarty, & Montello, 1999), or environments that varied in their physical characteristics, for example, underground subway versus city environments (Fontaine & Denis, 1999).

Study of a wayfinder's internal representation or conceptualization of a space is not limited to the study of route directions. Typically, various aspects of the wayfinder's internal spatial representation are elicited and then analyzed. This process reveals how humans store or represent spatial information in our cognitive system. Example of studies of this nature include those mentioned above that analyzed route descriptions provided by participants (Daniel & Denis, 1998) or studies that analyzed descriptions and depictions (Tversky & Lee, 1999).

A wayfinder's acquisition of spatial knowledge is also a significant area of interest in spatial cognition. Studies of this kind include exploring the concept of spatial familiarity (Gale, Golledge, Halperin, & Couclelis, 1990), exploring the concept of place recognition (Golledge, 1992), or exploring the effectiveness of various methods of spatial knowledge acquisition (Golledge et al., 1995).

A design of a wayfinding system and a wayfinder's interaction with a wayfinding system is in a large part dependent on the wayfinder's cognitive processes and abilities. Systems that are designed to take these considerations into account tend to reduce errors and improve the usability of the devices (Agrawala & Stolte, 2001; Klippel, Richter, Barkowsky, & Freksa, 2005). A large amount of work is dedicated specifically to the study of a wayfinder's interaction with a particular wayfinding system to analyze the effectiveness and efficiency of the system (Abowd, Mynatt, & Rodden, 2002).

The notion of landmarks has also received comprehensive attention. Landmarks have been found to play a key role in the wayfinding process (Presson & Montello, 1988; Raubal & Winter, 2002; Sorrows & Hirtle, 1999; Tom & Denis, 2003, 2004). Landmarks are usually locations of prominence which are popular among humans in a neighborhood or city. Landmarks have also been found to play an important role in the description of routes. This notion of landmarks has been extended further. Comprehensive surveys conducted as part of work in spatial knowledge acquisition reveals that, often times, locations that are considered "best known" or "landmarks", are locations that are tied to an individual's activity pattern—that is best known locations could be buildings that the individual may frequent (Gale et al., 1990; Golledge & Spector, 1978).

2.2 AFFECT AND COGNITION

Affect has historically been studied independently of cognition, but more recent studies have begun to look more closely at the relationship between affect and cognition (Dolan, 2002; Smith & Kosslyn, 2007). Researchers have approached this issue from a neurological perspective (Damasio, 1995; Dolan, 2002), or from a cognitive perspective (Brunyé et al., 2009; Forgas, 2000). Two broad approaches are used to capture the range of affective states. One approach is to define basic emotions, a primary component of affect (Ekman & Friesen, 1971). The basic emotions as described by Ekman and Friesen include Anger, Disgust, Fear, Happiness, Sadness and Surprise. The other approach is a dimensional approach that defines affective states on a continuum (Barrett & Russell, 1999; Russell, 1980). This approach involves modeling of affect on the dimensions of Valence (pleasant or unpleasant) and Arousal (activation or deactivation). According to this approach, motivation (as induced as part of this study) may be classified as an affective state with high arousal and positive valence. Each of the approaches just mentioned has its relative advantages depending on the context it is used.

In the field of affect and cognition, the relationship between affect, specifically emotion, and memory is of particular interest. Emotional arousal is known to enhance recollection (Christianson, 1992). For example, Heuer and Reisberg (1992) show that participants were able to remember emotional events better than neutral events. Kleinsmith and Kaplan (1963) show that higher percent of digits that were paired with high arousal words were remembered over time, while digits paired with low arousal words were forgotten over time, as shown in Figure 1.

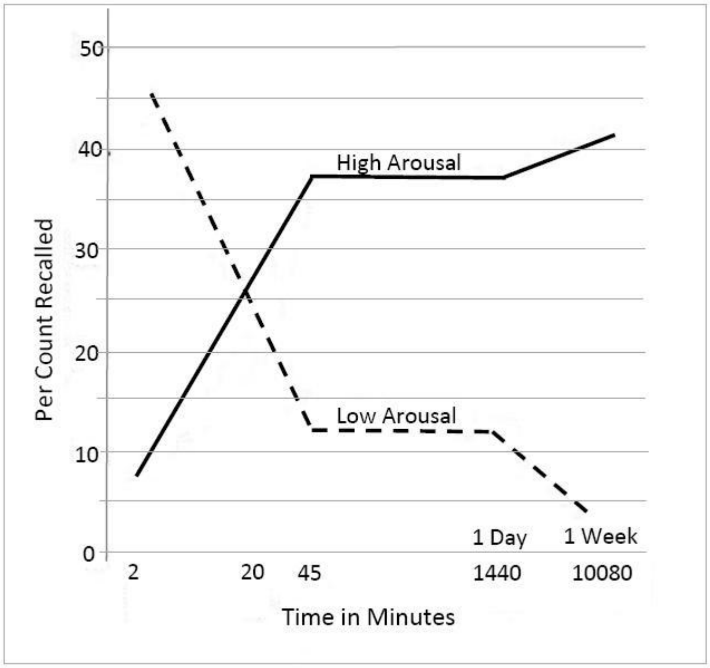


Figure 1. Differential recall of paired associates as a function of arousal level (Based on Kleinsmith & Kaplan, 1963)

The effect of affect, specifically stress, on memory storage tends to follow an inverted U-shaped curve, where moderate arousal is likely to enhance memory performance, whereas extreme or prolonged arousal response is likely to reduce memory performance, as shown in Figure 2 (see, Smith & Kosslyn, 2007, ch. 9). This is often referred to as the Yerkes-Dodson law named after their seminal work in the early part of the 20^{th} century (Yerkes & Dodson, 1908). However, as Teigen (1994) points out in his extensive review of arousal—performance studies—that the relationship between these factors can be complex. Teigen cautions that simplifying the relationship between stress and memory to an inverted U-shaped curve may not be accurate in all instances.

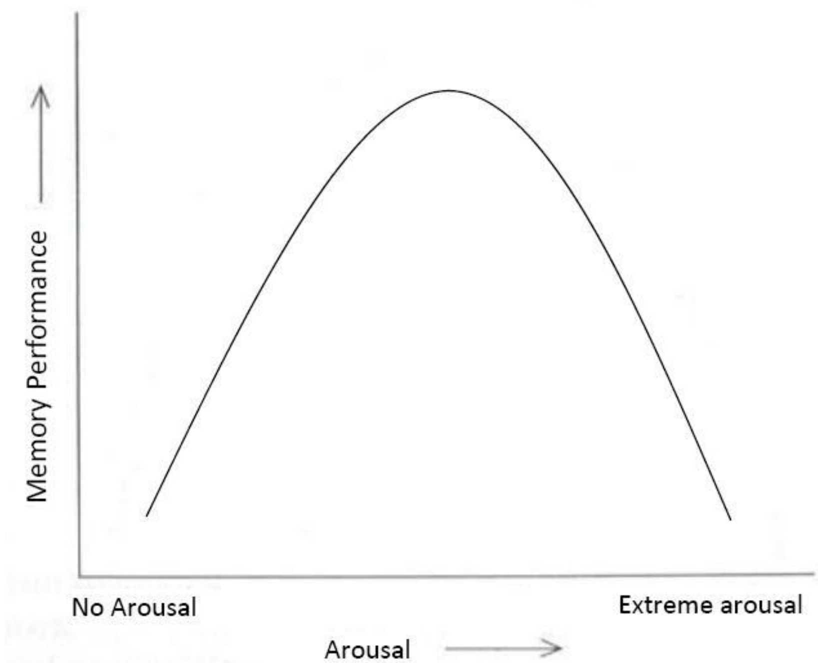


Figure 2. Typical relationship between memory performance and arousal

Closely related to stress is the effect of mood on memory. For example, Bower (1981) demonstrated that participants exhibited mood-state-dependent memory in the recall of word lists and experiences. Memory has also been shown to be influenced by highly emotional public events. Some relatively recent research in this area include studies of participants memories of events such as the 9/11 terrorist attacks (Talarico & Rubin, 2003), or the O. J. Simpson trials (Schmolck & Buffalo, 2000). These results have shown that while memories of emotional public events may not be entirely accurate, they are still more likely to be recollected to a higher degree than non emotional events over passage of time.

Affect has also been shown to interact with attention. For example, Pratto and John (1991) use a modified version of the Stroop test to demonstrate that undesirable words had a greater effect in distracting participants from the color naming task. In a more recent study, Fox and colleagues (2001) found that threatening stimuli tended to hold participants attention longer than neutral or positive cues. Affect has been found to capture attention and impair performance on a task. However, it has also been found to improve attentional processing. The “Face in the crowd” experiments have shown that threatening faces tended to stand out more than happy or neutral faces in search tasks (Hansen & Hansen, 1988; Ohman, Lundqvist, & Esteves, 2001).

Closely related to attention is the effect of affect on well learned or proceduralized tasks. Beilock and Carr (2001) found evidence that *performance pressure* (desire to perform well in a given situation) can induce *chocking* in proceduralized tasks. In their exploration of a golf putting task, the researchers first verify that golf putting by experts is indeed a proceduralized task that involves less attention paid to step-by-step execution. The researchers then demonstrate that performance pressure negatively effects performance of putting by golf experts—the proceduralized task. This evidence lends support to the *self focus* or *explicit monitoring* theories that explain chocking under pressure (Baumeister, 1984; Lewis & Linder, 1997). Explicit monitoring theories propose that choking under pressure is caused due to increased attention paid to well learned tasks that are usually conducted with little or no attentional resources. Explicit monitoring theories are a contrast to the *distraction theory* (Wine, 1971). The distraction theory proposes that performance pressure leads to a diversion of attentional resources away from the task performed, which results in choking.

2.2.1 Affect and Spatial Cognition

Work in the interdisciplinary field of affect and spatial cognition is relatively less common. While there is considerable literature in the field done on animals (Teigen, 1994), research done on the effect of affect on human spatial cognition is relatively scarce. Some early work has looked at human performance in stylus maze tasks as a function of anxiety (Farber & Spence, 1953; Matarazzo, Ulett, & Saslow, 1955) and punishment (Vaughn & Diserens, 1930). Matarazzo and colleagues (1955) investigated the proposed curve or functional relationship between anxiety and performance in a stylus maze experiment that served as a complex task. Their results indicated a U shaped function with time as the learning criteria, where moderately anxious participants performed better than participants with low or high anxiety levels. The results also show a rectilinear function with 'number of trials' as the learning criteria. Farber and Spence (1953) investigated the influence of drive on the performance across a stylus maze task with varying levels of complexity. They compared the performance of an anxious and non-anxious group (with the assumption that anxiety reflects drive level), on a stylus maze task consisting of varying levels of complexity or difficulty. They found that drive level improved performance on simple tasks but reduced performance on complex tasks. These results were similar to those found by Vaughn and Diserens (1930), who investigated the relationship between efficiency and learning in a stylus maze task, as a function of punishment.

More recent work in the area of affect and wayfinding looks at detecting drivers stress with driver safety as the principle goal (Healey & Picard, 2005; Lin et al., 2007). Healy and Picard (2005) investigate the reliability of physiological measures in indicating a driver's stress level. In their study, the investigators attached physiological sensors to measure driver's skin conductivity and heart rate metrics. Participants performed real world driving tasks across varied conditions of rest, city, or highway driving conditions. The results of their research suggest that physiological sensing can be used to determine varying levels of drivers stress in a real world driving task. The investigators suggest that detecting stress levels of a driver in driving conditions might prove useful in customizing the driver's 'in vehicle environment'. A small but important technical step in precisely this direction was taken by Lin and colleagues (2007) who developed a "smart wheel". The device was shown to satisfactorily measure a driver's pulse wave, breathing wave, skin temperature and gripping force in real time. Lin and colleagues state that such a system would prove useful in enhancing driver safety. The most recent research in the field of affect and spatial cognition investigated the effects of affective state on memory for map-based information (Brunyé et al., 2009). In their research, Brunyé and colleagues demonstrated that arousal amplifies symbolic distance effects and leads to a globally-focused spatial mental representation.

2.3 ADAPTIVE WAYFINDING SYSTEMS

A well established method of improving usability in information systems is to tailor the presentation of the system output to a particular user's goals, need or preference. Such "Adaptive Systems" are well established in the field of education and online information systems (Brusilovsky, 2001, 2007; Kaplan & Fenwick, 1993). More recently, the field of adaptive systems has extended into the domain of mobile guides (Kray & Baus, 2003; Kruger, Baus, Heckmann, & Kruppa, 2007). These mobile guides may range from travel guides (Cheverst, Mitchell, & Davies, 2002; Simcock, Hillenbrand, & Thomas, 2003) to personalized navigation systems (Baus, Krüger, & Wahlster, 2002). An important factor in adaptive systems is the content that is adapted and the factors that determine the adaptation. For most adaptive mobile guides, the content adapted is the presentation of output in the form of route directions or maps. The main factors that determines adaptation, is the user's location and the available resources.

The GUIDE adaptive mobile system was designed to replace the generic tourist guide, given that the generic tourist guide is designed for multiple users and may contain information that may not be of interest to a particular individual (Cheverst et al., 2002). The system was designed to provide visitors with up-to-date and context aware information while they visit the city of Lancaster, England. The information presented to users was adapted based on the user's location, personal interest and the visitor's personal profile (e.g., set of locations already visited). The system could use this information to tailor its output to an individual's activity pattern. For example, if the user returns to an attraction that was previously visited, the system could display a message to welcome the user back to that attraction. User experience with the system was found to be positive, suggesting that user's felt "reassured" with information presented in this manner. Simcock and colleagues (2003) develop another tourist guide that tailors information for a particular user based on user's location, accounting for nearby attractions, buildings in view, and public utilities. In their paper, Simcock and colleagues present some of the technical challenges related to presenting context aware information given resource limitations (e.g., small screen size, low bandwidth) of mobile systems.

Baus and colleagues (2002) present a system that takes into account the various transportation means employed during navigation. In their work, they suggest that personal wayfinding may often take place across various modalities (e.g., walking and driving). Hence, they present an adaptive mobile wayfinding system that takes into account various factors that might change across these modalities. Their hybrid system was developed to account for the various positioning techniques used across these modalities, and work toward providing the user with a seamless transformation between these modalities.

Work in the area of adaptive mobile systems has primarily involved the adaption of output based on user's location and resources of the mobile device. More recent work in this area has included the modeling of user's affective or belief states (Bianchi-Berthouze & Lisetti, 2002; Hudlicka & McNeese, 2002). Hudlicka and McNeese (2002) present an adaptive interface system named–Affect and Belief Adaptive Interface System (ABAIS). The ABAIS senses or infers a user's affective state, and performance relevant beliefs. ABAIS identifies the potential impact of the user's affective state on their performance. The system then selects a compensatory strategy and implements this strategy in terms of specific GUI adaptations. The user's affective profile is updated by various means, including but not limited to self-reports and physiological sensing. The system's bias prediction is based on empirical findings in affect research combined with knowledge of the context of the task. In closely related work, Bianchi-Berthouze and Lisetti (2002) develop a modeling technique that is designed to sense a user's affective state and adaptively build concepts of affective states based on user feedback.

Another important and closely related stream of work is the modeling of user's knowledge with the goal of tailoring output of route directions or maps, to the user's mental representations, or prior route or survey knowledge (Patel, Chen, Smith, & Landay, 2006; Schmid, 2008; Schmid & Richter, 2006; Srinivas & Hirtle, 2007; Tomko & Winter, 2006). Researchers have followed two broad approaches in an effort to tackle this issue. One approach is to develop algorithms and systems that help generate system output that is tailored to an individual's personal knowledge or mental representation (Patel et al., 2006; Schmid, 2008; Schmid & Richter, 2006; Tomko & Winter, 2006). Another approach is to develop theoretical models that represent routes of this nature (Srinivas & Hirtle, 2007). Work by Schmid and Richter (2006) involved the extraction of “places” from location data streams. These places are extracted from a continuous input of data about the user. The algorithm developed by them uses a clustering technique to cluster incoming data with previous records. The clustering algorithm has a high data sampling rate and a low threshold for clustering. This allows for differentiating between locations at a high level of granularity, e.g., a junction at a signal, or a corner of a street, where a wayfinder may stop often. Schmid (2008) also implements a prototype solution for presenting users with personalized knowledge based route information on maps for small displays. In his work, Schmid also discusses some relevant prototypical spatial configurations and assistance scenarios in detail. In another system driven approach to the problem, Patel and colleagues (2006) present a routing technique that incorporates knowledge of known locations and landmarks in presenting what they term “personalized” routes to the wayfinder. These personalized routes consist of simpler directions with less route direction elements, which in turn, reduce the cognitive load of the wayfinder. While the system does not sense user information, the researchers do address an important problem of automatically generating personalized routes based on user familiarity.

2.4 KNOWLEDGE ROUTE THEORY

Srinivas and Hirtle (2007) present an alternative approach to the issue of personalized routes. They present a theoretical model that helps represent known and unknown regions along the same route. An example of such a route would be a wayfinder’s travel from his home to a new city. They refer to these routes as partially familiar routes or knowledge routes (*k-routes)*[1]. One of the most basic forms of a knowledge route (<k-route>) is one which incorporates a familiar route segment (<K>) within a known region and an unfamiliar route segment (<N>) within an unknown region, along the same route, shown in Figure 3. This gives the most basic form of a partially familiar route. The braces indicate that the order of <K> and <N> can be interchanged.

<k-route> ::= <O> {<K> <N>} <D>

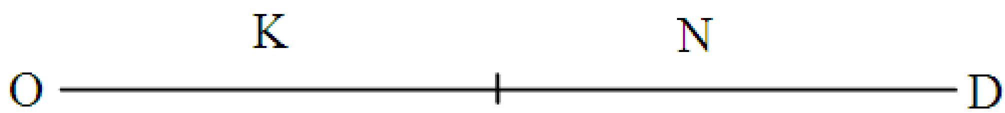


Figure 3. The most basic form of a k-route

The knowledge route theory identifies points along the familiar portion of the route as known locations (KLs). A KL can be one of three types of points: (1) a well-established landmark within a neighborhood, (2) a familiar building that is often frequented, even if it does not rise to 'landmark' status, and (3) the intersection of two segments along a route that the user is able to locate during navigation. Thus, a KL is defined as a point along a route that a person is confident of being able to navigate to while in the K region of the route. They use the concept of KLs in producing schematized route directions and list three broad categories of KLs. One is a local landmark (e.g. "The Capitol"), the second is a building or address that an individual may frequent (e.g. "Hillman Library"), and the third is a decision point (e.g. "Bates Street entrance ramp to I-376"). While decision points and landmarks have been studied extensively (Daniel &

[1] These have been called kroutes by Srinivas and Hirtle (2007), but I use the notation k-routes as it more accurately represents the way it is pronounced.

Denis, 1998; Klippel, 2003b; Lovelace et al., 1999; Presson & Montello, 1988; Raubal & Winter, 2002; Sorrows & Hirtle, 1999; Tom & Denis, 2003), concepts relating to the second category of KLs have been the focus of relatively fewer studies in the past (Gale et al., 1990; Golledge & Spector, 1978; Tom & Denis, 2004).

The third concept they introduce is a special case of a KL which is the KL that is closest to or at the intersection of a <K> and <N> segment of a route, called a known decision point and denoted as <DPk>. DPk's are the transition points between a known region and an unknown region. Thus <K> can be decomposed into (known) route segments <seg> and known decision points <DPk>. An <N> can be decomposed into (unknown) route segments <seg>. Upon inclusion of this concept, the basic form of a <k-route> is further represented as.

<k-route$_{f:u}$> ::= <O> <K> <N> <D>

<K> ::= <seg> <DPk>

<N> ::= <seg>

Instructions to the wayfinder would consist of "Travel to <DPk>" followed by detailed instructions from that point on. Travel may also take place from unknown regions to known regions—modeled as NK— wherein the N region immediately follows the origin O. Here, the alternative case is represented.[2]

<k-route$_{u:f}$> ::= <O> <N> <K> <D>

<N> ::= <seg>

<K> ::= <DPk> <seg>

In this case, instructions to the wayfinder would consist of detailed instructions to <DPk> and then the single instruction of head to <D> to complete the route.

[2] The subscript is used to distinguish a knowledge route ordered fam:unf from a knowledge route ordered unf:fam. However, in the future the subscripts will be left off as the ordering will be clear from the context.

Other models for coding familiarity include KNK, NKN which include routes with exactly one K and two N regions or vice versa. Routes such as KKN or KNN need not be considered, since they can both be represented as just KN by collapsing over similar regions. In the interest of completeness, Srinivas and Hirtle present the $KNKN^+$ and $NKNK^+$ models, the components of these models can be formed by combining individual concepts from the KN, NK, NKN and the KNK models.

Along with the concept of knowledge routes, Srinivas and Hirtle (2007) introduce the concept of *knowledge chunking* of route direction elements. Knowledge chunking involves grouping all the segments in the region of K into one 'knowledge chunk.' These concepts for coding familiarity, and knowledge chunking, serves as a basis to generate route directions that are schematized based on a wayfinder's prior knowledge—a concept that the authors refer to as "Knowledge-based schematization." The knowledge route theory forms the theoretical basis for the empirical study. Section 3.0 lists details of the theory as are relevant to the research design. Extensions to the knowledge route theory are presented in Section 5.0

2.5 WAYFINDING STUDIES—VIRTUAL REALITY (VR) ENVIRONMENTS

Wayfinding studies have typically been conducted in real environments (Allen, 2000; Schmitz, 1999; Streeter et al., 1985), and more recently, in virtual environments (Bakker, Werkhoven, & Passenier, 1999; Cutmore, Hine, Maberly, Langford, & Hawgood, 2000; Gillner & Mallot, 1998; Golledge et al., 1995; Jansen-Osmann, 2002; Richardson, Montello, & Hegarty, 1999; Riecke, van Veen, & Bülthoff, 2002; Rossano & Reardon, 1999; Rossano, West, Robertson, Wayne, & Chase, 1999; Ruddle, 2005; Ruddle, Payne, & Jones, 1998; Steck & Mallot, 2000). Allen (2000) investigated principles and practices in the communication of route knowledge with a real test environment that included a college campus, a residential area and a commercial area along the same route. Allen found that route direction protocols that were consistent with principles-based practices resulted in greater wayfinding success than the protocols that were inconsistent with these practices. Some of these practices included, a) presenting directions in a correct and natural temporal-spatial order, b) concentrating information about choice points and c) using spatial designations that are common to most listeners—using mutual knowledge. Streeter and colleagues (1985) investigated the effectiveness of navigations aids—driving directions versus route maps, in a real world driving task. In their study, they used seven routes that were actual routes driven by employees of a local firm to their homes. The routes ranged in a distance from 3-20 miles and were divided into three categories-limited access, moderately difficult local route, and complicated local road categories. Their results suggest that taped (or voice) instructions, was a more efficient tool for communicating route information than route maps.

The study of wayfinding behavior in real world environments—conditions and circumstances permitting—are most ideal. Especially as subjects in most VR experiments remain seated or stationary; where the lack of proprioceptive feedback gained through walking could affect the spatial experience. Bakker and colleagues (1999), in their examination of this issue, found that the lack or kinesthetic feedback, or the presentation of visual flow alone, lead to inaccurate and unreliable orientation in participants. While there are currently efforts such as the development of the omni-directional treadmill to account for this, these solutions remain costly and hence cannot be easily employed (Bülthoff, Campos, & Meilinger, 2008). While VR is currently not yet an ideal replacement to a real world environment, it is also well accepted that controlling conditions in the real world is a significant hurdle that cannot always be overcome.

VR tools allow experimenters to control specific environmental conditions, manipulate variables that might not be possible in the real world, and allows for a realistic experience (Bülthoff et al., 2008). Given these advantages and recent advances in VR technology, recent studies in spatial cognition have involved the use of VR environments. These studies vary significantly in the kinds of research issues addressed. For example, in an effort to evaluate VR as a tool to study spatial cognition, Jansen-Osmann (2002) conducted a study in VR that attempted to replicate a desktop spatial cognition study conducted by Cohen and Schuepher (1980). The study investigated the role of landmarks in navigation. The original finding by Cohen and Schuepher was replicated in the study conducted in the VR environment providing a certain degree of validity to VR as a tool for spatial cognition study (Jansen-Osmann, 2002). Golledge and colleagues (1995) conducted a spatial cognition study to investigate the acquisition of route versus survey knowledge in unfamiliar environments. Golledge and colleagues used a walkthrough of a computer simulation as a test environment that resembled the interior of a building. The environment consisted of 90 degree turns, carefully chosen colored symbols were used as landmarks, and doors and windows were added arbitrarily to enhance realism. Rossano and colleagues (1999) conducted a similar study to investigate the nature of acquisition of route versus survey knowledge from computer models; when compared to the knowledge acquired through maps or direct experience. The VR environment in this study was a college campus. In a related study, Rossano and Reardon (1999) conducted a study to investigate the effect of goal specificity on the acquisition of survey knowledge. Goal specificity was found to interfere in the acquisition of survey knowledge of a virtual college campus.

3.0 RESEARCH DESIGN

3.1 PROBLEM

3.1.1 Purpose

The goal of the study was to explore the role of affect in the domain of human wayfinding. While there are a wide range of affective states defined in the literature (see, Smith & Kosslyn, 2007 Ch. 9), this study focused on the effect of motivation on a human wayfinding task. A VR Theatre was used to simulate the interior of a building. This was used as a test environment. Participants were asked to perform certain navigation tasks under normal (control) or motivated conditions. All participants learned to navigate along both simple and complex routes. They were later tested on these previously learned routes, as well as new routes that could be derived from the previously established spatial knowledge. Finally, participants were tested on their ability to follow schematized instructions to explore unfamiliar areas in the VR environment. The performance of the tasks across the two conditions was compared. Results of the empirical study were used to create a theoretical model, presented in Section 5.0 which accounts for possible influence of affect on the wayfinding task performance. Results of this research, including implications for the design of future wayfinding systems, are discussed in Section 6.0

3.1.2 Theory, Research Objectives and Scope

The original knowledge route (k-route) model is extended to include the situation where one learns certain routes in an area, but then needs to navigate by putting the known links in a new order, possibly reversing some of the links. For example, you might learn the route ABC and the route ECD, but now have to travel DCBA. From past knowledge, you can easily deduce the new route, but it would not reach the same level of ease as the known route. To account for this situation, the concept of deducedK is introduced as an extension of the knowledge route theory. DeducedK is knowledge of a route segment that is not explicitly established but may be derived from previously—explicitly established—spatial knowledge.

Stage 1 of the experiment was designed to investigate the influence of motivation on the access to established spatial knowledge—the K region of a knowledge route (k-route). As mentioned in Section 2.4, the most basic form of a k-route is a KN route. In Stage 1 of the experiment, the K region of the k-route is considered in isolation. This is therefore simply referred to as a K route (as compared to KN route). Stage 1 was also designed to investigate the influence of motivation on the access to deduced spatial knowledge. This type of route knowledge is referred to as deducedK. The routes in Stage 1 of the experiment that include deducedK segments are called deducedK routes. These routes consist of routes to locations that the participant has incidentally viewed as part of the training phase. Unlike the well established knowledge of destinations in a K route, participants were not explicitly trained to locate the destination of a deducedK route. Hence, traveling a deducedK route may involve the extra cognitive load of deducing the shortest path to the destination. Each kind of route, K and deducedK, had two levels of structural complexity—Simple and Complex. The final set of routes is referred to as SimpleK (SK), ComplexK (CK), SimpleDeducedK (SDK) or ComplexDeducedK (CDK) routes.

Finally, Stage 2 of the experiment was designed to investigate the effectiveness of schematized directions on wayfinding in familiar and unfamiliar environments under motivated and control conditions. The familiar and unfamiliar environments are part of the same route. These routes represent of the most basic k-route—the KN route—as mentioned in Section 2.4. The KN routes as part of Stage 2 of the experiment vary in the kind of knowledge, K or deducedK. They also vary in their structural complexity, Simple or Complex. Hence Stage 2 of the experiment is designed to investigate the effective of schematized directions when travelling through four kinds of KN routes—SimpleKN, ComplexKN, SimpleDeducedKN and ComplexDeducedKN routes.

3.1.3 Research Questions

Overall research question: How does motivation influence wayfinding task performance?

3.1.3.1 Confirmatory Research Questions

1. Does performance of a wayfinding task improve for the motivated group?
    a) Do the motivated instructions reduce time taken to travel a route?
    b) Do the motivated instructions result in fewer errors while travelling a route?
2. Is the effect of the motivated instructions greater for wayfinding tasks of higher complexity?
    a) Is the effect of the motivated task instructions greater for deduced routes?

b) Is the effect of the motivated task instructions greater for structurally complex routes?

3.1.3.2 Exploratory Research Questions

1. Are schematized directions for KN routes effective across varied task conditions?
2. Are schematized directions for deducedKN routes effective across varied task conditions?

3.2 METHOD

3.2.1 Participant Recruitment

Forty two participants were recruited through flyers posted around the University of Pittsburgh campus (Appendix A). Participants were paid $15 for their participation in the experiment that lasted between one to one and a half hours. Their ages ranged from 18 to 36, with a mean of 23 years. One participant was omitted from the analysis because of a misunderstanding of the instructions. Another participant was omitted from the analysis because of a lack of comfort with navigating the VR environment during testing. The resulting sample consisted of twenty female and twenty male participants.

3.2.2 Materials

The materials consisted of a standard test for working memory capacity (Smith & Kosslyn, 2007) and the Perspective Taking/Spatial Orientation Test (Hegarty & Waller, 2004). A background questionnaire and post-test questionnaire to record participant's experiences were administered (Appendix B and C). In addition, a separate questionnaire measuring the participant's confidence in locating landmarks within the learned space was given. A single projector (Epson Powerlite 730c) and a laptop (Lenovo T61) were used to present the VR environment. A standard Logitech BT96a optical wired mouse and the laptop keyboard were used for navigation control. The windows desktop screen capturing software Hypercam v.2 was used to record participant's movement through the VR environment.

3.2.2.1 VR Environment

Four VR environments were constructed, each consisting of a single floor in a building. The first environment was a practice environment with a simple H shape and landmarks in the opposite corners of the space. The second and third environments were used for training and testing in Stage 1. Both environments had a similar asymmetric layout, consisting of corridors and rooms with ten unique locations as shown in Figure 4. Each location was made up of a unique shape and color, and are referenced in Figure 4 using the upper case letters. Figure 5 shows one such location; the white arrow in Figure 5 corresponds to location 'B' in Figure 4. The training and test environments were identical in layout and placement of labels. The only difference was the placement of the invisible walls. In the training environment, the invisible walls were placed in a manner that allowed the participant to take no more than one wrong turn away from the main route at any intersection along the route. The placement of invisible walls is explained in more detail in Section 4.2.2. In the test environment, the invisible walls were placed in a manner that allowed the participant to take at most two wrong turns. Invisible walls in the test environment restricted exploration in areas off the main route, while still allowing the traveler some degree of independence. The fourth environment expanded the test environment to include unknown N

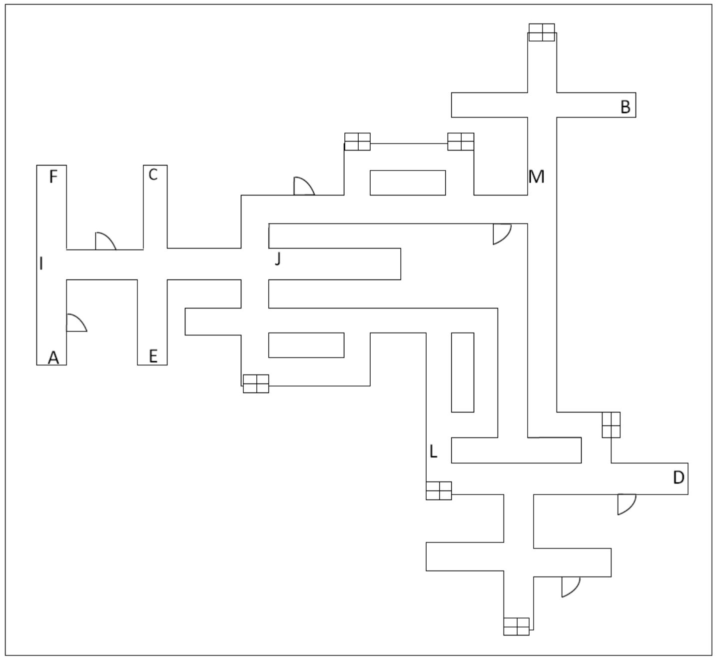


Figure 4. Layout of the training and test VR Environment for Stage 1.

regions. The details about the additions to this test environment that are used for the second stage of the experiment are given in Section 3.2.4.3.

In order to test performance across routes of varying complexity, the routes in the test environment satisfied certain predetermined factors. The factors were 1) Number of turns 2) Minimum number of forced views of each marked location (‘I,’ ‘J,’ ‘M,’ and ‘L’) during training phase (i.e. traversal of routes 1 to 4 during training phase ensures that each marked location ‘I,’ ‘J,’ ‘M,’ and ‘L’ is viewed at least twice), 3) Number of decision points, and 4) Minimum number of alternative (longer) routes. The factors and related details are listed in Table 1. Routes 1 to 4 were used in the training phase and the test phase, and routes 5 to 8 were used only in the test phase. Routes 1 and 2 were the SimpleK routes, while 3 and 4 were the ComplexK routes. Likewise, in the test session only, routes 5 and 6 were the SimpleDeducedK routes and routes 7

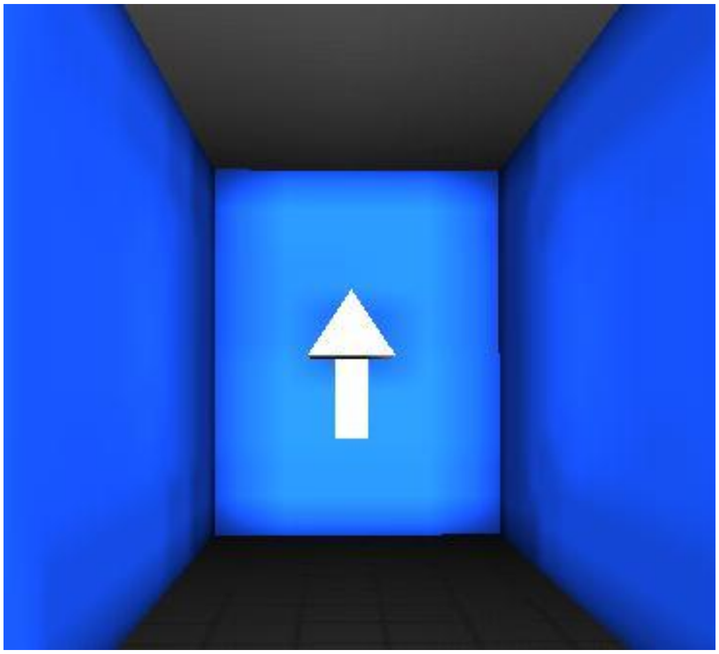


Figure 5. Snapshot of Location B - White Arrow

and 8 were the ComplexDeducedK routes. The ComplexDeducedK had the same structural complexity as a ComplexK route, however, the task of navigating a ComplexDeducedK route was estimated to be more complex. This is because deducing the shortest path to a new location was estimated to require extra cognitive processing. Likewise, a SimpleDeducedK route was estimated to require extra cognitive processing when compared to a SimpleK route (which has similar structural complexity). The varying levels of complexity within the routes were designed to answer the research questions as listed in Section 3.1.3.

Table 1. Details of K and deducedK routes

	Training and Testing Phase				Testing Phase			
	K				deducedK			
Route Complexity	Simple		Complex		Simple		Complex	
Route Number	1	2	3	4	5	6	7	8
Route Definition	A- J	C- I	A- B	C- D	B-M	D- L	B-E	D- F
Number of Turns	1	1	5	5	1	1	5	5
Min. Number of Forced views in Training Phase	2	2	2	2	2	2	2	2
Number of Decision points	2	1	7	8	1	2	6	9
Min. Number of Alternative (longer) Routes	0	0	2	2	0	1	2	2

3.2.3 Design

Participants were assigned to either the motivated (experimental) group or the not-motivated (control) group. A randomized block design was used with gender as the blocking criteria. Each group underwent an adaptation phase, a training phase and a test phase. The test phase consisted of two stages (as mentioned earlier). The following subsections lists details of the various phases of the experiment.

3.2.4 Procedure

3.2.4.1 Adaptation Phase

Prior to experimentation, all participants were allowed to get accustomed to the VR controls using the practice environment. Participants were asked to navigate between the two landmarks placed in this environment without walking into the walls of the corridors. Participants were judged to be comfortable navigating within the practice environment if they made no errors (did not touch the walls of the corridors) while navigating between the two landmarks.

3.2.4.2 Training Phase

Upon completion of the adaptation phase, participants in both groups underwent a training phase where they were asked to navigate and learn routes within the training VR environment. An overview of the environment (and the routes that were navigated) is shown in Figure 4. In this phase, participants entered the test environment at, for example, location ‘A’. They were given instructions to find a location within the space, e.g., find the “White Arrow” (shown in Figure 5 and corresponds to Location ‘B’ in Figure 4). Participants were informed that the route with the least turns is the shortest path. If the participant did stray from the shortest path, an invisible wall blocked their progress in the wrong direction. Hence, the training environment—by design—ensured that the participant followed the shortest path to an end location. The route taken by participants was observed. The task was repeated until the participant had navigated between ‘A’ and ‘B’ without deviating from the shortest path. Once the shortest path had been navigated without error, the participant was asked if they are confident in finding the destination, if the participant replied in the affirmative, then the path (Route 3 in this example, Table 1) was considered learned. The routes 1 through 4 (Table 1) were learned in this manner, with the order of routes counterbalanced across participants. Through the training procedure, it was assumed that knowledge of the four routes was established. These four routes served as the K region of our k-routes–our established route knowledge. As mentioned earlier, these are referred to as SimpleK or ComplexK routes. The terms Simple or Complex refer to the structural complexity of the route.

3.2.4.3 Test Phase

The test phase was conducted after the participants completed the spatial Perspective Taking/Spatial Orientation Test, which also served as the distracter task lasting five minutes. Participants in both groups (Motivated and Control) were instructed to find the shortest path to destinations in the test environment, some of which they were trained on in the training phase. Participants were informed that there was only one shortest path between each route. Participants were also informed that the shortest path between two locations was the route with least number of turns. In the control group, participants were asked to find their destination without any time constraint and were not offered a reward for completion in quick time. In contrast, participants in the motivated group were offered a reward for quick completion and were informed that their tasks were timed (details in the following subsection).

In the test phase each participant performed the navigation task in two stages. Stage 1 used the same environment, which had been well-learned and represented the known (K) area of the space. Stage 2 used an expanded version of the Stage 1 environment, as described below, and represented the both the known (K) and novel (N) area of the space. Each stage was designed to answer specific research questions listed in Section 3.1.3.

Stage 1. All participants were asked to find the previous set of four (Simple and Complex) K routes (Routes 1-4, Table 1), followed by a new set of four (Simple and Complex) deducedK routes (Routes 5-8 Table 1), and the order was counterbalanced within each set. The deducedK routes could be derived from the explicitly established route knowledge, but had not been directly traversed during the training phase. Hence this stage was designed to answer the confirmatory research questions as listed in Section 3.1.3.1.

Stage 2. In the second stage of the test phase, participants were provided with schematized directions and they were asked to find four KN and four deducedKN routes. The K routes (Routes 1-4, Table 1) served as the K segments of the KN routes and the deducedK routes (Routes 5-8, Table 1) served as the deducedK segments of the deducedKN routes. The N segments of the KN routes were added as extensions to the original VR environment. The corridors in the VR environment used in Stage 1 were opened in order to act as doorways to the unknown (N) regions that were added as part of Stage 2. Routes 9 to 16 of Table 2 extend routes 1 to 8 of Table 1. A sample VR environment with an extension (N) to route 3 of Table 1 is shown in Figure 6. Here, the origin remains the same, ‘A,’ but the new destination is point ‘X.’ The directions were schematized based on the participant’s prior knowledge. An example of the instructions given to participants is as follows, “You are currently facing the Green triangle. 1) Go to the “White Arrow.” 2) Walk past the white arrow and take the Second Right, 3) Take the

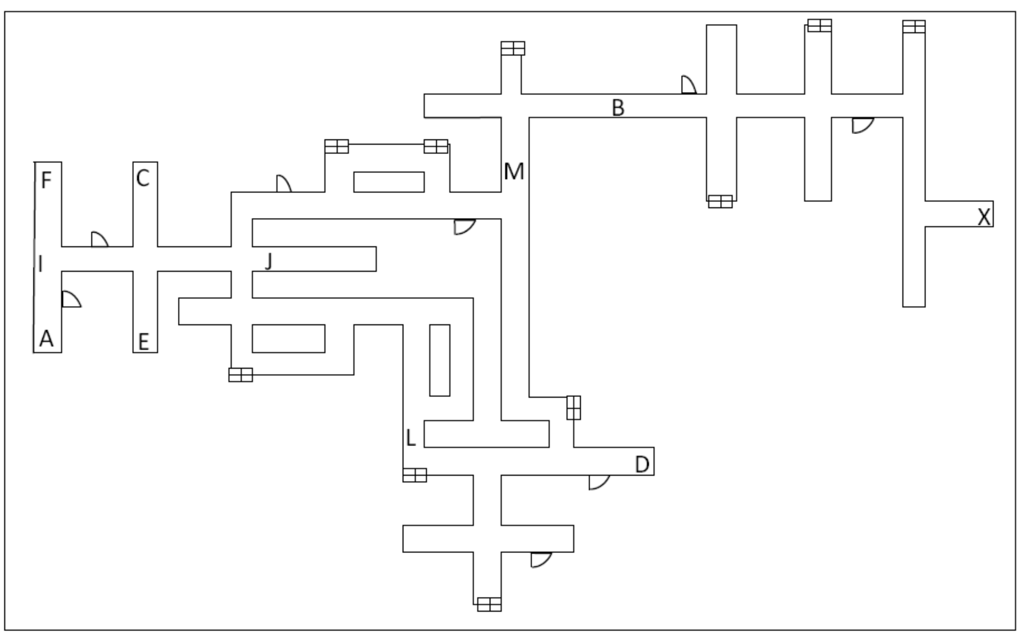


Figure 6. Layout of the test VR environment for route 11(ABX) in Stage 2

First Left, 4) You will stop at the end location marked with a yellow check mark." Details of the four KN routes and four deducedKN routes are listed in Table 2.

Measures. Measures included time to completion and number of wrong turns. Participant's movement through the VR environment was recorded using a screen capturing software. This enabled repeated playback of the route taken. Participants indicated that they were ready to begin the wayfinding tasks by clicking on the left button of the mouse, which resulted in a flash on the screen. This was recorded as the start time. Participants were then provided with the route directions and continued to proceed with their wayfinding task. The end time was recorded the moment a participant reached their target location. Thus the recorded time includes time spent in reading the route directions, any time spent in planning the route, and time taken to move through the environment to find the target location. Hence the reaction time measured includes both the planning time and movement time (Klatzky, Fikes, & Pellegrino, 1995). A directed movement away from the shortest path into the wrong hallway was recorded as a wrong turn.

Table 2. Details of KN and deducedKN routes

	KN				deducedKN			
Route Complexity	Simple		Complex		Simple		Complex	
Route Number	9	10	11	12	13	14	15	16
Route/path definition	AJZ	CIP	ABX	CDY	BMS	DLT	BFQ	DER
Number of Turns (K+N)	1+2	1+2	5+2	5+2	1+2	1+2	5+2	5+2
Number of Decision points (K+N)	2+2	1+2	7+3	8+3	1+2	2+2	6+3	9+3
Minimum Number of Alternative (longer) Routes	0	0	2	2	0	0	2	2

3.2.4.4 Inducing Motivation

In the motivated group, participants were instructed to perform the task "as fast as they can." Participants were asked to imagine working under a time constraint and that time was critical. The participants were also given an estimated average time for completing the task. It was recommended to participants in this group that in order to be eligible for the reward they must, at the very least, finish within that average time. This group was offered an additional reward of $15 if their performance (time to completion) ranked among the top five best performances of all participants.

At the end of the experiment, as part of a post-test questionnaire, all participants were also asked to rate the extent they felt motivated, rushed, or excited during the test phase.

4.0 RESULTS

4.1 SPATIAL ABILITIES AND LEARNING

Two standard tests were administered in order to assess any potential differences in memory or spatial skills. No differences were found. Participants' performance on the standard test for working memory capacity and the Perspective Taking/Spatial Orientation Test did not differ significantly across the motivated and control groups (alpha level .05; same in the analyses below). In order to establish whether working memory capacity or spatial orientation ability had an effect on performance, associative analyses were conducted between working memory capacity and spatial orientation ability and wrong turn and time, for each of the four kinds of routes. No significant correlations were found. Figure 7 shows the scatter plots of spatial orientation ability, working memory capacity and time for participants in control and motivated conditions. Figure 8 shows the scatter plots of spatial orientation ability, working memory capacity and wrong turns for participants in control and motivated conditions. Upon completion of training and prior to each stage of the test phase, participants were queried on their confidence levels in locating landmarks. A seven point Likert item was used. There were no differences in reported confidence levels across the two groups. This implies that landmark identification across the two groups prior to each stage of the test phase was the same.

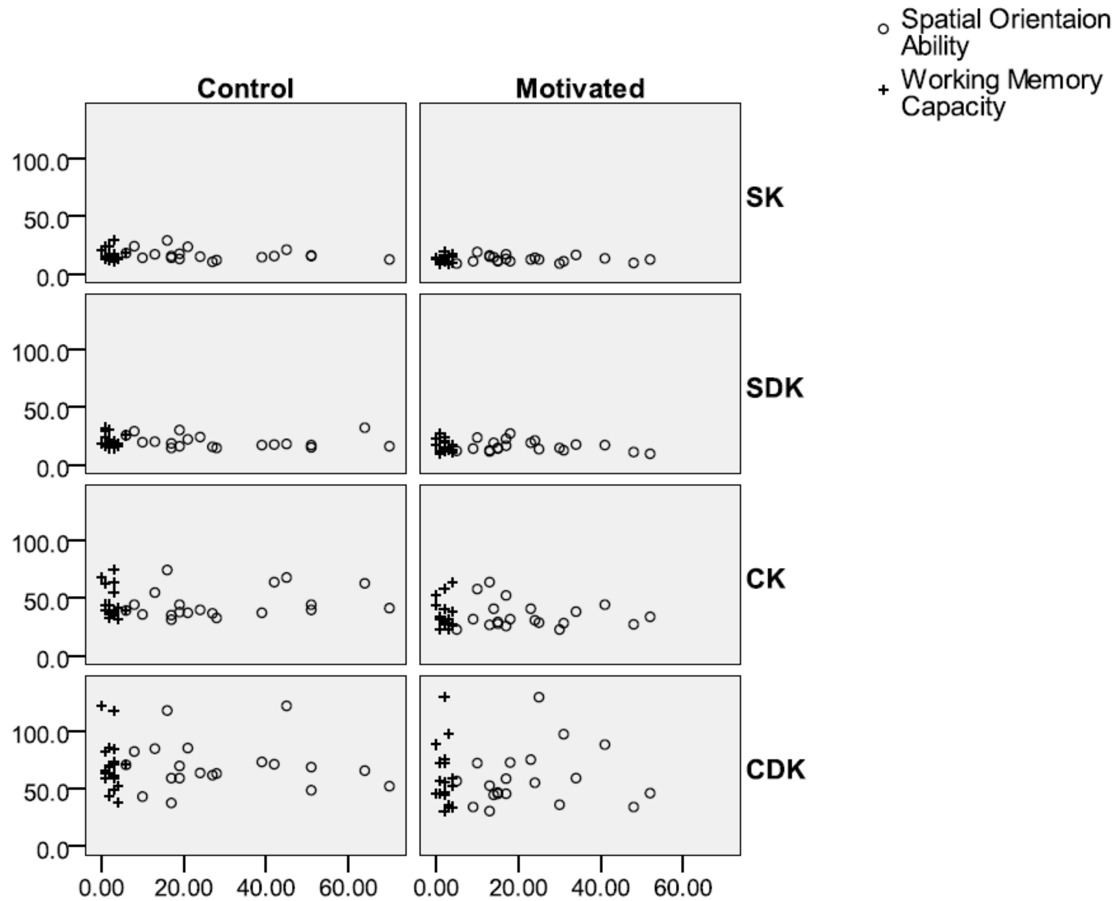


Figure 7. Scatter plots of spatial orientation ability, working memory capacity and time (Control and Motivated groups)

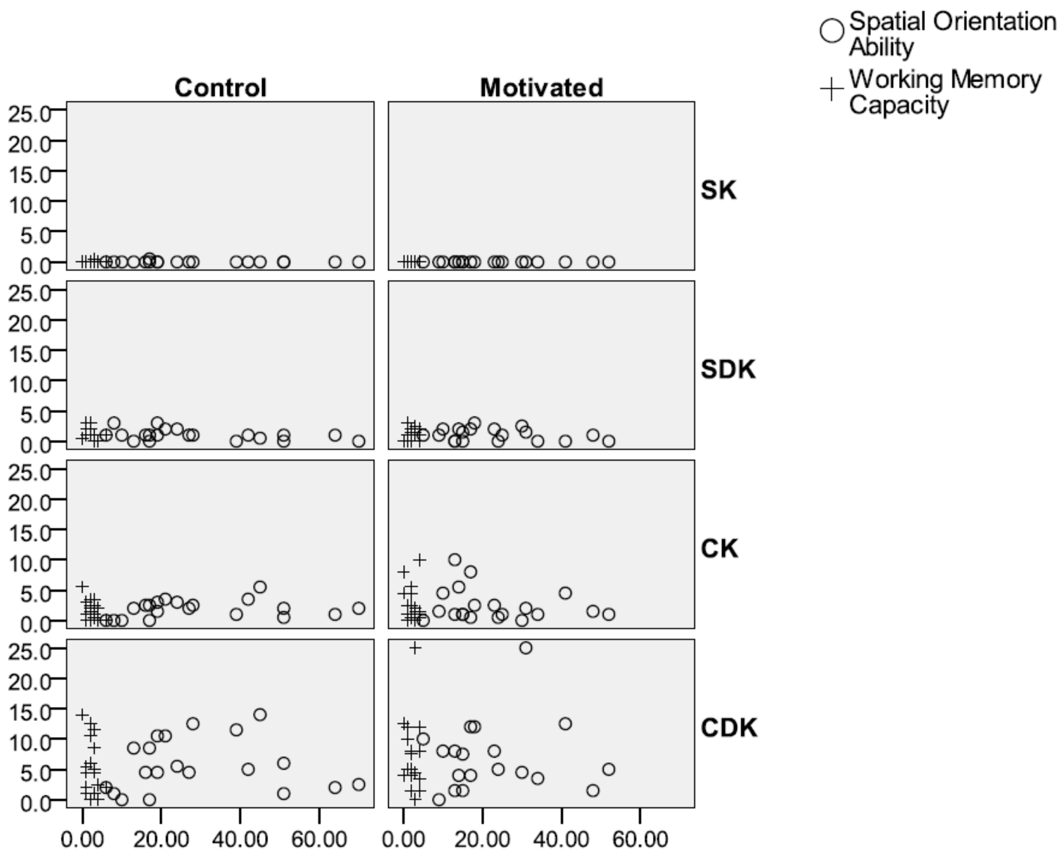


Figure 8. Scatter plots of spatial orientation ability, working memory capacity and wrong turns (Control and Motivated groups)

4.2 STAGE 1

4.2.1 Time

Time participants took to complete each route in Stage 1 was measured. A longer task completion time indicates that participants either lost their way more often, took their time in making decisions, or both. A 2 (Control, Motivated) x 4 (Complexity: SimpleK, SimpleDeducedK, ComplexK, ComplexDeducedK) analysis of variance (ANOVA) revealed main effects of experiment condition, $F(1, 36) = 4.88$, $p < .05$, indicating that the participants in the control group took a significantly longer time ($M = 30.74$) than the motivated group ($M = 36.24$), and route complexity, $F(3, 36) = 143.32$, $p < .01$, indicating that the more complex the route the longer the travel time. Additional t-tests to tease apart the source of the increased time for control group suggested strong differences for the SimpleK $t(37) = -3.11$, $p < .01$, SimpleDeducedK $t(37) = -2.43$, $p < .05$ and ComplexK $t(38) = -2.58$, $p < .05$, but not for the ComplexDeducedK route, as noted in Table 3. Figure 9 displays the mean travel times of SimpleK, SimpleDeducedK, ComplexK, and ComplexDeducedK routes for both groups.

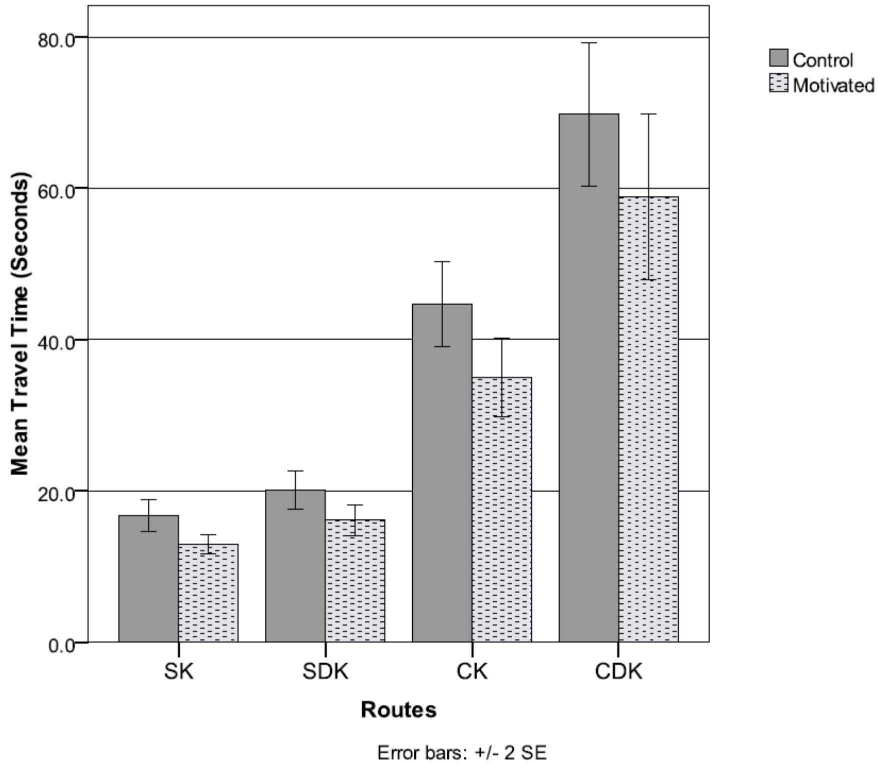


Figure 9. Plot of mean travel times (seconds) of SimpleK (SK), SimpleDeducedK (SDK), ComplexK (CK), and ComplexDeducedK (CDK) routes

Table 3. Mean travel times for SimpleK (SK), SimpleDeducedK (SDK), ComplexK (CK) and ComplexDeducedK (CDK) routes

		SK	SDK	CK	CDK
Control	Mean (sec)	16.07	20.08	44.75	69.78
	(Std. Dev.)	(4.66)	(5.50)	(12.56)	(21.15)
Motivated	Mean (sec)	12.95	16.13	35.00	58.88
	(Std. Dev.)	(2.75)	(4.66)	(11.53)	(24.44)
% Decrease in Mean Times		28.3%	19.7%	21.8%	15.6%
Significance		$p < .01$	$p < .05$	$p < .05$	n.s.

4.2.2 Wrong Turns

In the training phase, invisible walls were set up slightly away from each corner on the incorrect paths, so that participants could turn down an incorrect path, but then realize the mistake. This was akin to leading someone by hand where they are gently nudged back after taking a wrong step. The use of invisible walls is based on the notion of virtual fixtures, introduced by Rosenberg (1993). This study used forbidden-region virtual fixtures (Okamura, 2004) where participants could see down all every hallway, but may be blocked from travel by an invisible wall. In the test phase the invisible walls were moved beyond the second wrong corner as shown in Figure 10. This means that participants at any intersection could make up to two wrong turns, before having to retrace their steps back to the main path. Given the complexity of space, this

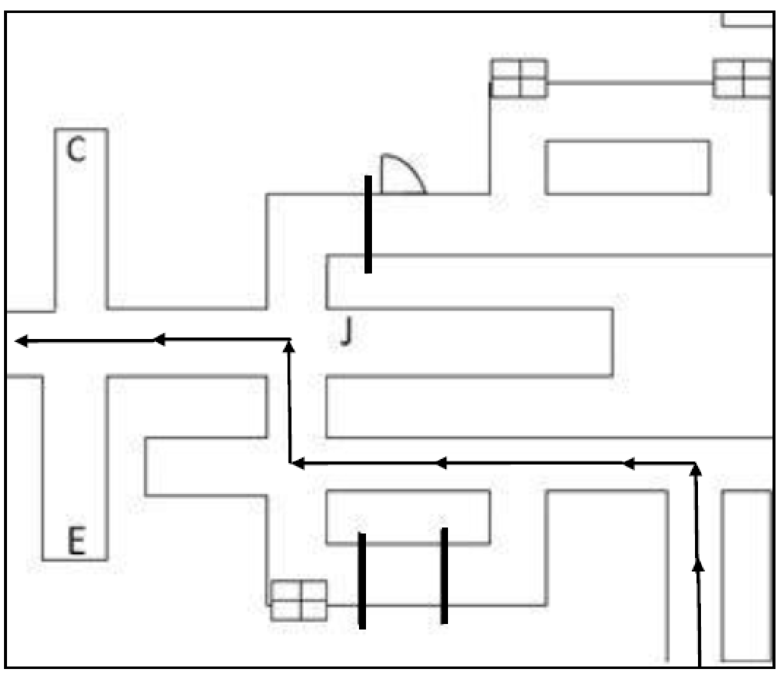


Figure 10. Layout of invisible walls for a route in the test phase.

insured that they did spend large amounts of time wandering in ‘back alleys,’ but at the same time, there would be a clear indication that participant did wander away from the appropriate path.

In Stage 1 of the test phase, participants in all but the simplest condition (Simple K) exhibited wrong turns when navigating the routes. There were no significant differences in the number of wrong turns between the motivated and control groups, which was somewhat surprising. However, an analysis into the data reveals some interesting insights. Figure 11 shows the average number of wrong turns for each of the four types of routes across the two groups. Strong positive correlations were found between wrong turns and time for motivated participants

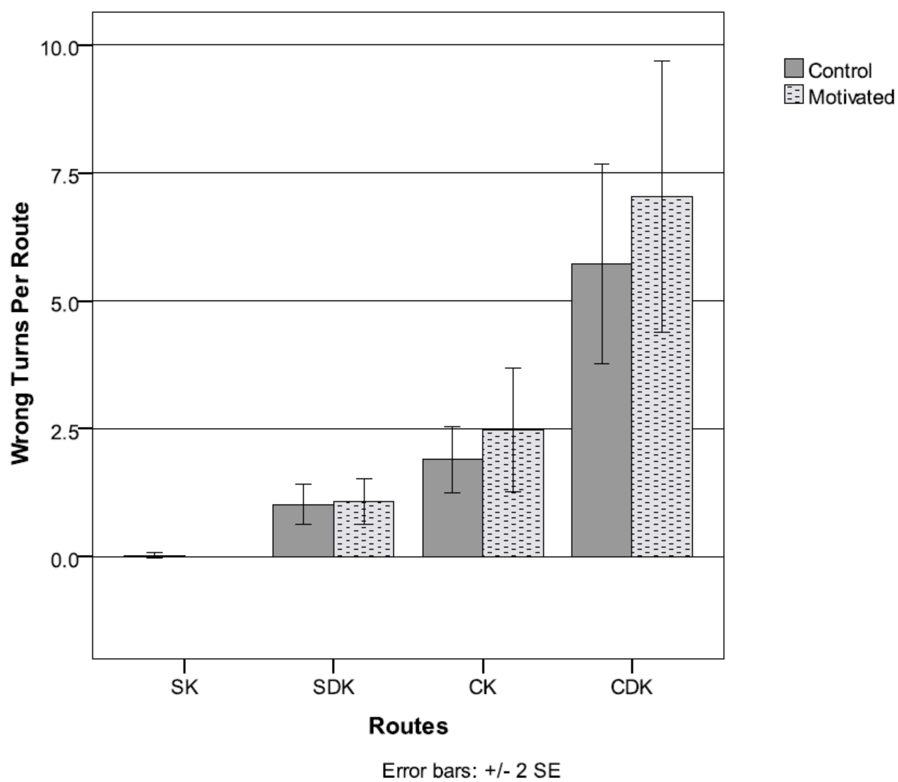


Figure 11. Plot of average number of wrong turns for each of the four types of routes—SimpleK (SK), SimpleDeducedK (SDK), ComplexK (CK) and ComplexDeducedK

travelling the more complex routes, the ComplexK $r(20) = .89$, $p < .01$, and ComplexDeducedK $r(20) = .85$, $p < .01$ as shown in Figure 13. As shown in Figure 12, the same correlations for the more complex routes, Complex K $r(20) = .45$, $p < .05$, and ComplexDeducedK $r(20) = .51$, $p < .05$, were not as strong for participants who travelled in the control condition. This suggests that participants in the motivated group spent less time making decisions, as that longer travel times were the direct result of an increased number of wrong turns. In contrast, participants in the control group spent more time making decisions and less time moving, so longer travel times were often just the result of careful consideration of the next step and not necessarily indicative of an travel error. This suggested that participants in the control group were thinking more. In order to investigate this notion further, an analysis was conducted of the number of wrong turns that were repeated (repeated wrong turns). Repeated wrong turns would suggest that participants were exploring the same space multiple times as a result of less conscious decision making. As shown in Figure 14, on average, participants in the motivated group had more repeated number of wrong turns. It is also seen that participants explored certain spaces three or four times, however, participants in the control group did not exhibit this kind of behavior.

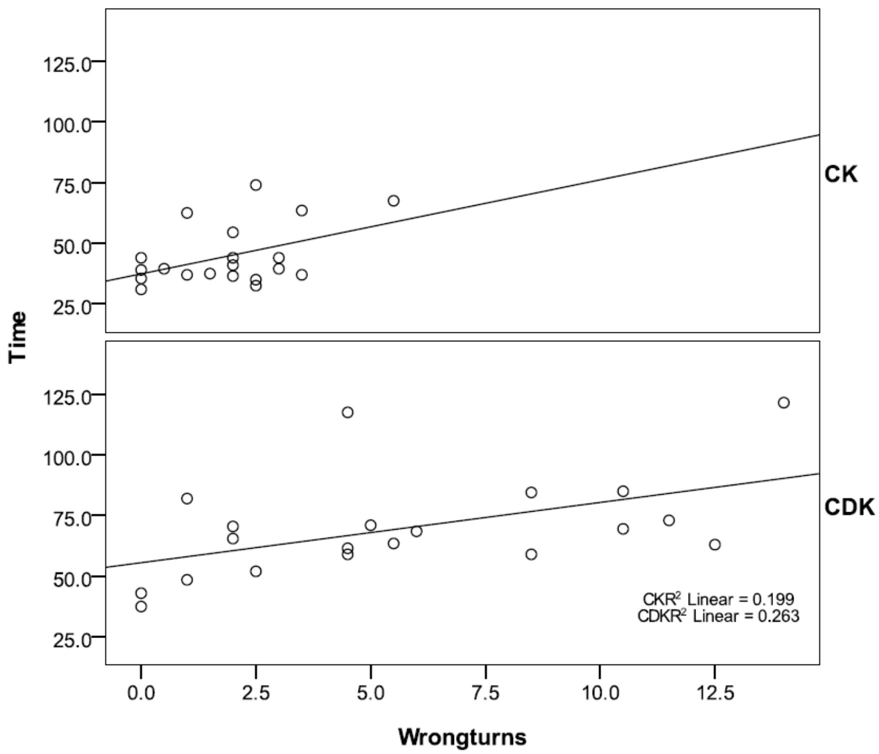


Figure 12. Correlations between wrong turns and time for more complex (Complex K, ComplexDeduced K) routes (Control condition)

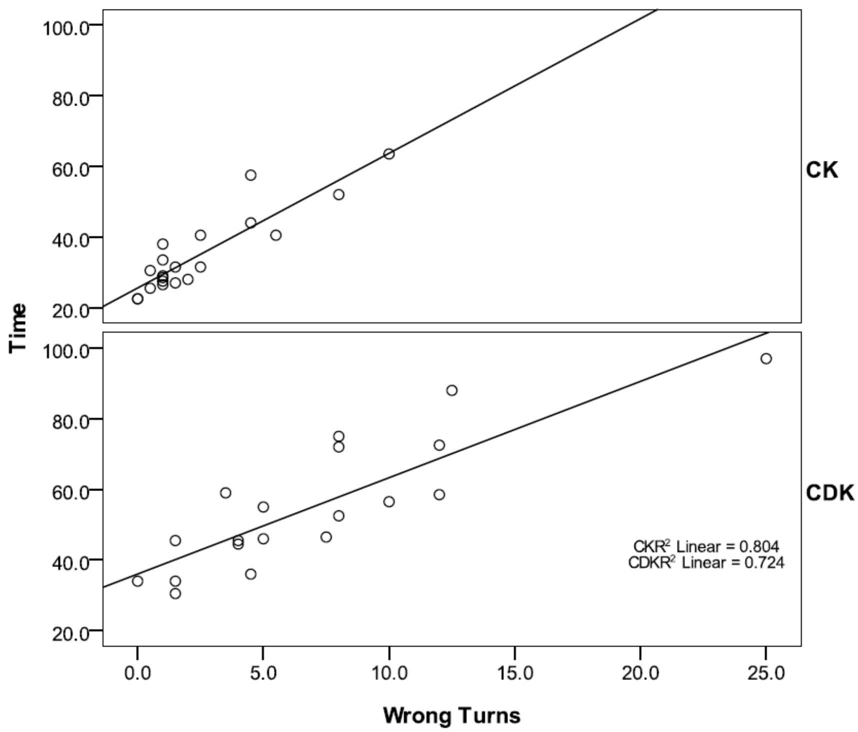


Figure 13. Correlations between wrong turns and time for more complex (Complex K, ComplexDeduced K) routes (Motivated condition)

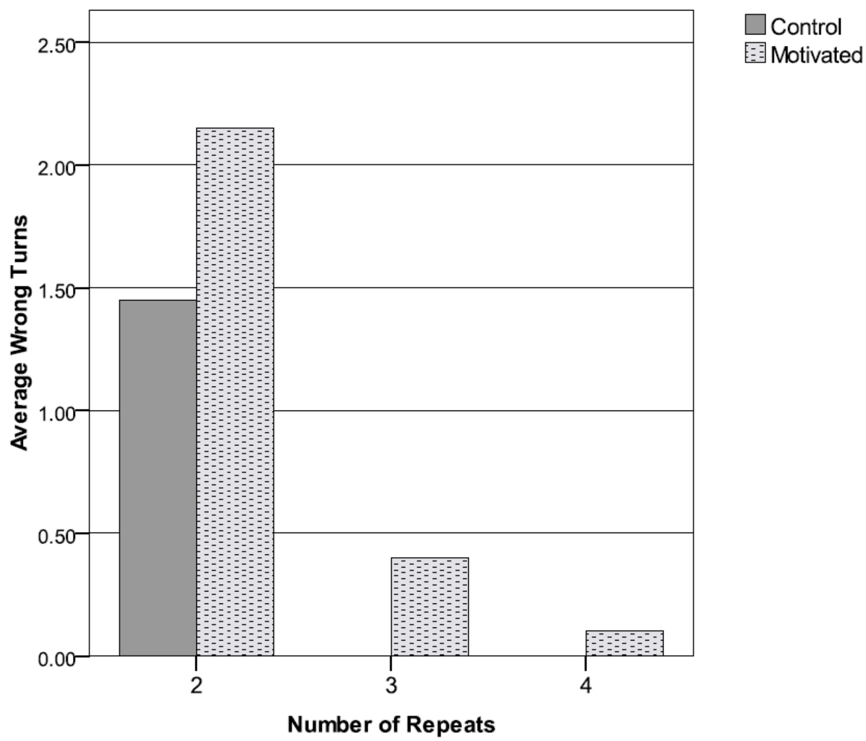


Figure 14. Average number of repeated wrong turns per route

4.3 STAGE 2

4.3.1 Time

As part of the exploratory analysis in Stage 2, participants were asked to follow instructions to find new targets outside the area of Stage 1. Each path had a known (K) part and unknown (N) part. As the travel on each region could be measured independently, I first measured the time participants took to complete the known regions of the route. This time was compared to the time taken to travel the same routes in Stage 1. A 2 (Control, Motivated) x 4

(Complexity: SimpleK, SimpleDeducedK, ComplexK, ComplexDeducedK) x 2 (Stage 1, Stage 2) analysis of variance (ANOVA) revealed main effects of experiment condition, $F(1, 36) = 9.35$, $p < .01$, indicating that the participants in the control group took a significantly longer time ($M = 35.10$) than the motivated group ($M = 29.03$), route complexity, $F(1, 36) = 171.02$, $p < .01$, indicating that the more complex the route the longer the travel time, and Stage, $F(1, 36) = 5.34$, $p < .05$, indicating that travel time was significantly faster in Stage 2 as compared to Stage 1. Additional t-tests to identify the source of the difference in travel times suggested that mean travel times for the simple routes were slower in Stage 2 when compared to Stage 1 for both motivated, $t(19) = -2.45$, $p < .05$, and control, $t(18) = -4.56$, $p < .01$, conditions, as noted in Table 4. Mean travel times for the most complex (ComplexDeducedK) routes were faster in Stage 2 than they were in Stage 1 for both motivated $t(19) = 3.36$, $p < .01$, and control $t(19) = 4.87$, $p < .01$, conditions. The faster times perhaps reflect the difficulty of the ComplexDeducedK routes in Stage 1 of the experiment as compared to a similar task in Stage 2, where a learning effect ensured that participants were more familiar with the routes. There were no significant differences found in mean travel times of the remaining routes. The figures below display the mean travel times in Stage 1 and 2 for each route, in both control (Figure 15) and motivated (Figure 16) groups.

Table 4. Mean travel times for trained regions of Stage 1 and Stage 2

			SK	SDK	CK	CDK
Control	Stage 1	Mean (sec)	16.74	20.08	43.21	69.78
		(Std. Dev.)	(4.66)	(5.49)	(10.80	(21.15)
	Stage 2	Mean (sec)	23.42	18.55	48.76	50.17
		(Std. Dev.)	(8.16)	(5.64)	(15.13	(17.68)
	% Difference in Mean Times		23.5%	7.6%	11.4%	28.1%
	Significance		p < .01	n.s.	n.s.	p < .01
Motivated	Stage 1	Mean (sec)	12.95	16.12	35.00	58.88
		(Std. Dev.)	(2.75)	(4.66)	(11.53	(24.44)
	Stage 2	Mean (sec)	16.17	13.65	40.45	39.02
		(Std. Dev.)	(6.90)	(6.86)	(15.01	(12.43)
	% Difference in Mean Times		19.9%	15.3%	13.5%	33.7%
	Significance		p < .05	n.s.	n.s.	p < .01

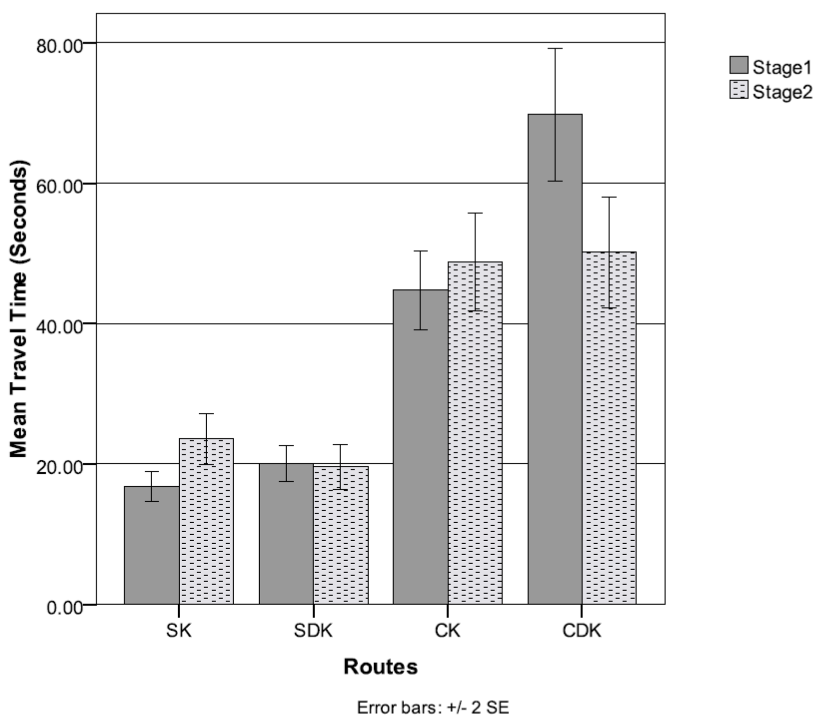


Figure 15. Mean times for K and DeducedK Routes in Stage 1 and 2 (Control group)

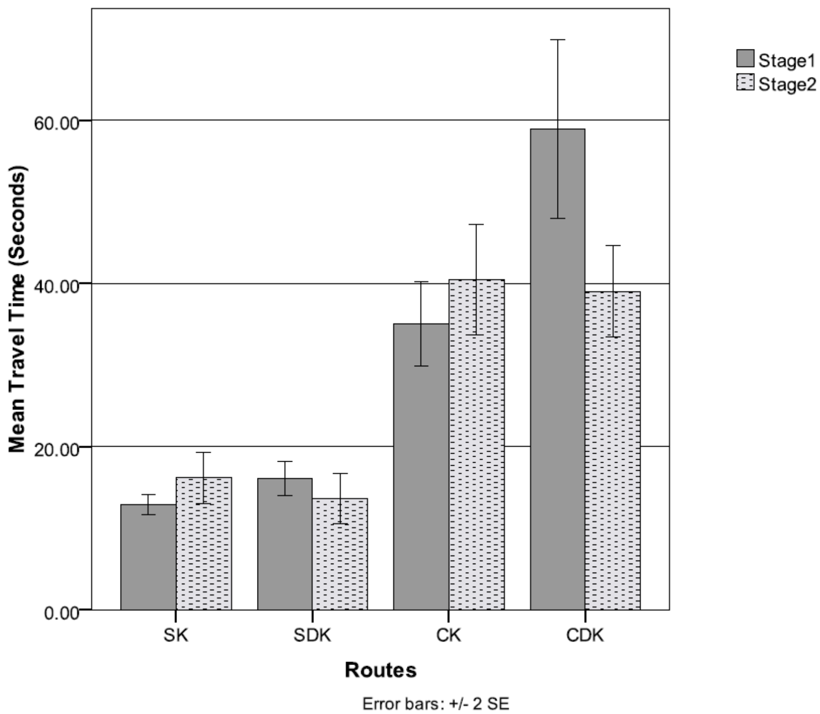


Figure 16. Mean Times for K and DeducedK Routes in Stage 1 and 2 (Motivated Group)

4.3.2 Wrong Turns

As mentioned earlier, in Stage 2, participants were asked to follow instructions to find new targets outside the area of Stage 1. Each path had a known (K) part and unknown (N) part. As the travel on each region could be measured independently, I first measured the wrong turns participants made while travel through the known regions of the route. For all the routes, the number of wrong turns per route for the known regions of Stage 2 was on par, or in some cases less than, the wrong turns taken for the same routes in Stage 1. The figures below display the average number of wrong turns for all routes in Stage 1 and Stage 2, for the control (Figure 17) and motivated (Figure 18) groups. The trend in wrong turns resembles the trend seen in the mean

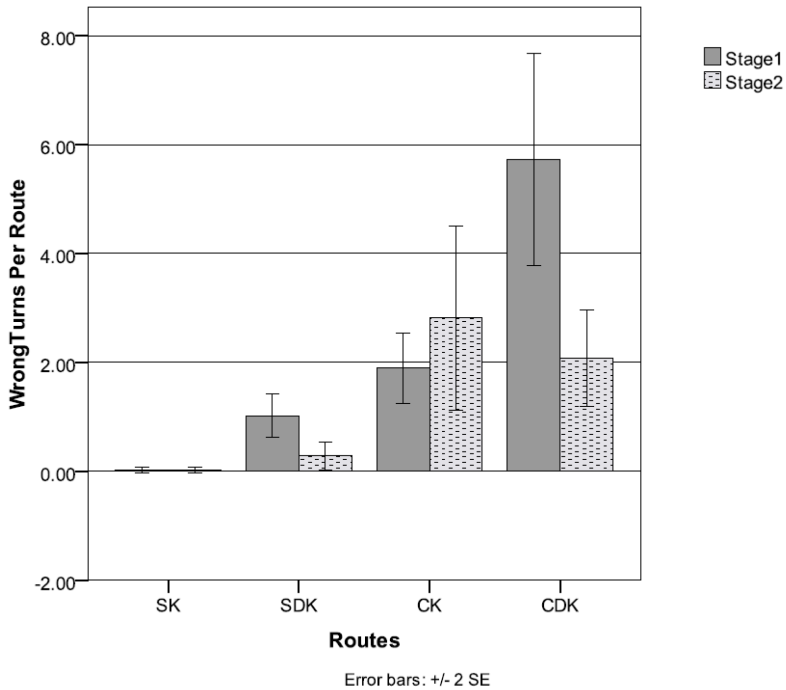


Figure 17. Average number of wrong turns per route for Stage 1 and Stage 2 (Control group)

travel times. The most apparent difference is visible for the most complex routes. This suggests that the participants made fewer errors as they learned the space across the repeated trials.

Finally, the wrong turns made while travel through the unknown regions of each route was measured. This measure was used to calculate an error rate. The error rate was calculated by dividing the number of wrong turns in each route by the number of decision points present for that route. The error rate was also calculated for travel through the known regions of the route for Stage 1. Table 5 lists the error rates during travel across known and unknown regions. The error rate was in the range of 0.001 to 0.467 across the known and unknown regions. The error rate for unknown regions remained mostly unchanged across the routes. This of course, is most likely due to the detailed instructions describing travel through these unknown sections. The error rate

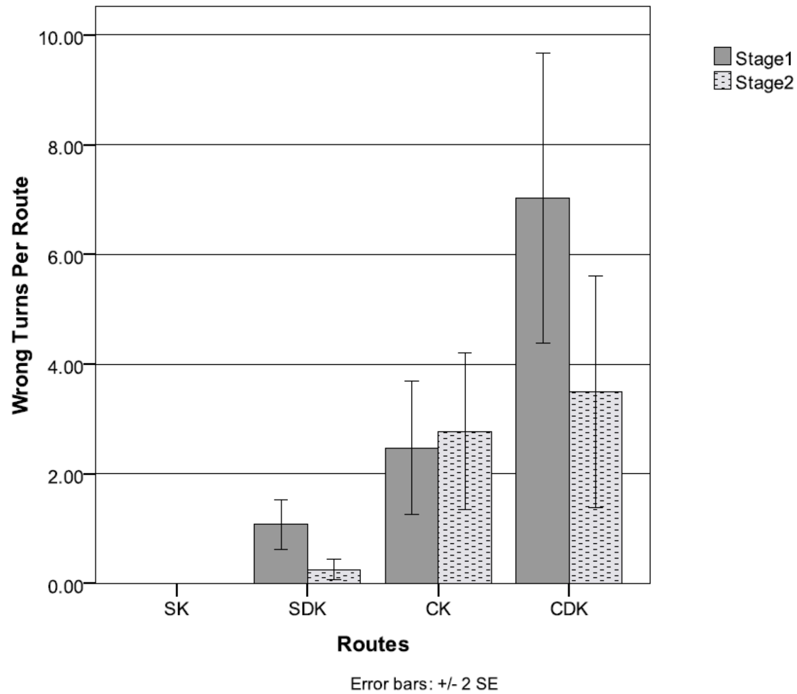


Figure 18. Average number of wrong turns per route for Stage 1 and Stage 2 (Motivated group)

for travel through known regions of the route was in the range of 0.017 to 0.467. The value for the simplest route was 0.017, and the value for the most complex route was 0.467. The varying error rate is likely due to the varying complexity of the navigation task performed. The error rates help in understanding the effectiveness of, and the overhead involved, when knowledge based schematized directions are used.

Table 5. Number of wrong turns per decision point

		SK	SDK	CK	CDK
Control	Known Regions	0.050	0.167	0.370	0.467
	Unknown Regions	0.015	0.002	0.001	0.001
Motivated	Known Regions	0.017	0.283	0.420	0.357
	Unknown Regions	0.008	0.008	0.002	0.003

4.4 MOTIVATION

Upon completion of the experiment, I queried participants in both groups on their level of motivation, excitement, or the extent to which they felt rushed. No significant differences across the two groups were found on the motivation and excitement measures. This lack of a difference could be attributed to the participants' interpretation of the query. However, participants in the motivated group reported that they felt more rushed while performing the experiment than participants in the control group. Responses to a seven point Likert item indicate that more participants in the motivated group reported feeling rushed—to extremely rushed (80%), than did participants in the control group (35%), χ^2 (6, N = 40) = 14.86, p = .02.

5.0 EXTENSIONS TO KNOWLEDGE ROUTE THEORY

5.1 OVERVIEW

The results of the experiment suggest that motivation effects performance during travel through known segments of a route. These results are consistent with the results reported by Brunyé and colleagues which indicate that basic affective states influenced the access to map-based information (Brunyé et al., 2009). This suggests that access to route knowledge in the Known (K) portions of a route may be influenced by motivation in particular, or Affect (E) in general. Access to knowledge is also known to be influenced by Attentional resources (A) that may be a allocated to the wayfinding task at hand (Smith & Kosslyn, 2007). Our recollection is also known to change over time (T), where access to, or recollection of route knowledge in long-term memory is likely to be depleted over time (Smith & Kosslyn, 2007). Finally, the differences observed in performance across deducedK and K routes suggest that a binary representation of knowledge—as originally proposed in the knowledge route theory introduced by Srinivas and Hirtle (2007)—may not completely or accurately represent all the levels and complexity of spatial knowledge. For instance, Schmid (2008) refers to three levels of knowledge—Familiar Environments, Partially Familiar Environments and Unfamiliar environments—in his work that involves the automated generation of knowledge-based wayfinding maps. Hence, as part of the theoretical extensions presented, spatial knowledge is represented as a continuum.

5.2 THEORETICAL EXTENSIONS

As part of the original knowledge route theory mentioned in Section 2.4, the most basic form or a partially familiar route, or (<k-route>), was represented as having a Known route segment (<K>) and an Unknown route segment (<N>) along the same route. Individual route segments were denoted as <seg>. As part of the extension presented here, in order to represent knowledge as a continuum, an individual known route segment is denoted as *k* and an individual unknown route segment is denoted as *n*. Hence, a known route K consisting of *x* individual known route segments may be represented as K::= $k_1, k_2, \ldots, k_{x-1}, k_x$. The concept of *k* (and *n*) differ from a <seg>, as each individual route segment in *k* and *n* is represented by a unique value denoting the level of route knowledge for that segment at the time of recall. This allows for the representation of knowledge as a continuum.

Access to existing spatial knowledge, is dependent on the strength of encoded route knowledge, or level of knowledge (L), it is also deemed to be affected by Affect (E), Attention (A) and Time (T).

$$k_i = f(L_i, E, A, T), \text{ where:}$$

$$-1 \leq E \leq 1$$

$$-1 \leq A \leq 1$$

$$-1 \leq T \leq 1$$

$$\varepsilon \leq L_i \leq 1$$

Each of these factors, Knowledge Level (L_i), Affect (E), Attention (A) and Time (T), influences the access to spatial knowledge k_i as follows:

The level of encoded route knowledge, or L_i, may take on a value from {ε, 1}, where 1 represents complete or perfectly encoded route knowledge and ε represents faint or poorly encoded route knowledge. Access to an individual known route segment k_i depends on this value. For instance, a route segment that is well learned is represented with the value $L_i = 1$ and will hence be recalled most easily and quickly. On the other hand, a route segment that is not very clearly encoded in memory may be represented by a value of $L_i = \varepsilon$. Such a poorly known route segment may not be easily recalled or remembered. Each individual unknown route segment *n* represents a complete lack of knowledge of the route segment. Route knowledge is hence represented as a continuum. This may be considered as an extension to the three levels of knowledge—Familiar Environments, Partially Familiar Environments and Unfamiliar environments—as proposed by Schmid (2008). A stronger encoding of L_i (e.g., $L_i = 1$), will make it less susceptible to the other factors (i.e., E, A or T) that may influence its access.

It is proposed that the influence of Affect on the access to k_i will follow the inverted U function as shown in Figure 19. Given this study identifies only two points along the curve (control and motivated) it will be impossible to judge whether the relationship is linear or curvilinear. Additional experimentation would be needed. However, the related research suggests the inverted U is likely place to begin the modeling process. A value of -1 for E implies a strong negative influence on the access to k_i. A value of 0 implies no significant influence on the access to k_i, and a value of +1 indicates the optimal condition of the access to a known route segment k_i.

It is proposed that the effect of attention on the access to k_i will follow a function similar to that shown in Figure 20. A value of -1 for A (implies a strong negative influence on the access to k_i. A value of 0 implies no significant influence on the access to k_i, and a value of +1 indicates the optimal condition of the access to a known route segment k_i. It is proposed that the effect of time on the access to k_i will follow a function similar to that shown in Figure 21. At the time of

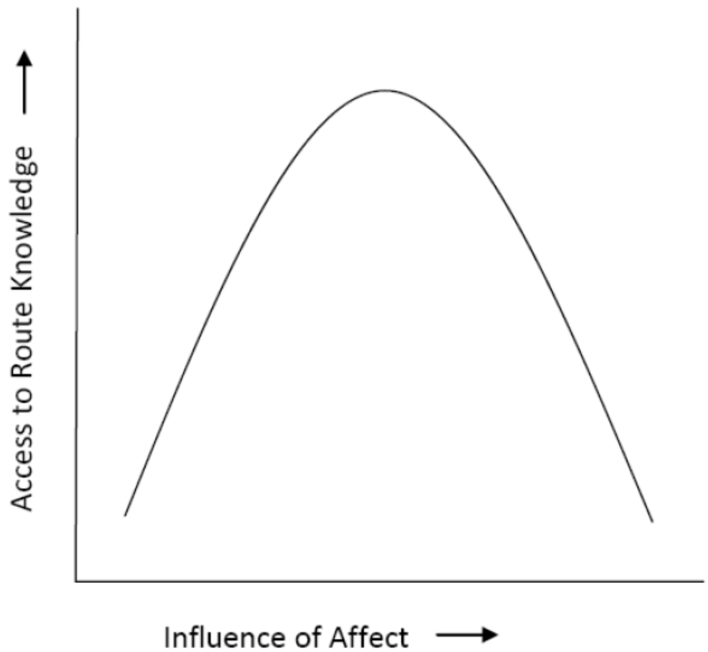


Figure 19. Proposed effect of affect on access to k

encoding, time has a positive effect on the access to k_i and assumes a value of +1. As time passes, knowledge fades, and the access to k_i is negatively affected by time, this is modeled as a negative value (-1) for Time T.

5.3 EXPERIMENTAL RELEVANCE OF THEORETICAL CONCEPTS

Aspects of the experiment design as part of this research may be modeled by the theoretical concepts presented. The various levels of task complexity are represented by the levels of route knowledge, i.e., $\varepsilon \leq L_i \leq 1$. The SimpleK routes as part of the experiment are routes that have multiple known route segments k_i. Given that SimpleK routes were well learned, each known

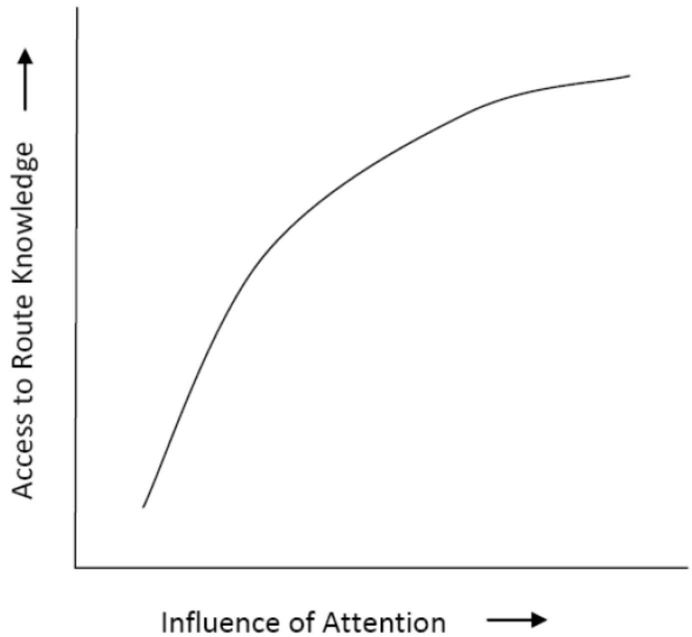


Figure 20. Proposed effect of attention on access to k

segment k_i along a SimpleK route could be represented by knowledge level L_i that may take on a value of 1 (or nearly 1) depending on the level of encoding. The value of L_i for DeducedK may be assumed to be significantly less than 1. In general, assuming other factors (E, A, T) remain optimal, poor performance—multiple errors and long time to completion—on a wayfinding tasks may be modeled by a small value of L_i resulting in a small value of k. The effect of motivated instructions and time constraints may be modeled by E. An improvement in overall performance when working under a time constraint may be modeled by a positive value of E. As part of the experiment, the time between the training phase (encoding) and test phase (recall), was relatively short. Hence, the value of T with respect to the experiment may be modeled as being nearly equal to 1. This represents the recency effect related to recall.

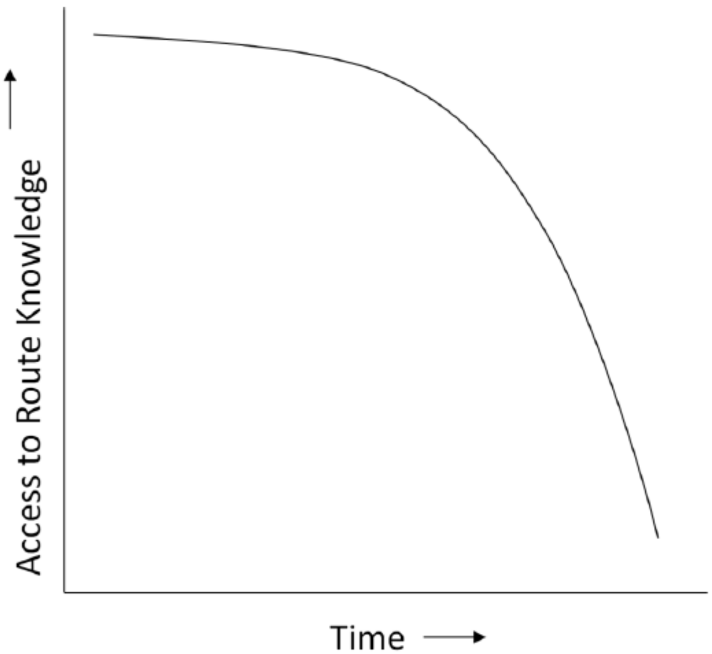


Figure 21. Proposed effect of time on the access to k

Real world scenarios of travel may also be represented by the theoretical model presented. Affect may have a differential effect on varying levels of route knowledge. As mentioned earlier, a specific level of extreme stress that is modeled to have a negative effect (E = -1) on the access to encoded route knowledge, may have little or no effect on a well learned route, (L_i = 1). For instance, consider that an emergency arises at your home and you need to rush to the nearest hospital. The neighboring hospital is located only two blocks away from your home (a well learned route). In this instance, the effect of stress may have very little effect on your existing spatial knowledge. You may be able to locate the hospital with minimum number of wrong turns. However, the same level of stress (E) may negatively affect a poorly encoded route (L_i = ε). For instance, consider that the same emergency arises at a restaurant in an unfamiliar neighborhood. You need to rush to nearest hospital. However, in this instance, the nearest hospital is one that you vaguely remember passing by on your way to the restaurant (a poorly encoded route). In this instance, the added extreme stress of the situation may make it harder for you to locate the hospital, than it would under optimal or less stressful affective states.

The fading of knowledge over time is another real world scenario that may be modeled by the theoretical concepts presented is. For instance, consider a scenario where you have lived in a neighborhood for many years. The route segments from your home to the neighborhood grocery store may each be encoded with a strong level of knowledge (L_i = 1) and Time (T = 1). However, assume you now move to a new city and live there for a few years. Given that significant time has passed, it may be estimated that knowledge of the old route (previous home to neighboring grocery store) has faded. This may be modeled by changing the value of T—for each route segment from your old home the old grocery story—from 1 to -1. The scenario of cell phone use while driving (or wayfinding in general) may also be modeled by the theoretical concepts presented. Attention demands due to cell phone use may be modeled by negative values of A. As mentioned earlier, the effects of cell phone use on the recall of route knowledge may vary depending on various factors such as L_i, E and T.

Estimation of one's route knowledge (L) in an automated system is a challenging task that is being currently explored (Schmid, 2008; Schmid & Richter, 2006). The effects of affect and attention on the access to *k* are understandably harder to determine. However, the notion of modeling affect and belief states and their effect on performance has been explored recently (Bianchi-Berthouze & Lisetti, 2002; Hudlicka & McNeese, 2002). An individual's optimal level of motivation is likely to be influenced by personality traits and individual differences. For instance, participants who usually perform well under time constraints and motivated conditions might be modeled with optimal values of +1 (or nearly +1) for Affect (E) and Attention (A).

However, participants who are easily stressed may be negatively influenced by motivation and reward. This may be modeled by a negative value for E and A. The values for L_i, E, A and T are particularly challenging to model in real time and is an important area for future research.

6.0 DISCUSSION

This research was an attempt to explore the effect of affect on human wayfinding. Specifically, Stage 1 of the study was designed to explore the effect of motivation on the time and wrong turn related performance on variably complex routes in a partially known region of space. The results indicate that route complexity does in fact interact with motivation. Motivation improved time related performance of simple and moderately complex tasks. However, motivation failed to improve time related performance on the most complex tasks. No significant difference was found with respect to the number of wrong turns made between the two groups. Hence, motivated participants performed their tasks in less time, but they did not make fewer errors.

Earlier studies have shown that affect can improve performance of simple tasks, whereas they can hinder performance on more complex tasks (Farber & Spence, 1953; Vaughn & Diserens, 1930). The results of our study follow a similar trend. While performance in the most complex (ComplexDeducedK routes) tasks was not hindered by motivated instructions; motivated participants failed to improve their performance on these tasks. It is interesting to note that a ComplexDeducedK route, and a ComplexK route share a similar structural complexity, the only difference between these routes being the extra cognitive processing to deduce the destination in a ComplexDeducedK route. This suggests that with respect to motivated travel; structural complexity of the route may be less of a factor if the route is well known.

The results of Stage 1 of our study gain relevance as they form the basis for future work that would investigate possible performance degradation on very complex tasks, under highly motivated or rushed conditions. The results may also be viewed in the context of the real world scenarios of travel as mentioned in the introduction. The results suggest that rushed or highly motivated travel through an unfamiliar airport will be less productive than rushed or highly motivated travel through a familiar neighborhood park (assuming that both the environments have similar structural complexity). This was seen as a 28.3% significant difference in ComplexK routes and a 15.6% (n.s.) difference in ComplexDeducedK routes (as shown in Table 3).

It is also important compare the nature of this study, and the implications of the results, with the choking under pressure studies mentioned earlier in Section 2.2 (Baumeister, 1984; Beilock & Carr, 2001; Lewis & Linder, 1997; Wine, 1971). The nature of affect induced in the motivated group varies, but only slightly, from the performance under pressure studies. In the present research, participants in the motivated group were motivated by reward and rushed due to an imposed time constraint. While this pressure is subtlety distinct from the performance pressure induced as part of the chocking studies, the one common aspect of the two kinds of manipulations is an affective state of high arousal, or pressure, that demands a higher than usual task performance. The nature of the task performed also plays a vital role in the pressure related performance degradation. Explicit monitoring theories usually explain degradation of sensorimotor tasks such as golf putting (Beilock & Carr, 2001; Lewis & Linder, 1997) or the "roll up" game (Baumeister, 1984), that are well learned. Distraction theory better explains performance degradation in tasks that involve access to elements in working memory. The tasks presented as part of this research primarily involved access to stored knowledge, but also involved some amount of sensorimotor control (control of VR). Given that the major aspect of the task performed by participants in this research involved the access to stored memory, the wrong turn related performance degradation may be primarily explained by the distraction theory. However, as Beilock and Carr (2001) mention, it is likely that the two theories may complement rather than oppose each other. This is perhaps true for more complex tasks such as human wayfinding, where both theories may be needed to completely and accurately explain performance degradation.

Additionally, the effectiveness of schematized directions in various route conditions was investigated as part of the exploratory work in Stage 2 of the study. In general, participants in both conditions were able to use schematized directions and comfortably complete their wayfinding tasks. Trends in the data indicate that the effectiveness of schematized directions was found to be inversely proportional to the complexity of the task at hand. Schematized directions were found to be most effective for the simplest wayfinding task—travel through the known regions of the SimpleKN routes. This is of importance considering that travel through unknown regions of the route was guided by detailed route directions, and travel through the known regions had no detail. These directions were schematized based on the knowledge chunking concepts mentioned earlier. This suggests that knowledge based schematized directions may be presented if there is some knowledge of the environment and the task at hand is relatively simple, or if knowledge is firmly established while performing complex wayfinding tasks.

The effect of motivation on the performance of wayfinding tasks gains importance in light of the recent research developments in automatic route guidance systems. Recent efforts in this area involved modeling of user's knowledge with the goal of tailoring output of route directions or maps, to the user's mental representations, or prior route or survey knowledge (Patel et al., 2006; Schmid, 2008; Schmid & Richter, 2006; Srinivas & Hirtle, 2007; Tomko & Winter, 2006). These personalized routes, while describing travel through a known region, consist of simpler directions with less route direction elements. This in turn reduces the cognitive load of the wayfinder. These research initiatives are an important step toward the automatic generation of personalized routes based on user familiarity.

Indications from our study and earlier work in the area suggest that affect indeed influences wayfinding. These findings are similar to those found most recently by Brunyé (2009) These findings were used to extend the knowledge route theory introduced by Srinivas and Hirtle (2007). The theory was expanded to include the influence of affect, as well as additional factors such as attention and time, that influence the access to knowledge. The theory suggests that these factors need to be taken into account while schematizing route directions (based on knowledge) for travel in the real world.

These extensions to the theory are relevant for future automated route guidance systems that may need to tailor their personalized route directions in accordance to not only a wayfinder's prior knowledge, but also their affective state. This would require a future wayfinding system to sense a wayfinder's affective state and route knowledge and present them with personalized route guidance based on these factors. Recent research in this area suggests that detecting stress levels of a driver in driving conditions might prove useful in customizing the driver's 'in vehicle environment'. A small but important technical step in precisely this direction was taken by Lin and colleagues who developed a "smart wheel" (Lin et al., 2007). The device was shown to satisfactorily measure a driver's pulse wave, breathing wave, skin temperature and gripping force in real time. Lin and colleagues state that such a system would prove useful in enhancing driver safety. While their study was intended to improve driver safety, it is easy to imagine that these systems could also be used to improve usability. One could imagine future wayfinding systems that would direct highly motivated or stressed users to longer but simple routes with less turns.

An interesting area for future study would also be the effect of motivation or stress on route learning. This would imply that future route guidance systems might need to consider the affective state of the driver while they attempt to automatically infer a driver's knowledge of a route. Another interesting area for future investigation is the nature of navigation strategies employed by wayfinders in different affective states. For example, do wayfinders resort to landmark based "homing in" strategies while under highly motivated or stressed conditions? These findings may have further implications for future route guidance systems.

APPENDIX A

RECRUITMENT ADVERTISEMENT

Experiment Subjects Needed

Subjects are needed for the study involving navigational behavior. Any undergraduate or graduate student, age 18 or older, at the University of Pittsburgh, is eligible. Participants will be paid $15 per hour for their participation in a single session, that would last for not more than two hours.

The Study is conducted by Samvith Srinivas, School of Information Sciences, 135 N. Bellefield Ave, Pittsburgh, PA.

The Study will be conducted at: 2B04, School of Information Sciences, 135 N. Bellfield Ave, University of Pittsburgh.

For more information contact:

Samvith Srinivas, sas29@pitt.edu or call 412-860-9738

APPENDIX B

BACKGROUND QUESTIONNAIRE

Please fill in these background questions

1) Gender : M F

2) Age :

3) Student Status : Undergraduate Student Graduate Student

(if applicable)

4) How many years have you been studying at the University of Pittsburgh? 00

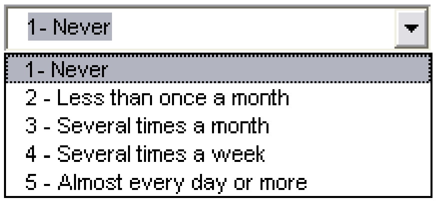
(if applicable)

5) Handedness : Right Left Ambidextrous

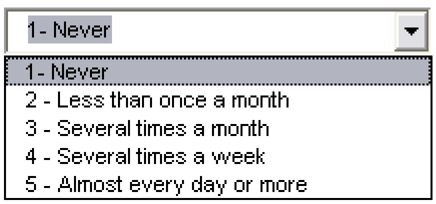
6) What is your Major or Field of Study ?

(if applicable)

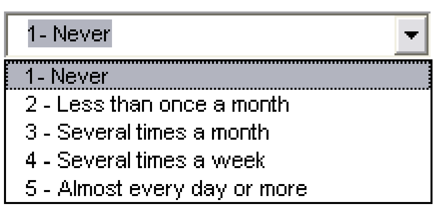
7) How often do you use a computer?



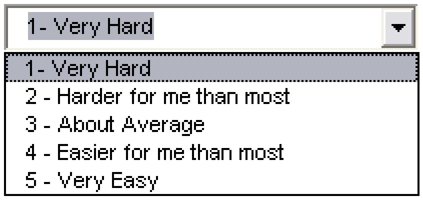
8) How often do you use the World Wide Web?



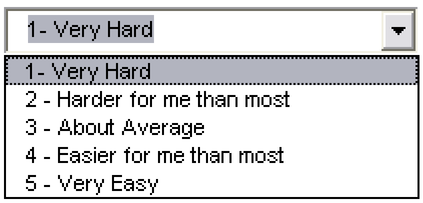
9) How often do you play games with a first person view in a 3D environment (e.g., Unreal Tournament, Halo etc.)



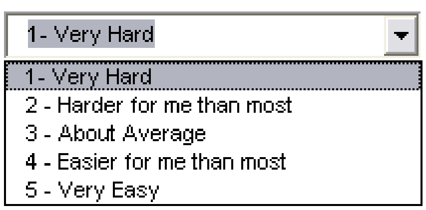
10) Compared to others, rate the ease with which you navigate a Virtual Reality (or 3D) computer environment.



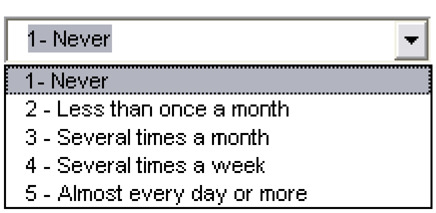
11) Compared to other people you have seen, rate the ease with which you learn how to find new locations:



12) Compared to other people you have seen, rate your ability to use a map:



13) How often do you use route finding systems such as MapQuest, Yahoo maps, or Google maps?



APPENDIX C

Part 1:

Please rate your emotional state during the experiment:

1) Please rate the level of your stress (during the second half of the navigation task) on the scale below:

1-I was extremely relaxed

2-

3-I felt Normal

4-

5-I was extremely stressed

2) Please rate the degree to which you felt rushed (during the second half of the navigation task) on the scale below:

1-I absolutely did not feel rushed

2-

3-I felt normal

4-

5-I felt extremely rushed

3) Please rate the level of your excitement (during the second half of the navigation task) on the scale below:

1-I was absolutely bored

2-

3-I felt normal

4-

5-I was highly excited

4) In general, please rate your attitude toward stressful situations:

1-I absolutely enjoy stressful situations

2-

3-I have no particular like or dislike of stressful situations

4-

5-I absolutely detest stressful situations

5) In general, please rate your performance under stressful situations as compared with others:

1-I work very poorly under stressful situations

2-

3-I perform moderately under stressful situations

4-

5-I perform much better under stressful situations

6) In general, please rate your attitude toward timed tasks:

1-I detest working under time constraints

2-

3-Time constraints do not affect me in any way

4-

5-I enjoy working under time constraints

BIBLIOGRAPHY

Abowd, G. D., Mynatt, E. D., & Rodden, T. (2002). The human experience [of ubiquitous computing]. *Pervasive Computing, IEEE, 1*(1), 48-57.

Agrawala, M., & Stolte, C. (2001). *Rendering Effective Route Maps: Improving Usability Through Generalization.* Paper presented at the Conference on Computer Graphics and Interactive Techniques.

Allen, G. L. (1997). From Knowledge to Words to Wayfinding: Issues in the Production and Comprehension of Route Directions. *Lecture Notes in Computer Science, 1329*, 363-372.

Allen, G. L. (2000). Principles and Practices for Communicating Route Knowledge. *Applied Cognitive Psychology*, *14*, 333-359.

Bakker, N. H., Werkhoven, P. J., & Passenier, P. O. (1999). The Effects of Proprioceptive and Visual Feedback on Geographical Orientation in Virtual Environments. *Presence: Teleoperators & Virtual Environments, 8*(1), 36-53.

Barrett, L. F., & Russell, J. A. (1999). The Structure of Current Affect: Controversies and Emerging Consensus. *Current Directions in Psychological Science, 8*(1), 10-14.

Baumeister, R. F. (1984). Choking under pressure: Self-consciousness and paradoxical effects of incentives on skillful performance. *Journal of Personality & Social Psychology, 46*(3), 610-620.

Baus, J., Krüger, A., & Wahlster, W. (2002). *A resource-adaptive mobile navigation system.* Paper presented at the 7th international conference on Intelligent user interfaces, San Francisco, California, USA.

Beilock, S. L., & Carr, T. H. (2001). On the fragility of skilled performance: What governs choking under pressure? *Journal of Experimental Psychology: General, 130*(4), 701-725.

Bianchi-Berthouze, N., & Lisetti, C. L. (2002). Modeling Multimodal Expression of User's Affective Subjective Experience. *User Modeling and User-Adapted Interaction, 12*, 49-84.

Bower, G. H. (1981). Mood and memory. *American Psychologist, 36*(2), 129-148.

Brunyé, T. T., Mahoney, C. R., Augustyn, J. S., & Taylor, H. A. (2009). Emotional state and local versus global spatial memory. *Acta Psychologica, 130*(2), 138-146.

Brusilovsky, P. (2001). Adaptive hypermedia. *User Modeling and User-Adapted Interaction, 11*(1-2), 87-110.

Brusilovsky, P. (2007). Adaptive Navigation Support. In P. Brusilovsky, A. Kobsa & W. Nejdl (Eds.), *The Adaptive Web* (Vol. 4321, pp. 263-290): Springer Berlin - Heidelberg.

Bülthoff, H. H., Campos, J. L., & Meilinger, T. (2008). *Virtual Reality as A Valuable Research Tool for Investigating Different Aspects of Spatial Cognition (Keynote-Abstract).* Paper presented at the International Conference Spatial Cognition, Freiburg, Germany.

Cheverst, K., Mitchell, K., & Davies, N. (2002). The Role of Adaptive Hypermedia in A Context-Aware Tourist GUIDE. *Communications of the Acm, 45*(5), 47-51.

Christianson, S. A. (1992). *The Handbook of emotion and memory : research and theory*. Hillsdale, N.J.: Erlbaum Associates.

Cohen, R., & Schuepfer, T. (1980). The Representation of Landmarks and Routes. *Child Development, 51*(4), 1065-1071.

Cutmore, T. R. H., Hine, T. J., Maberly, K. J., Langford, N. M., & Hawgood, G. (2000). Cognitive and gender factors influencing navigation in a virtual environment. *International Journal of Human-Computer Studies, 53*(2), 223-249.

Damasio, A. R. (1995). *Descartes' Error: Emotion, Reason, and the Human Brain*: Harper Perennial.

Daniel, M.-P., & Denis, M. (1998). Spatial Descriptions as Navigational Aids: A Cognitive Analysis of Route Directions. *Kognitionswissenschaft, 7*(1), 45-52.

Denis, M., Pazzaglia, F., Cornoldi, C., & Bertolo, L. (1999). Spatial Discourse and Navigation: An Analysis of Route Directions in the City of Venice *Applied Cognitive Psychology, 13*(2), 145-174.

Dolan, R. J. (2002). Emotion, Cognition, and Behavior. *Science, 298*, 1191-1194.

Ekman, P., & Friesen, W. V. (1971). Constants Across Cultures In The Face And Emotion. *Journal ol Personality and Social Psychology, 17*(2), 124-129.

Farber, I. E., & Spence, K. W. (1953). Complex learning and conditioning as a function of anxiety. *Journal of Experimental Psychology: General, 45*(2), 120-125.

Fontaine, S., & Denis, M. (1999). *The Production of Route Instructions in Underground and Urban Environments.* Paper presented at the International Conference on Spatial Information Theory: Cognitive and Computational Foundations of Geographic Information Science.

Forgas, J. P. (Ed.). (2000). *Feeling and Thinking: The Role of Affect in Social Cognition*: Cambridge Universtiy Press.

Fox, E., Russo, R., Bowles, R., & Dutton, K. (2001). Do Threatening Stimuli Draw or Hold Visual Attention in Subclinical Anxiety? *Journal of Experimental Psychology: General, 130*(4), 681-700.

Freundschuh, S., & Egenhofer, M. (1997). Human Conceptions of Spaces: Implications for Geographic Information Systems. *Transactions in GIS, 2*(4), 361-375.

Gale, N., Golledge, R. G., Halperin, W. C., & Couclelis, H. (1990). Exploring Spatial Familiarity. *The Professional Geographer, 42*(3), 299-313.

Gillner, S., & Mallot, H. A. (1998). Navigation and acquisition of spatial knowledge in a. *Journal of Cognitive Neuroscience, 10*(4), 445-463.

Golledge, R. G. (1992). Place Recognition and Wayfinding: Making Sense of Space. *Geoforum, 23*(2), 199-214.

Golledge, R. G. (1999). *Wayfinding Behavior: Cognitive Mapping and Other Spatial Processes*. Baltimore and London: The Johns Hopkins University Press.

Golledge, R. G., Dougherty, V., & Bell, S. (1995). Acquiring Spatial Knowledge: Survey versus Route-Based Knowledge in Unfamiliar Environments. *Annals of the Association of American Geographers, 85*(1), 134-158.

Golledge, R. G., & Spector, A. (1978). Comprehending the Urban Environment. *Geographical Analysis, 10*, 403-426.

Hansen, C. H., & Hansen, R. D. (1988). Finding the Face in the Crowd: An Anger Superiority Effect. *Journal of Personality & Social Psychology, 54*(6), 917-924.

Healey, J. A., & Picard, R. W. (2005). Detecting stress during real-world driving tasks using physiological sensors. *IEEE Transactions on Intelligent Transportation Systems, 6*(2), 156-166.

Hegarty, M., & Waller, D. (2004). A dissociation between mental rotation and perspective-taking spatial abilities. *Intelligence*, *32*, 175-191.

Heuer, F., & Reisberg, D. (1992). Emotion, arousal, and memory for detail. In S. Christianson (Ed.), *The handbook of emotion and memory*. Hillsdale, N. J.: Lawernce Erlbaum Associates.

Hirtle, S. C., & Hudson, J. (1991). Acquisition of Spatial Knowledge for Routes. *Journal of Environmental Psychology*, *11*(4), 335-345.

Hudlicka, E., & McNeese, M. D. (2002). Assessment of User Affective and Belief States for Interface Adaptation: Application to an Air Force Pilot Task. *User Modeling and User-Adapted Interaction, 12*, 1-47.

Jansen-Osmann, P. (2002). Using desktop virtual environments to investigate the role of landmarks. *Computers in Human Behavior, 18*, 427-436.

Kaplan, C., & Fenwick, J. (1993). Adaptive Hypertext Navigation Based on User Goals and Context. *User Modeling and User-Adapted Interaction, 3*, 193-220.

Klatzky, R. L., Fikes, T. G., & Pellegrino, J. W. (1995). Planning for hand shape and arm transport when reaching for objects. *Acta Psychologica*, *88*(3), 209-232.

Klein, W. (1982). *Local deixis in route directions*: New York: Wiley.

Klein, W. (1983). *Deixis and spatial orientation in route directions*: New York: Plenum Press.

Kleinsmith, L. J., & Kaplan, S. (1963). Paired-associate learning as a function of arousal and interpolated interval. *Journal of experimental psychology, 65*(2), 190-193.

Klippel, A. (2003a). *Wayfinding Choremes.* Paper presented at the Spatial Information Theory: Foundations of Geographic Information Science. Conference on Spatial Information Theory (COSIT).

Klippel, A. (2003b). *Wayfinding Choremes - Conceptualizing Wayfinding and Route Direction Elements.* Unpublished Doctoral Thesis, University of Bremen, Bremen, Germany.

Klippel, A., Richter, K.-F., Barkowsky, T., & Freksa, C. (2005). The Cognitive Reality of Schematic Maps. In L. Meng, A. Zipf & T. Reichenbacher (Eds.), *Map-based Mobile Services - Theories, Methods and Implementations* (pp. 57-74): Springer, Berlin.

Kray, C., & Baus, J. o. (2003). *A Survey of Mobile Guides.* Paper presented at the HCI in Mobile Guides, Udine, Italy.

Kruger, A., Baus, J., Heckmann, D., & Kruppa, M. (2007). Web Based Mobile Guides. . In P. Brusilovsky, A. Kobsa & W. Nejdl (Eds.), *The Adaptive Web* (Vol. 4321). Berlin - Heidelberg: Springer.

Krüger, A., Butz, A., Stahl, C., Wasinger, R., Steinberg, K., & Dirschl, A. (2004). *The Connected User Interface: Realizing a Personal Situated Navigation System*. Paper presented at the IUI2004: International Conference on Intelligent User Interfaces.

Lewis, B. P., & Linder, D. E. (1997). Thinking about Choking? Attentional Processes and Paradoxical Performance. *Personality and Social Psychology Bulletin, 23*, 937-944.

Lin, Y., Leng, H., Yang, G., & Cai, H. (2007). An Intelliget Noninvasive Sensor for Driver Pulse Wave Measurement. *IEEE Sensors Journal, 7*(5), 790-799.

Lovelace, K. L., Hegarty, M., & Montello, D. R. (1999). Elements of good route directions in familiar and unfamiliar environments. *Spatial Information Theory, 1661*, 65-82.

Mark, D., Freksa, C., Hirtle, S., Lloyd, R., & Tversky, B. (1999). Cognitive models of geographical space. *International Journal of Geographical Information Science, 13*(8), 747-774.

Mark, D., & Gould, M. (1992). Wayfinding directions as discourse: A comparison of verbal directions in English and Spanish. *Multilingua, 11*(3), 267-291.

Matarazzo, J. D., Ulett, G. A., & Saslow, G. (1955). Human Maze performance as a function of increasing levels of anxiety. *Journal of General Psychology, 53*, 79-95.

Medyckyj-Scott, D., & Blades, M. (1992). Human Spatial Cognition: Its Relavance to the Design and Use of Spatial Information Systems. *Geoforum, 23*(2), 215-226.

Ohman, A., Lundqvist, D., & Esteves, F. (2001). The Face in the Crowd Revisited: A Threat Advantage With Schematic Stimuli. *Journal of Personality & Social Psychology, 80*(3), 381-396

Okamura, A. M. (2004). Methods for haptic feedback in teleoperated robot-assisted surgery. *Industrial Robot: An International Journal, 31*(6), 499-508.

Patel, K., Chen, M. Y., Smith, I., & Landay, J. A. (2006). *Personalizing routes*. Paper presented at the Proceedings of the 19th annual ACM symposium on User interface software and technology.

Pratto, F., & John, O. (1991). Automatic Vigilance: The Attention-Grabbing Power of Negative Social Information. *Journal of personality and social psychology, 61*(3), 380-391.

Presson, C. C., & Montello, D. R. (1988). Points of reference in spatial cognition: Stalking the elusive landmark. *British Journal of Developmental Psychology, 6*, 378-381.

Raubal, M., Egenhofer, M. J., Pfoser, D., & Tryfona, N. (1997). Structuring space with image schemata: Wayfinding in airports as a case study. *Spatial Information Theory: A Theoretical Basic for Gis, 1329*, 85-102.

Raubal, M., & Winter, S. (2002, September 25-28). *Enriching Wayfinding Instructions with Local Landmarks.* Paper presented at the Geographic Information Science: Second International Conference, GIScience 2002, Boulder, CO, USA.

Richardson, A. E., Montello, D. R., & Hegarty, M. (1999). Spatial knowledge acquisition from maps and from navigation in real and virtual environments. *Memory & Cognition, 27*(4), 741-750.

Riecke, B. E., van Veen, H. A. H. C., & Bülthoff, H. H. (2002). Visual Homing Is Possible Without Landmarks: A Path Integration Study in Virtual Reality. *Presence: Teleoperators & Virtual Environments, 11*(5), 443-473.

Rosenberg, L. B. (1993). *Virtual fixtures as tools to enhance operator performance in telepresence environments.* Paper presented at the Telemanipulator Technology and Space Telerobotics, Boston, MA, USA.

Rossano, M. J., & Reardon, W. P. (1999). Goal Specificity and the Acquisition of Survey Knowledge. *Environment and Behavior, 31*(3), 395-412.

Rossano, M. J., West, S., O., Robertson, T. J., Wayne, M. C., & Chase, R. B. (1999). The Acquisition of Route and Survey Knowledge from Computer Models. *Journal of Environmental Psychology 19*, 101-115.

Ruddle, R. (2005, March 12-16). *The effect of trails on first-time and subsequent navigation in a virtual environment.* Paper presented at the Virtual Reality, 2005. Proceedings. VR 2005. IEEE, Bonn.

Ruddle, R., Payne, S., & Jones, D. (1998). Navigating large-scale `desk-top' virtual buildings: Effects of orientation aids and familiarity. *Presence: Teleoperators & Virtual Environments, 7*(2), 179-192.

Russell, J. A. (1980). A Circumplex Model of Affect. *Journal of Personality and Social Psychology, 39*(6), 1161-1178.

Schmid, F. (2008). Knowledge-based Wayfinding Maps for Small Display Cartography. *Journal of Location Based Services*, *2*(1), 57-83.

Schmid, F., & Richter, K.-F. (2006). *Extracting Places from Location Data Streams.* Paper presented at the UbiGIS 2006 - Second International Workshop on Ubiquitous Geographical Information Services, Muenster, Germany.

Schmitz, S. (1999). Gender Differences in Acquisition of Environmental Knowledge Related

to Wayfinding Behavior, Spatial Anxiety and Self-Estimated Environmental

Competencies. *Sex Roles: A Journal of Research, 41*(1), 71-93.

Schmolck, H., & Buffalo, E. A. (2000). Memory distortions develop over time: Recollections of the O.J. Simpson trial verdict after 15 and 32 months

Preview By: . *Psychological Science*, *11*(1), 39-45.

Simcock, T., Hillenbrand, S. P., & Thomas, B. H. (2003). *Developing a Location Based Tourist Guide Application.* Paper presented at the Research and Practice in Information Technology-Workshop on Wearable, Invisible, Context Aware, Ambient, Pervasive and Ubiquitious Computing, Adelaide, Australia.

Smith, E., & Kosslyn, S. (2006). *Cognitive Psychology Mind and Brain*: Pearson Prentice Hall.

Smith, E., & Kosslyn, S. (2007). *Cognitive Psychology: mind and brain* (1st Ed. ed.): Pearson Prentice Hall.

Sorrows, M. E., & Hirtle, S. C. (1999). The nature of landmarks for real and electronic spaces. *Spatial Information Theory, 1661*, 37-50.

Srinivas, S., & Hirtle, S. C. (2007). Knowledge Based Schematization of Route Directions. In T. Barkowsky, M. Knauff, G. Ligozat & D. R. Montello (Eds.), *Spatial Cognition V* (Vol. 4387, pp. 346-364). Bremen, Germany: Springer.

Staedter, T. (2006). 'Biomaps' Track Urbanite Moods. *Discovery News*.

Steck, S. D., & Mallot, H. A. (2000). The Role of Global and Local Landmarks in Virtual Environment Navigation. *Presence: Teleoperators & Virtual Environments, 9*(1), 69-83.

Streeter, L. A., Vitello, D., & Wonsiewicz, S. A. (1985). How to tell people where to go: comparing navigational aids. *International Journal of Man-Machine Studies, 22*(5), 549-562.

Talarico, J. M., & Rubin, D. C. (2003). Confidence, not consistency, characterizes flashbulb memories. *Psychological Science, 14*(5), 455-461.

Talmy, L. (1975). *Semantics and syntax of motion*: New York: Academic Press.

Teigen, K. H. (1994). Yerkes-Dodson: A Law for All Seasons. *Theory & Psychology, 4*(4), 525-547.

Tom, A., & Denis, M. (2003). Referring to landmark or street information in route directions: What difference does it make? *Spatial Information Theory, Proceedings, 2825*, 362-374.

Tom, A., & Denis, M. (2004). Language and spatial cognition: Comparing the roles of landmarks and street names in route instructions. *Applied Cognitive Psychology, 18*(9), 1213-1230.

Tomko, M., & Winter, S. (2006). Recursive Construction of Granular Route Directions. *Journal of Spatial Science, 51*(1), 101-115.

Tversky, B. (1993). *Cognitive Maps, Cognitive Collages, and Spatial Mental Models*. Paper presented at the Spatial Information Theory: A Theoretical Basis for GIS, Proceedings COSIT.

Tversky, B., & Lee, P. U. (1999). Pictorial and Verbal Tools for Conveying Routes. *Spatial Information Theory*, from <Go to ISI>://000086779100004

Vaughn, J., & Diserens, C. M. (1930). The Relative Effects of Various Intensities of Punishment on Learning and Efficiency. *Journal of Comparative Psychology, 10*(1), 55-66.

Wine, J. (1971). Test anxiety and direction of attention. *Psychological Bulletin, 76*(2), 92-112.

Wunderlich, D., & Reinelt, R. *How to get there from here*: New York: Wiley.

Yerkes, R. M., & Dodson, J. D. (1908). The Relation of Strength of Stimulus to Rapidity of Habit-formation. *Journal of Comparative Neurology and Psychology, 18*, 459-482.