# Motional Strategies of Spatial Orientation in a Virtual Morris Maze Task

Thesis for graduation

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2004

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## Acknowledgements

This work was carried out at the Spatial Orientation and Research Laboratory, Institute of Psychology, University of Pécs, Hungary. I wish to express my deepest gratitude to my supervisor, János Kállai, PhD, Head of the Laboratory and Head of the Institute of Behavioural Sciences, University of Pécs for his supportive and encouraging comments concerning my work as well as his open-mindedness and cooperative attitude towards new initiatives and ideas. I have learnt the importance of interdisciplinarity in sciences in his laboratory amongst researchers of various fields.

I am grateful to every research members and students of the laboratory for the exciting discussions about spatial strategies and behaviour.

I want to thank László Bernáth for the statistical revision and for his critical comments.

I am more than grateful for the exhaustive help of Mary-Jane Curry for her suggestions on the academic writing style of the manuscript.

Finally, I wish to thank the support of Endre Grastyán Scientific College for providing tranquil but inspiring circumstances for my research.

## Abstract

In the present thesis, some frequently occurring motion patterns were investigated during spatial orientation behaviour in a virtual Morris maze. The research was focused on the validation of such motion patterns, the temporal progression of strategy-use, and the role of strategies in successful spatial performance with a considerable number of subjects (N = 112). Three motional strategies were found relevant that predicted spatial performance. One such motion pattern is called *enfilading* that refers to the approaching-abducing nature of an active exploration close to the target location. The *wall-touching* denotes a motional behaviour when subjects keep a continuous contact with the circular wall of the maze. The underlying cognitive strategy reflects to the early stages of spatial representation construction by assuring the required external reference, while on an emotional level it satisfies the need for safety in the novel environment. During the third, *pacman* strategy, an active scanning is performed in a fixed position while a visual shift between two distal cues happens. Additionally to these motion strategies, some turning-points in spatial performance could be identified considering the formation of spatial knowledge and the changes in platform finding latencies. Finally, the background of spatial behaviour success was investigated. It was found that the motional strategies of good and poor performers are different at the turning-points of spatial learning.

Keywords: spatial orientation, spatial representation, virtual reality, motion pattern, spatial strategy, exploration, enfilading, pacman, wall-touching, Morris water maze, mereology, spatial performance

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> *"Henceforth, space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality."*
> --Herman Minkowski (1849-1909)

# 1. INTRODUCTION

Following the thoughts of the mathematician Minkowski the concept of space need to be extended with the aspects of time and continuous change. As a consequence, the notion of static space should be exchanged with a dynamic space; and thinking about its phenomena needs to be anchored into the framework of the space-time continuum. The dimensions of goal-directed behaviours such as spatial orientation are to be explored, so as the variations of the connected attributes. One of the possible ways of investigation is the analysis of navigation paths and interpreting the functions of the frequently appearing motion patterns. The present thesis attempts this, whereby trying to build a bridge between the spatial behaviour and the mental representations in our head. With the tool of virtual reality, strategic motion patterns will be examined in their temporal progress. I wish to provide plausible interpretation for their functions and their role in the successful spatial orientation behaviour.

## 1.1. Spatial Representation

Constructing a mental representation or cognitive map (Tolman, 1948) of the space surrounding an individual is an active and dynamic process of the cognitive system that requires a spatial and temporal causality of the self and the environment. The story begins with an encounter between the two relatively different entities – the self and the environement - and the progression of embodiment, inclusiveness and inherence alongside the boundaries establishes spatial relations amongst the navigating agent and the extended objects. Acquisition of the spatial configuration is bounded to a specific neural structure of the brain and happens by means of representational enrichment of the external features (i.e. cues, nodes, angles, distances, paths and borders) and their computational matching with the internal state (i.e., error-correction of previously existing knowledge with the novel modality inputs).

Human spatial knowledge consists of three interrelated categories: knowledge of landmarks, knowledge of routes and configurational knowledge (Siegel and White, 1975). The development of spatial representation consequently follows these stages. Only after getting in touch with distinct cues and learning the paths between them can one construct a cognitive map. This general cross-sectional model also corresponds to the ontogenetic development of children's spatial abilities. Neurological evidences of place learning and map constructing also support this three-stage model (O'Keefe and Nadel, 1978).

Salient cues for orientation have an important contribution to the process as these navigational aids mark the meeting points of the subject and its environment. Usually visually emergent features (e.g., corners, signs, crossroads) serve as landmarks, but the boundary of the space may also represent such orientating locations. These cues or landmarks exist on their own in the early stages of spatial construction with no relation to other cues or to the surroundings. When based on merely one navigation landmark orientation is not an easy task. An example of this phenomenon is when we are lost in a crowded shopping centre and we locate ourselves on the phone to others by saying, for example, -"next to the Springfield shop".

Route learning involves the pair-wise association of cues along a known path, but without spatial relation between the starting and the target positions. These routes may exist in parallel and independently from each other in a same area. During walks on the learnt paths the directions change from time to time but the focus is on procedural knowledge (i.e. turn right on the corner) instead of on the absolute position of the cues. Hartley et al. (2003) argue that such route-following involves an action-based representation, where response learning takes place. The activation of a distinct neural substrate (the head of the right caudate nucleus) accompanies this type of spatial performance. On the other hand, way-finding on novel routes requires place learning in a cognitive map; the corresponding neural structure is the right posterior hippocampus (Hartley et al., 2003).

Configuration or survey knowledge has an integrative and global notion of the space where the topological relations of salient cues and learnt routes are represented in a Euclidean coordinate system (Siegel and White, 1975). It is also clear that a map-like representation is built up by route knowledge previously acquired from either a procedural (e.g. walked) or declarative (e.g. saw a sketched map) type of learning (Anderson, 1982). For instance, there evidence that blindfolded subjects can create a mental image of an environment learned by traversing paths (Klatzky et al., 1990). Although some scientists argue that procedural and declarative learning create two slightly discrepant configurational representations, this difference can be diminished by paying special attention to the settings of the applied task (McDonald and Pellegrino, 1993). However, it is still not clear from the literature what makes the difference. Apparently, the most perplexing example is spatial learning in virtual reality, where no self-motion is present.

A survey representation provides an overview of spatial layout and has an allocentric (or exocentric) frame of reference. In this frame, the distal objects are represented on a dynamic mental map. Data about “what” and “where” are recorded in interconnected network of cues and landmarks in certain brain areas (Maguire et al., 1998). The observer is part of this representation but the actual centre is mentally weighted and computed based on the saliency of the spatial features (O’Keefe, 1991). The motion of this observer does not have an effect on the configuration. Continuous updating in the vectorial summation of the object-relations happens as a consequence of any change in the perceived reality (e.g. motion, structural modification, etc.).

Route representations assume the point of view of a person (egocentric frame) moving through an environment and are anchored to a number of salient landmarks. This reference frame is the first existing approach to a novel space, where no configuration knowledge has yet been settled. The subject relates every cue to his or her own body; therefore these definitions are only temporarily existing locations. This subject-dependent form of representation is very sensitive to motion. The cues lose their spatial relevance to each other, as the subject’s body changes its position and moves away. For a well functioning route representation, the subject has to position him- or herself proximally to a salient cue; the subject’s viewpoint has to coincide with the viewpoint acquired during the learning of that particular route (King et al., 2002).

Similar processing modes are revealed in Hartley and Burgess (2002), which summarizes that the two reference systems differ in both spatial and temporal means and that the related neural substrates are also different. Hippocampal processes are concerned with large distances and long timescales, whereas parietal processes are more concerned with short timescales and the space immediately surrounding the body (id., p.2.) The importance of updating positions and headings is also emphasised in connection with the egocentric frame of reference, while in the case of the allocentric frame, the computational functions of the locations on the anchored cognitive map are accentuated (Burgess, 2002).

The way that a transition to allocentric representation might be extracted from egocentrically encoded sensory information is still a matter of debate (Hartley and Burgess, 2002). Path-integration is one possible answer (Wishaw, 1998; Loomis et al., 1993), in which a computational calibration of internal (e.g. self-motion, vestibular or motor information) and external signals (e.g. salient landmarks) happens. Another possibility is that conjunctions of the external cue features create the ego-independent spatial representation. Both possibilities are conceivable; perhaps the combination of path integration and external cue summation plays an important part in the transition process.

Another theory of spatial representation is provided by Thinus-Blanc et al. (1991), based on many of their infra-human and human experiments. They assume the existence of two levels in spatial processing: a lower visual and a higher abstract one. Visual images of some parts of the environment would be stored in a panoramic snapshot-view; the role of early spatial orientation is to gain multiple numbers of perspectives of the space. The second level is made up of more abstract representations conceived as schemata, which guide and organize the information-gathering process and extract spatial invariants.

From the different models of spatial representation it seems that the orientating agent, the navigational cues and the target all play an important role in spatial orientation. They are equally represented on the final allocentric map bounded to the hippocampus (O’Keefe, 1991), but their cognitive relation to each other offers an interesting opportunity to investigate spatial behaviour.

In the next section I will step aside from psychological terminology to a more metaphysical approach that demonstrates the possible modes of locations of physically extended objects with their surrounding spatial environment. Thereby, I wish to ground an ontological basis for the assumptions raised in my hypothesis. Furthermore, I will attempt to connect the formation of spatial representations with the topological and parthood relations of objects. This will lead us to the notion of spatial strategy; and its interpretation will be based on the spatial and temporal aspects of this relationship.

## 1.2. Spatial Objects, Boundaries and Spatial Relations

Boundaries of extended objects have a peculiar position in understanding spatial relations. To locate an object, boundaries are essential parts of demarcation. On one side of the boundary exists the object itself and on the other side there is a different entity. The neighbour can be another object or the surrounding space, but the significance is in the separable feature given by the boundary.

The dilemma of boundaries (known as the Brentano – Bolzano debate, id. Casati and Varzi, 1999) questions whether there is only one or two boundaries between two adjacent objects (Varzi, 1997). The identification of the part to the whole is implicitly present in this question; this metaphysical theory is called mereology (Zalta, 2004). Some reductionist philosophers give a façons de parler answer to this problem, meaning that it depends on the particular viewpoint of the observer. This answer contributes little to a functional understanding of spatial relations. Instead of such ad hoc explanation, Varzi (1997) describes spatial objects' possible relations to each other. His idea moves the question from mereology to mereotopology, which combines parthood relations and spatial location examinations.

Casati and Varzi (1999) demonstrate the theory of location, in which spatial boundaries are ontologically on a par with extended parts. As a consequence, the relations of spatial objects can be investigated through involve the description of the dynamic status of their embodiment in any space (i.e. someone enters a room where he or she has not been before and while learning the spatial constellation of the fixtures, his or her explorations, glances and locomotion are informative about the parts of the room that are being processed). This dynamic approach deals with parthood and, spatial and temporal aspects of existence. Not only is the static location of the object examined but also the mereological relations in their related temporal occurrence.

The theory of location creates an ontology of object relations through the analysis of their dynamic nature. The dynamism comes from the fact that the objects might have many addresses: permanent or temporary; minimal or broad; spatially unstructured or structured.

A ‘permanent address’ refers to the location of the object without the criteria of having the object in that particular position in the actual moment. The term ‘temporary address’ is given to the object’s static existence in the specified space. Note that temporary address is what usually meant as the position of a subject, although it lacks the existence of time and relations. A sentence saying ‘the chair is on the table’ does not say anything about the chair’s regular position in the room, but reflects a static cross-section of a timeless state.

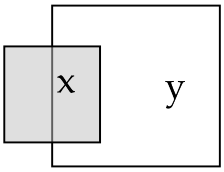
A ‘spatially minimal address’ changes with every movement of an object. This happens in an egocentric reference, where the environment is defined by the inner features of one part. The spatially minimal change in an address does not depend on the spatial structure or relation of the surroundings, but only on the object’s own movements. On the other hand, in a section of the certain space, any movement of the object is permitted without the change of its broad address. This is more like an allocentric frame referring to spatially known area, where object relations are set and delineated by an imaginary boundary of cognition.

Semantically comprehended movement, which is spatially non-relevant, is called an ‘unstructured address’. In a well-known area, a route of a pleasant wandering or a non-strategic search involves such spatially unstructured change in address. One can discover the small canals of Venice with this method, but might have the misfortune of missing the picturesque view of the Piazza San Marco. In contrast, a spatially structured address is overtly spatially determined. It contains exact locations, directions and relations of the objects within a familiar space. It is worth noting that a goal-directedness plays a crucial role in discriminating the two categories of spatial structure addresses.

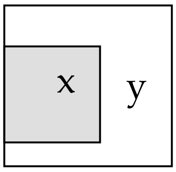
With Casati and Varzi’s (1999) mereotopological approach, a detailed spatial behaviour analysis can be done to object relations in a temporal and conceptual context. Taking mereology and theory of locations together, mereotopology describes the connections of object-to-object and object-to-environment relations in space. The application of this approach leads us to an ontologically based description of spatial motion strategies.

### 1.2.1. Modes of Locations in Spatial Navigation

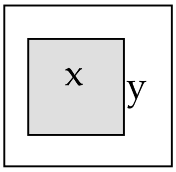
The process of an object entering a novel space is continuous and dynamic. It has stages of adjacency, in which the spatial relations become characterizable by parthoods (defined by the boundaries), locations (related to other spatial components) and temporal elements. The interactions of the objects make the model dynamic and spatially relevant. The following details (modes of locations) are only static intercepts of this process; the diagrams (based on Casati and Varzi, 1999) represent a zero time moment.



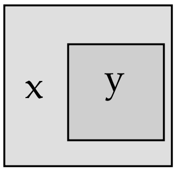
When an object contacts a novel space, it brings its own features into the environment and has no representation of the entered area’s inner configuration. The boundaries are overlapping and both forms have a necessary effect on each other. This is the moment of the first encounter, which has a huge impact on their future co-existence. The recipient and the entering part have had their self-existence that will be modified upon this contact. In the human world, apercu (the first impression of a new person) has important consequences based on previous attitudes and stereotypes towards an unknown person. Only with this heuristic reduction of information – which might be considered a first impression – will one become able to select from the redundant amount of information coming from the outer world. Using this social analogy, we can say that when an object enters a new place, it is an outsider until the first contact has happened. Although, because of the above mentioned boundary dilemma, in the temporal aspect occurrence without contact is only feasible for a limited period during the encounter.



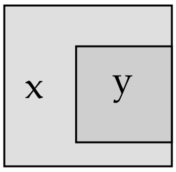
If the "first touch" comes to pass, the co-existence of the object and its environment begins. It is still an egocentric representation from the object's perspective, because the reference frame is inside the known world (i.e. in the object /x/ itself). This phase is the setting of a broad context of the environment, in which the object (x) finds itself inside the environment (y). A permanent address is formed by changes to the temporary address. The distances are proximal ones, and therefore close connections have to be settled with the surrounding space. The most probable linkage is alongside the boundaries. A wall or fence is the typical boundary of a defined physical area. A first encounter with the spatial environment usually turns into experiencing the "limits" of the space. Hence, a strategic element of initial spatial locomotion is the outlining of the edges, whereby distress from unknown world is reduced simply by becoming the inner part of the ambient.



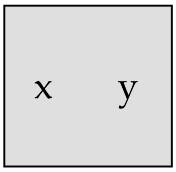
After the boundaries are known relative to the object's position, an adventurous but unintentional exploration takes place. Spatially minimal movements increase but the representation of the space is still referenced with an unstructured address. Other objects are not related to each other nor anchored to a fixed position in the environment. Major representation is still egocentric, but the beginnings of object-to-object linkages might occur. Searching is non-strategic and only vague approximations are performed to a desired position. Distances and directions are not properly used partly because of egocentricism and partly from the unevenly estimated values of the explored salient cues (other objects). Despite this contingency, the unstructured space turns into a structured one by developing spatial relations between the object (x) and the boundaries of (y). The more these connections made, the more an interrelated structure is formed.



In the next step, an intent structuring strategy happens. All the relevant spatial relations are known by now and their mereotopological values have to be set properly. To do so, the extent of parthood and location inside the space have to be determined in the case of every component. This is typically an allocentric representation with a focus on the other objects (y) and their relations as independently existing agents. With a constant broad address of location the movements do not happen along the spatial constancies. As a consequence, strategic behaviour (e.g. exploratory activity) emerges into notice at this stage. When an object (y) is reached, the proximal location co-ordinates are compared to distant cues (i.e. other objects, $y_2$, $y_3$, etc.) and their relation is added to the structure of the space. This monitoring is usually bonded to the fixed position of (y) but may also happen together with a minimal address variation.



Important feedback comes from those objects, whose position is closely located near the boundaries of the surroundings. The basic difference between this stage and to egocentric “wall-touching” is that while in the first case the emphasis is on the object (x), now the space is being referenced by representing the other object (y) contra the space. Even with already allocentric representations and strengthened spatial relations, the whole “marketplace” has to be anchored. Cardinal directions are to be orientated and salient cues are to be marked in contrast to the wall of the area. Such spatial referencing has to happen with goal-driven intentions in order to form reliable lines of navigation.



The final mode is the constitutionised allocentric spatial representation of the whole spatial area with the relevant parts (x, y) and the whole (space). These mereological concepts are spatially structured and interrelated units in a temporally continuous development. Intentional spatial movements – such as goal-driven navigations – use strained and focal strategies. The planning and execution of such motions are based on the relational hierarchy of the internal representation of space.

The theory of locations provides a metaphysical explanation of spatial relations of extended objects. The above presented modes are the basic models of spatial interactions. The dynamic process of object adjacencies can be implemented in psychology in terms of spatial behaviour analysis. In the next chapter, the possible levels of interpretations for spatial strategies will be demonstrated. The modes of locations will be considered as ontological background for defining spatial motion strategies.

### 1.3. Different Levels of Spatial Strategies

The concept of spatial strategy varies in the research literature. The term “strategy” causes this confusion, as it refer to some summation of techniques or abilities applied in any behaviour. For a comprehensive understanding of spatial strategies, I will give a brief review of the various ways the term is used in the literature.

The most classic means of investigating the nature of a behaviour is to observe the differences in performance and determine the possible reasons. Analysing the trajectories of rats during the completion of spatial tasks and describing the most common motion patterns is a simple and effective way to research. Most of the studies used this method are interested in exploratory activity concentrated around a specific object or area of the search space (Gaunet and Thinus-Blanc, 1996). From another perspective, every goal-directed spatial action might be interpreted as spatial strategy (O’Keefe and Nadel, 1978; O’Keefe, 1991). If an animal uses landmarks in its navigation for exploring or avoiding a certain place, this behaviour is evidentially a fruitful and adaptive response to the environment. Other researchers emphasise the macro features of spatial behaviour such as modes of information acquisition or individual differences in cognitive sub-processes (Pazzaglia and De Beni, 2001). Another example comes from data about gender differences in spatial strategies (Dabs et al., 1998; Lawton, 1996).

In studies on spatial strategies, there are different levels of the application of the term “strategy”. These levels are only conceptually different viewpoints of the same phenomena, and applying such distinction serves only conceptual and methodological reasons. Experimenting with cell firing rates in the hippocampus requires a representational and computational approach, while investigating personal factors of spatial behaviour needs a more global conceptual background.

### 1.3.1. Goal-Directed Strategies

In their seminal book, John O’Keefe and Lynn Nadel (1978) have identified a set of spatial behaviours they call spatial strategies. These strategies involved exploration of a novel environment, detection of changes of a familiar environment, navigation to a goal from different starting locations and detour behaviour. The main feature of a strategy is that subjects utilize it during their goal-directed spatial response to the environment. These strategies are usually in connection with another objects or boundaries or an obstacle. Note that on this level of interpretation the action representations and their neural correspondence play a central role, but the way is not detailed as the strategies are being carried out.

Spatial strategies require the existence of an allocentric mapping system. O’Keefe and Nadel were the first to argue that the hippocampus is the neural centre of spatial processing and plays an important role in the organization of topological information. Through this neural substrate any new information can be integrated into the mapping system on the basis of single experiences.

A distinction was made between two spatial strategy categories: taxons and guidances. A taxon strategy is a route-like system in which a simple motoric response happens to a stimulus; as a consequence a moving from one part of an environment to another takes place. The guidance strategy involves approaching or avoiding particular cues. This latter motion involves egocentric references, and goal-oriented locomotion happens within this frame. The guidance (or orientation) strategy relies on the association of particular cues with particular responses. One such response strategy is the rotation of the direction of pointing by an angle within the egocentric axis in the presence of a particular cue (O'Keefe and Nadel, 1978).

It is assumed that the representation of an environment is originally constructed during exploration; this process is viewed as a cognitive activity that keeps the maps in register with the environment. When an animal or a human enters an environment, the mapping system searches for a representation with the correct set of cues and boundaries to match the incoming sensory data. Competitive fine-tuning and error-correction of computational settings begin immediately after the first encounter with the novel space (O'Keefe, 1991).

### 1.3.2. Exploratory Strategies

Exploration as a sensorimotor activity and spatial knowledge are closely related to each other by functional reciprocal links (Thinus-Blanc et al., 1991). In the first case the information is organized along a body-centred reference, while in the latter case the representations are distributed in allocentric topographical cognitive maps.

Exploratory activity is displayed by most mammalian species in novel situations. Internal emotional and motivational factors (i.e. curiosity, fear, anxiety) together with external spatial features (i.e. geometric and topographic) are related to it in both animals and humans. During the organism's exploratory reaction to the environment, spatial knowledge is created. Thus animals build up a cognitive representation of the problem space that is necessary to deal with the situation (Thinus-Blanc, 1996).

Gaunet and Thinus-Blanc (1996) report two types of exploratory patterns. First, they distinguish a "Cyclic pattern" consisting of visiting all the objects successively, beginning and finishing at the same one. The other pattern – the "Back and Forth pattern" – involves making repeated contacts between two objects. According to Gaunet and Thinus-Blanc, their data support the idea that some organizing strategies underlie spontaneous exploratory behaviours, which result in more or less accurate spatial representations.

Some basic exploratory strategies were also identified by Hill et al. (1993). The first strategy is bounded to the boundaries of the surrounding space. The actual amount of exploration is low, as the explorer stays close to the wall in order to maintain relative safety in the novel and frightening environment. The second, a network-type explorer, concentrates on the straight lines for advancing; any object that intervenes will be explored. An object-to-object strategy is third, where random wandering happens until the first cue is found. After the exploration of this point, any possible relation of other closely located cues are sought. If the exploration is successful, the same procedure is executed with the next object. If no such point is found, the wondering continues. A mixture of the first and third strategy is also possible, when the boundary is a reference point and those objects that are found in the nearby will be explored. A special case is the fifth strategy, when a salient landmark is used as base reference and every exploratory activity is carried out in relation to this point.

### 1.3.3. Way-finding Strategies

The highest level of spatial strategies is way-finding behaviour, representing an abstract level of cognition. It is influenced by complex personality and biological factors. Thinking spatial behaviour is an integrated part of the acquired repertoire of a living being; thus this interpretative category identifies individual differences in responses and navigational forms in an evolutionary context.

Route and survey representations can be related to different strategies used in way-finding tasks. Lawton (1994, 1996) has distinguished between route strategy, based on information about a route to be followed, such as when and where to turn, and orientation strategy, based on reference to global reference points, such as compass directions in outdoor environments, or the general building configuration in indoor environments. Route and orientation strategies are often equally efficient in way-finding tasks, even if route strategy is more frequently associated with a high level of spatial anxiety and gender specificity (Lawton, 1994).

Much research literature has reported gender differences in spatially involved tasks and way-finding strategies (Parsons et al., 2004; Lawton and Kállai, 2002; Kimura, 1999; Dabbs et al., 1998; Moffat et al., 1998; Lawton, 1994, 1996). Though there was a traditional belief that males possess a superior spatial ability, recent research has demonstrated the importance of other factors such as task dependencies (Astur et al., 1998; Sandstrom et al., 1998), differences in brain activation (Grön et al., 2000; Hamilton, 1995), hormonal fluctuations (McCourt et al., 1997; Choi and Silverman, 1996; Kimura, 1992) and other evolutionary aspects (Kimura, 1999; Silverman and Eals, 1992) that made this argument more sophisticated. The conclusion from these results is that both individual development and the details of the complex environment have an effect on the gender differences of spatial performances and strategies (Astur et al., 2003; Hite, 2003).

From a study by Kállai and colleagues (2002) it seems that childhood navigation experiences and adulthood fears determine the utilized spatial strategies. They reported that way-finding preferences not only depend on the physical features of the current environment and the subjects' sex role but also on anxiety characteristics and childhood attachment factors. Anxiety decreases orientation strategy use and triggers the route-finding strategy in both men and women. However, in other respects gender analysis shows that women focus on maintaining the inert structure of a bordered environment with a protective route-finding strategy, while men maintain the spatial structure of the current environment probably to elaborate a preventive-like orientation strategy (Kállai et al., 2002).

### 1.3.4. Spatial Motor Patterns

As mentioned in the beginning of this chapter, trajectory pattern analysis is based on the description of the most commonly occurring components of navigation paths. The basic idea of analysing such patterns on navigation maps comes from previous observations during experiments of spatial memory and learning. It was noticed that during completion of a Morris maze tasks subjects tend to use similar types of well traceable path shapes. These distinct parts of their navigation are created as a result of certain motion patterns.

Apart from the observational validity of these motion patterns, an ontological derivation from the theory of location and modes (described in Chapter 1.2.1.) can be made, as the parthood relations of the orientating subjects and the cues or boundaries are well identifiable on the maps. The motion patterns reflect spatial relations to identifiable locations of the space or situations of the orientation activity (e.g. close to the walls, close to the target position, during visual search for a salient distant cue). Note that these path maps are only a summation of the behaviour, so for a comprehensive interpretation, the temporal aspects have to be considered as well. Therefore a time-related mereo-topology of spatial objects and their relations is used to recognise these patterns.

Motion analysis relies on the output of behaviour (i.e. navigation path), therefore the actual way of causality of mental representation of space and the observed motion pattern can be a matter of dispute (see Chapter 6.2. for a possible explication). Despite this fact, I will argue in this thesis that spatial motion strategies are valid and useful components in describing and predicting performances in spatial tasks.

Before presenting the experiment in which spatial motion patterns were analysed and their characteristics detailed in respect to spatial performances, let me now turn to a recent application method of spatial behaviour research: virtual reality. I will argue that it offers an excellent opportunity for precise examination of spatial activity and trajectory patterns on navigation maps.

## 1.4. Virtual Reality in Scientific Research

Virtual reality (VR) has become a widely accepted and reliable research tool recently, but its first appearance dates to the late 1950s (Virtual Reality: History[1]). As technical inventions (i.e. transistors, graphical displays) made computers and IT more advanced, user-friendly interfaces and programmable software environments laid the groundwork for virtual reality.

The first applications of VR opportunities mainly occurred in the military beginning in the 1960s. Radar defence systems, aircraft designing programs and flight simulators

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[1] http://archive.ncsa.uiuc.edu/Cyberia/VETopLevels/VR.History.html (Access: 01/03/2004)

were all rapidly developing under the aegis of Cold War arms races. The U.S. army and its related industrial complex pumped millions of dollars into technology to simulate flying airplanes, driving tanks and steering ships. Training fighter pilots and crewmembers became easier and safer in the virtual environment, where emergency situations could be modelled.

Another huge market for VR was the entertainment industry, which also enhanced the refinement of such technical solutions. Computer animated movies, video games, virtual artworks and artificial worlds spread by the early 1980s. Science fiction movies like Star Wars and Terminator dominated the cinemas and Nintendo or GameBoy entered children's rooms and their fantasies.

For scientific research purposes, VR technology has been used since the mid-1980s. Modelling dynamic processes, understanding complex structures and simulating galactic scales would not have been possible without high-performance computers and high-resolution image rendering graphical interfaces with relative low-cost investments. Nowadays the scientific currents of VR research have a pervasive influence on the fields of human-computer interactions, intelligent agents development, medical and computer imaging or design.

Virtual reality provided an opportunity for behavioural scientists – such as psychologists in cognitive science – to create models of cognitive mechanisms and virtual simulations of everyday life and examine people's reactions in highly controlled circumstances. The plots were already given with the technology of flight simulators and virtual worlds, but the validity and reliability of the method had to be proven.

Indeed, a prospective astronaut sitting next to a computer screen in a simulator, which imitates everyday routines inside a virtually existing spacecraft or potentially dangerous situations outside the capsule during a space walk might seem too artificial or even oversimplified. What assures us that the reaction to a virtual danger of oxygen leakage would resemble a similar real world situation on the bridge of the International Space Station? How can we be sure that a learnt route in a virtual city will help us to find the corresponding building in the reality? Many studies have examined these questions of transference from VR to the real world and found promising results of performance similarities in between the two environments (Farrell et al., 2003; Burgess and King, 2001; Oman et al., 2000; Péruch et al., 2000; Astur et al., 1998; Ruddle et al., 1997). It seems that information acquisition in VR promotes the adaptation and well functioning in real world situations in both fields of spatial representation and spatial skills.

### 1.4.1. Virtual Reality in Research of Human Navigation Behaviour

By creating virtual rooms or cities and asking people to find certain locations in them, precise experimenting of human spatial navigation and place learning seems possible (Jansen-Osman, 2002; Jacobs et al., 1997). In such environment self-motion is usually controlled by a joystick or keypad and the view on the screen or in the head-mounted display changes according to the hand or body movements. The first-person view of the visual feedback makes VR realistic. Other visual features, for instance the viewpoint, affect the detour finding strategies (Janzen, 2001).

There are two basic types of VR systems used in research: desk-top based and immersive display systems. The latter uses devices like head mounted displays (HMDs) and tracking systems, which give the user the impression of being completely ‘immersed’ in the virtual world, without any trace left of the real world. In contrast to this, desk-top systems display the virtual world on a monitor screen (Jansen-Osmann, 2002). Both techniques are well established the only difference between them is that immersive systems have an even more realistic view of the virtual world (Ruddle et al., 1999).

There are certain important limitations for the interpretations of human navigation results with VR. Early developmental studies with cats demonstrated, that active explorations and self-induced movements are required for their healthy spatial competency and cognition (Held and Hein, 1963). A substantial body of data indicates, that for most mammals at least vestibular, motor, and visual information are significant components of any internal representation of abstract spatial relations (McNaughton et al., 1996). During virtual wandering there is no real locomotion of the body, therefore no sensorimotor feedback is present. Relying only on the visual and perhaps on the auditory modality and lacking one important aspect of spatial cognition (e.g. sensory inputs of the balancing system) makes virtual learning different from real world situations. A mismatch in the visual input and the non-visual control information on the reproduction of actively performed virtual tasks sometimes leads to conflicts on the memorization of the travelled path (Lambery et al., 2002).

Active explorations, on the other hand, has similar but less significance in virtual space learning as in the real world. In an experiment, Gaunet et al. (2001) compared three groups of subjects who performed different travelling in a virtual city. The first group used active explorations, which meant that they could control their journey with a joystick while accurate directions were given to them. Members of the second group were the passive explorers, because they travelled through the designated route by the computer, but the subjects were not allowed to look around or deviate from this virtual sightseeing. The third group was shown snapshots of the route that they should take with the major buildings and streets on it. Spatial memory performances were compared between the three groups concerning the scene recognition, orientation of the departure and destination places and drawings of the path shape. Differences were only found in path shape reproduction, where snapshots group members were less accurate. The researchers concluded that drawing the path shape involves a deliberate reconstruction process (Gaunet et al., 2001). It might be added that such results indicate the visual dominancy of VR tasks and therefore it emphasises a limitation for interpreting the processes equivalent to real world spatial navigations.

The geometric and local features of the landmarks used inside a virtual room have a huge impact on the performance. Navigational learning is affected by different types of navigational cues. These cues need to have memorable forms if people’s navigational efficiency is to be improved (Ruddle et al., 1997). The use of distal or proximal distances of landmarks also contributes to the construction of the cognitive map in the virtual space (Jacobs et al., 1997).

Visually dominant cognitive sub-processes of virtual spatial tasks require relatively good perceptual skill competency in mental rotation and stereoscopic vision (Rizzo et al., 1998; Oman et al., 2000). There is evidence that good mental rotation task performances correlates with spatial memory and other spatially involved performances (Astur et al., 2003; Karádi et al., 2001) while they counterbalance verbal concept formation (Makány et al., 2002). Similarly, in everyday life situations, we rely on our ability to use imagery to turn over or manipulate objects mentally. Experiments with temporary disorientated conditions show that the locations of objects in a room are encoded individually, but the locations of geometric features are encoded in a single, unified representation (Wang and Spelke, 2000). Adaptation to the changed topographical circumstances is only possible with a cognitive reconfiguration of the spatial representations. In the real world, this restructuring occurs even in blind situations with the sensory feedback from self-motion that causes an automatic updating of an internal representation of locations that is more accurate than our ability to deliberately perform the equivalent mental rotation (Burgess et al., 2002). In VR, we lack sensorimotor inputs, so a "virtual self-motion" is built up by the visuospatial congruencies of the joystick movements and what is seen on the monitor.

Other factors might influence virtual research, such as the prior degree to which general computer experience transfers specifically to VR (Waller, 2000) or the effects of age on virtual place navigation and allocentric cognitive mapping (Moffat and Resnick, 2002). This latter study compared older adults to younger ones, where both groups performed a virtual spatial place-finding task. Older volunteers traversed a longer linear distance to locate the target place and had significantly fewer platform intersections. Map reproduction analyses also indicated that older participants used proximal objects to locate the goal but did not use room geometry cues to aid navigation. These findings demonstrate that age-related deficits are present in a VR environment and suggest that deficiencies in allocentric mapping may be inadequate.

Considering all these limitations, there is still a good correspondence between the level of virtually acquired knowledge and the real world performance; hence virtual reality can be used with high reliability to examine spatial and other behaviour interactions in realistic simulated settings (Burgess and King, 2001; Rose and Foreman, 1999). There is an increasing number of studies reporting special trainings with VR technologies on various fields from the systematic desensitization of phobias (Rothbaum et al., 2000; Wald and Taylor, 2000) through individual trainings in various real world situations (Waller, 2000) to weightless situations in a spacecraft (Oman et al., 2000).

### 1.4.2. Virtual Morris Water Maze In Spatial Research

The spatial orientation and way-finding performances of animals have been objectively investigated with water maze tasks by ethologists and animal behaviour scientists. The small circular pool, filled with water where the animal – usually a rat – is introduced, has an escape platform that emerges from the unpleasant watery environment. Throughout the trials the animal increasingly learns the location of this platform by remembering distal cues outside the pool (Morris, 1981).

Jacobs et al. (1997) have extended this Morris-type water maze procedure to humans exploring a computer-generated virtual space. In their series of experiments participants had to find the location of an invisible target in a virtual room. Their spatial learning and memory performances were analysed during several trials. Subjects were tested in different conditions to see whether the features of the cues (proximal or distal) or novel starting positions had an effect on their learning rate. The platform finding latencies were decreasing linearly across acquisition trials, indicating that the location of the target was learnt. Moreover, as a result of the settings of the virtual arena it was clear that distal cues had prior significance in learning the location of the invisible target. Jacobs and colleagues concluded that subjects constructed a mental representation of the virtual space that was independent of their actual spatial position.

Since the first introduction of Morris water maze in 1981, the application of the method has become commonly used for investigating spatial navigation and place learning in both real world and in virtual reality. Its repeatability and precise measurability has made such a task widespread in psychology research. Behavioural scientists highly benefited from the high extent of immersion created by the more and more realistic settings of the VR environments. Cognitive and neural aspects of spatial performances and navigational strategies can be examined in details with the help of this method.

## 2. Hypothesis and Research Aims

The present thesis has three main aims. The first and most important aim is to validate visually observed spatial motion patterns and determine their functions in a virtual environment. Presuming that such patterns have different functional roles in navigation behaviour, I argue that their quantitative distribution in a virtual spatial task will determine spatial performance with high predictability.

In terms of the first hypothesis (i.e., that motion patterns are distinct functional features of spatial behaviour and performance), the temporal distribution of the applied spatial strategy will be outlined. I expect some turning-points in strategy-use as a consequence of spatial learning. If this second hypothesis is verifiable, than subsets of dominant strategic trials will be found according to spatial performance changes.

Finally, I attempt to explain performance differences between groups of good and poor spatial performers on the basis of their divergent strategy-uses at turning-points in the place-learning process. This last aim implies the hypothesis that the real difference behind individual spatial abilities is based on spatial motion strategies.

# 3. Methods

## 3.1. Participants

Participants were undergraduate students from various faculties of the University of Pécs, Hungary (N = 112). The group was composed of 42 males and 70 females. The mean age was 21,4 years (SD = 1,6) with a range of 18-27 years. All of them were paid voluntaries, recruited with advertisements. Everyone was informed in advance about the aims and procedures of the experiment. None of them had previous psychiatric illnesses nor any physical disabilities that would have restrained them from completing the computer-based spatial task.

Anticipating a possible distortion coming from individual differences of computer game playing practice (Waller, 2000), the participants were pre-selected during the recruit on the basis of a questionnaire, which asked about computer using habits. Only those students could become actual participants whose computer game playing hours per week did not exceed one and a half hours.

## 3.2. Apparatus – The Computer-Generated Arena (CGA)

For measuring spatial performances and registering motion patterns in virtual environment, a desk-top based computer program was used. This Computer-Generated Arena (CGA) was developed by Jacobs et al. (1997) to explore various aspects of spatial cognition.

Human adaptation of the Morris mazes – both real world and virtual versions – are recently used by psychologists, behaviour researchers and neuroscientists to describe human spatial cognition and navigation (Makány and Kállai, 2004, 2003; Astur et al., 2002; Burgess et al., 2002; Jacobs et al., 1997). Salient landmarks, effective platform finding routes and navigation strategies together with underlying cognitive and neural mechanisms are the foci of these research studies.

In the three-dimensional (3D) computer desk-top task used in this study (*Picture 1.*), the participants are tested on a standard PC displaying a multicolored view of a circular arena. The arena is located within a square room, and the subjects viewed the scene as though standing on the floor of the arena. With the movements done by a joystick the first-person display view moves around the arena, and the portion of the screen taken up by the arena and room walls varies accordingly. Each wall has a distinctive pattern of windows or arches, thereby providing a means by which participants could orient themselves within the virtual space.

The C-G Arena is divided into four imaginary quadrants, and a blue square target (visible in the first two trials T1 and T2, but hidden from T3) is located in a constantly fixed position. The aim of the subjects is to find and navigate onto this target platform under the shortest time possible and remember its place in order to repeat the trial with even better temporal performance.

### 3.3. Procedure

Subjects were sitting next to a standard desk-top based PC equipped with a 17” SVGA screen and stereo speakers. A joystick was positioned on the table for directing the movements the same as in first-person shooter games. There were two types of rooms. The first was a practice room, with no objects or platform. Only purpose of this place was to acquire the ability of virtual locomotion with the joystick.

After finishing in the practice room, the subject is teleported to the actual test room. Inside this arena there are distal objects on the wall and a blue platform rectangle on the floor, which is visible in the first two trials (T1-T2), and invisible from T3. The position of the visible cues and the platform were constant in all the 10 trials. The subjects had 3 minutes for searching in each trial. If the trial was unsuccessful (i.e. the platform was not found) the program teleported the user to the next practice room.

Before starting the trial set, the task was acquainted to the participants. A standard text was read out to them (*Appendix A*). As the first two test trials (T1 and T2) were completed, subjects were remembered that from the next trial the platform is invisible, but still placed at the same position as before. After the last trial, the program closed itself and the trial set was over.

## 4. Data Analysis

One of the great advantages of virtual environments is that every happening inside such space is precisely recorded and carefully analysed by the program. C-G Arena measures distances, routes and temporal factors of the subjects' navigations. The distances are in virtual meters that is the dimension of the software and proportionally equivalent to the real world distance of one meter. Wall-touching and circling strategies have not been calculated directly in such length but in degrees. The process of transformation of the degree values into virtual meters is described in Chapter 5.

### 4.1. Spatial Performances in the CGA

C-G Arena collects quantitative data of the subjects' navigations. Path lengths to the platform and platform finding times are the two most characterizing variables of spatial performance. In the first trials, the time for finding the target is higher than in the latter trials. This is a linear temporal decrease, which is accompanied by the actual walking path length decrease consequently as more accurate orientation in the virtual space is acquired.

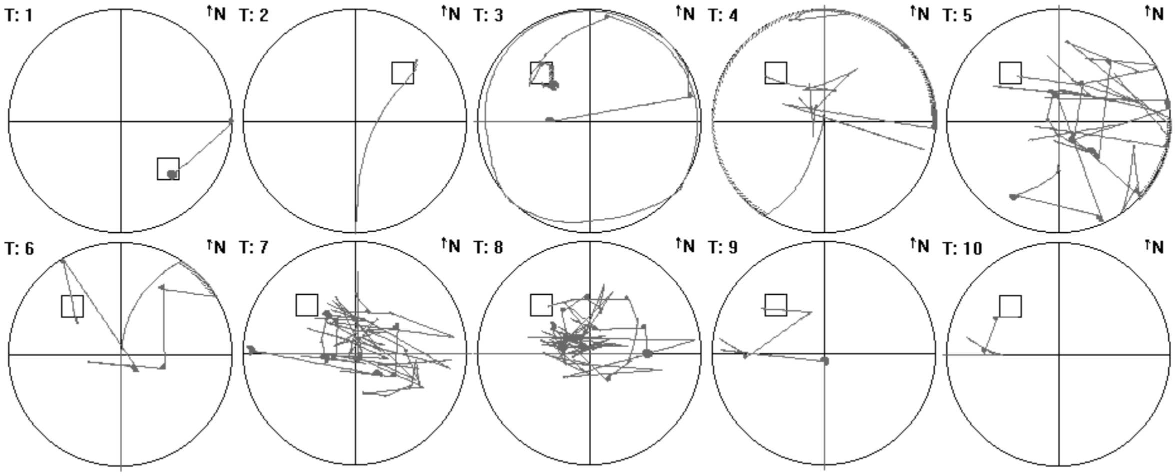
These two aspects (time and length) should be considered together when observations are made upon spatial performances. It is known from animal maze studies that merely the time under the rats found the reward food might have not necessarily meant that a good map of the maze was constructed, because trial-error type search could have also led to very low time values. Instead, the search path length has to be taken as a control variable for temporal changes. Only if there is no extremity (over 2 SD) in the path length of the subject, than could platform-finding time be considered as reliable indicator of spatial abilities.

Travelling pace in this virtual space is constant that can be either zero, if the subject's walked distance during a certain time is also nil, or one, during virtual locomotion. Speed variable therefore can be counted as a simple division of path length per time. This quality is rather an index of navigation activity as a consequence of constant velocity, than the actual speed of search.

The summation of the walked navigation path in each trial is visualized in maps drawn by the C-G Arena program. The circular arena is showed in a plan-view and it is divided into quadrants. The platform is also indicated on these maps so as the number of the actual trial (e.g. T:6) and the hypothetic direction of North. ( ↑N ). Navigation pathway is drawn with a continuous green line. These maps are drawn automatically by the program and converted into bitmap files for further qualitative analyses.

### 4.2. Analysing the Spatial Motion Strategies

Spatial Motion Strategies are frequent motion patterns that are separable parts of a subjects' navigation path walked in each trial. These virtual actions are qualitative data and they are distinctively present on the path maps (*Picture 2.*). Nevertheless the strategies are usually jointly existing motion forms, so precise definitions are essential for the identification.



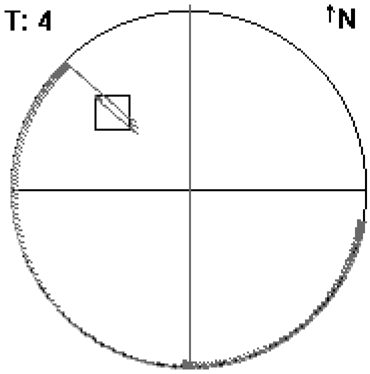
**Picture 2. –** Path maps of a subject during the 10 trials

The actual joystick control creates the virtual locomotion in the arena. Because the perspective on the desktop monitor is first-person view, the map reflects the walked pathways by the subject in each trial from a "bird's eye" perspective. Therefore by examining salient features of these drawings, observations can be done to the navigation behaviour. The goal-directed motor action (performed by the hand movements over joystick control) is the virtual implementation of the real world way-finding and spatial orientation. The goal is to find the hidden platform and the actual pathway – recorded in these navigation paths – is the savour of such spatial action.

By analysing the principal components of the navigation maps, four distinct spatial motion behaviours or strategies could have been distinguished: wall-touching, circling, pacman and enfilading.

### 4.2.1. Wall-touching

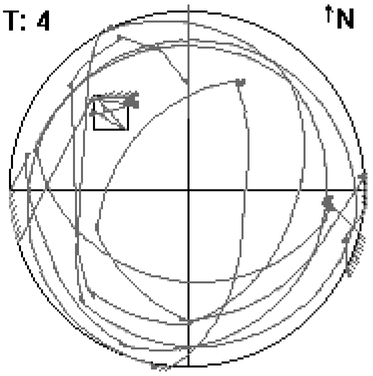
Wall-touching represents the degree of those particular circular part of the path that is walked close to the wall (*Picture 3.*). This is a summed value of every such motion in the actual trial. In many cases wall-touching happens repeatedly on the same area of the arena wall, so the final summed value may exceed 360 degree (the total circle of the arena wall).



**Picture 3.** – Wall-touching motion pattern

This strategy gives the subject a constant attachment to the stable element (i.e. wall) of the environment as a reference frame that is given by its own independent existence. A 'virtual touch' is necessarily present as a linkage to the object wherethrough the subject can define its own position.

### 4.2.2. Circling



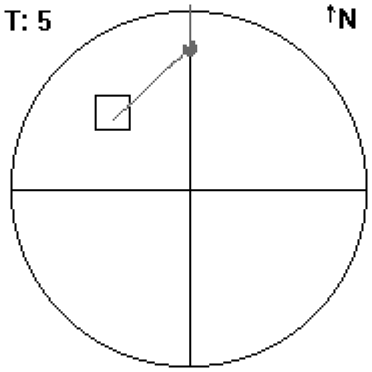
**Picture 4.** – Circling motion pattern

If a subject moved on an arc shaped path somewhere inside the arena but not next to the wall and this circular motion had the same incurvation as of the arena wall, then it is called circling (*Picture 4.*). The dimension of circling is in virtual meters and a summed value of this motion pattern is counted in each trial.

Circling can be observed when subjects pushed the joystick forward and to either left or right at the same time. During this motion strategy they can monitor the changing distal cues on the wall correspondingly to their own allocentric position exchange. This monitoring requires only visual feedback and no ‘virtual-touch’ is needed.

### 4.2.3. Pacman

When a subject looks around in a fixed position – without changing its’ co-ordinates – it is called pacman[2] (*Picture 5.*). Pacmans are counted as individual nominal values because the actual walking distance during this strategy is zero. Not every such exploratory behaviour was counted as pacman only those with at least 20 degree of turning. With this restriction, the subject’s small corrections of its position or in its visual focus were excluded from this strategy.



**Picture 5. –** Pacman motion pattern

Pacman represents the active visual scanning of the distal cues and more importantly the shift from one cue to another. The 20-degree criteria in such turns ensure the observer that the subject had switched its visual focus between cues on the wall. This is the minimal angle of a turn needed from any part of the arena for a visual shift. A pacman practically happens, when the joystick is pushed left or right direction without pushing it forward or backward at the same time.

### 4.2.4. Enfilading

Enfilading motion strategy is somewhat different from the other three. This is a combination of relatively small position corrections and non-strategic motions. It happens usually when the subjects assume that the location of the hidden platform should be close to their actual position. It seems that a rapid seek is performed on a limited area of the virtual space with small direction changes and straight lines of walk. It is the virtual equivalent of “Back and Forth” exploratory strategy by Gaunet and Thinus-Blanc (1996).

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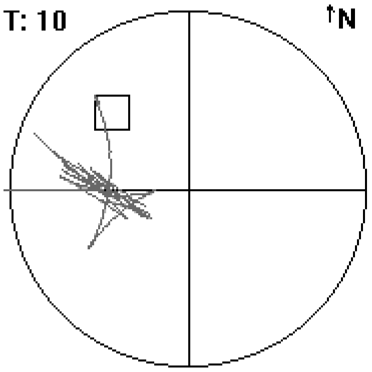
[2] The name comes from the old DOS arcade game ‘Pacman’ because the shape of the route map resembles to the small creature in the game.

Note that enfilading may also happen with less amount of cognitive control then the other three patterns during the search and therefore it is not clear whether it is a conscious strategy or a state of non-strategic motion.

Either a cognitively loaded, goal-directed search or an almost totally motion-directed, automatic process, enfilading is focused to a limited area and it is a well separable motion pattern on the navigation maps (*Picture 6.*).



**Picture 6. –** Enfilading motion pattern

In enfilading, the joystick is practically pushed forward and backward for several times and if this straight path is unsuccessful with finding the platform than a slightly different reversal (less than 20 degrees) follows.

The dimension of enfilading is measured in virtual meters and counted with a subtraction of the non-zero length strategies (wall-touching, circling) from total path length.

## 5. Statistics and Results

Statistical analysis of the data set was performed with SPSS for Windows Version 11.0. All the spatial performance results from the CG-Arena and the measured spatial motion strategies were stored in a database. The used variables were: Code (identification number of each subject), Gender, Trial, CPFT (platform finding time in sec), CPFL (path length to target in virtual meters[3]), Group (grouping variable upon CPFT), CGWALL (wall-touching distance in virtual meters), CGCIRC (circling distance in virtual meters), CGENFI (enfilading distance in virtual meters), CPACM (number of pacmans in the actual trial) and CSPEED (average speed of the subject in the actual trial in virtual meter per sec).

The distances within wall-touching (CGWALL) and circling (CGCIRC) strategies are all adjusted measurements into virtual meters. The adjustment was calculated on the basis of the following formula:

$$\text{CGWALL} = \frac{\pi}{180} * wall^{\circ} * r_{CGA}$$

where $wall^{\circ}$ is the degree in radius of the measured distance and $r_{CGA}$ is the radius of the C-G Arena[4] in virtual meters. The same as in the case of circling, respectively (CGCIRC):

$$\text{CGCIRC} = \frac{\pi}{180} * circling^{\circ} * r_{CGA}$$

The normal distribution of all variables was controlled by Kolmogorov-Smirnov Test. All but one (CSPEED) were normally distributed. In this single case the variances were not homogenous enough for normal distribution (Levene's Test of Homogeneity of Variances was not significant).

Temporal linearity in each variable was tested (with ANOVA Linear Contrast) and found to be significant in all instances ($p<0{,}001$ in all subsets). This means that

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[3] A virtual meter is the dimension of the C-G Arena software and proportionally equivalent to the real world distance of one meter.

[4] The radius of the C-G Arena is 50 virtual meters.

temporal changes of the performances and the motion strategies can be interpreted in a linear manner and linear regression models are applicable for these data.

In the spatial behaviour and motion strategy analysis the data represent the values taken from Trial 3 to Trial 10, because the first two trials (T1 and T2) are only for practice with visible targets.

### 5.1. Validity Test for the Spatial Motion Strategies

A stepwise linear regression was used for controlling the first hypothesis, whether the presumed and measured spatial motion strategies are reliable and valid constructs of individual spatial orientation in virtual space. For proving this assumption, the differences in spatial performance have to be described and followed by the consequent changes in the motion strategies.

The CPFT (platform finding time) was set as dependent variable in the regression model and the four strategies (CGWALL, CGCIRC, CGENFI and CPACM) were set as predictors for the linear changes. The stepwise method filters out the non-significant predictors and takes those into account, which are strong enough for the model to reach the level of significance.

Out of the four predictors, three remained in the model (CGWALL, CGENFI, CPACM) and one (CGCIRC) was dropped out. With this correction the square of regression was 0.864, which is a very high value ($R^2 = 0.864$; $p<0.001$). *Scatterplot 1.* illustrates the strong linear correlation and probability index of the model.

This result shows high predictability of the spatial performance (CPFT) from the assumed spatial motion strategies excluded circling. This verifies the first hypothesis about the validity and existence of motion patterns and their contribution to human spatial navigation in a virtual environment.

## 5.2. Turning-points in Performance

Temporal changes in the applied motion strategies can be informative for understanding their functions. Due to the formation of spatial representations, the performance and strategy values should decrease. The rate of this decrease was revealed with a One-Way ANOVA. Dependent variables were CPFT (platform finding time), CGWALL (length of wall-touching), CGENFI (length of enfilading) and CPACM (number of pacman per trial). The grouping variable was the number of the trials.

Tests of between-subjects effects confirmed the expectations (Table 1.). Temporal changes in platform finding times (CPFT's F(7)=14,613 p<0,001) and strategies (CGWALL's F(7)=3,172 p<0,005; CGENFI's F(7)=9,598 p<0,001; CPACM's F(7)=11,890 p<0,001) were all significant. Estimated marginal means are showing a markable temporal decrease (*Diagram 1.*).

| Dependent Variable | df | F | Sig. |
|---|---|---|---|
| Platform finding time (CPFT) | 7 | 14,613 | 0.000 |
| Wall-touching (CGWALL) | 7 | 3,172 | 0.003 |
| Enfilading (CGENFI) | 7 | 9,598 | 0.000 |
| Pacman (CPACM) | 7 | 11,890 | 0.000 |

**Table 1. –** Results of the tests of between-subjects effects in the temporal analysis

Between-subjects results are only indicators for great differences in main effects. For an in-depth exploration of the results, Duncan's post-hoc test was performed. This procedure enables clustering homogeneous subsets of data by temporal means.

Subsets derived from CPFT based on strategies showed that there are shifts in strategy-use during the eight trials (T3 to T10). These qualitative turning-points are usually happened immediately after T3 (this is the first in the test trial series) and around T6. Post-hoc analysis identified three distinct subsets of trials (*Diagram 2.*).

### 5.3. Difference Between Good and Poor Spatial Performance

Using the overall mean of platform finding times[5], the subjects were classified into groups of good and poor spatial performers. The level of criteria for belonging into good performers' group (n=46) was an average CPFT less or equal to 46,12 sec during the eight test trials from T3 to T10. Subjects having higher overall CPFT means were put into poor performers group (n=66).

For analysing the strategy differences between good and poor performers, a second stepwise linear regression was performed separately in the two groups. The dependent variable was again the spatial performance (CPFT) and the predictors were the three validated motion strategies (wall-touching, pacman and enfilading).

The results indicated that the different spatial performances between the two groups were based on the inverse application of two strategies: pacman and wall-touching. In other words, the subjects of the two groups were using consequently different strategies. In addition, this disjunction happened exactly at the previously described turning-points (see *Diagram 3.* for an overview of group differences).

A good overall spatial performance is linked with the application of pacman strategy around the main turning-points (T3, T6 and T10); and a one-shot increase of wall-touching around T5 and T6. On the other hand, poor performers apply spatial strategies inversely; they utilize wall-touching at the turning-points of spatial learning process.

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[5] In some cases a relatively low platform finding time can be obtained by an almost random like search with respectively long path length. This behaviour should not be considered as good performance. Therefore subjects using extremely high (over +2 SD) platform finding length were put into poor performers group.

## 6. Discussion

In the present thesis, I am arguing for the functional validity of motion strategies in virtual environment during spatial orientation. Human spatial studies have the construction of representations (Golledge, 1999; Gaunet and Thinus-Blanc, 1996; Loomis et al., 1993; Siegel and White, 1975), the role of related neural structures (Burgess, 2002; Astur et al., 2002; Magurie et al., 1998; O'Keefe and Nadel, 1978) and individual differences (Pazzaglia and De Beni, 2001; Astur et al., 1998; Lawton, 1994) in the foci of research, while the motional strategic aspects of the behaviour is less extensively described. This thesis experimentally tested four fundamental spatial motion strategy patterns in a virtual environment and described their spatio-temporal distributions and effects on the process of place learning.

I have demonstrated some reasons pro and contra in Chapter 1.4. that virtual reality offers an excellent tool for spatial research (Burgess and King, 2001; Rose and Foreman, 1999). One of the most important feature is that subjects can navigate themselves on the screen from a first-person view – and with some practice – it gives the user an impression of immersiveness in this virtual world and though the performance and strategical parameters can be precisely recorded. Further on that, computer generated software displays the path map of the subjects' trajectories whereat the motion patterns are well traceable so as their trial-to-trial temporal distributions.

The review and interpretation of the results in this section will follow the three hypothesises conceived in Chapter 2. Here, I attempt to combine experimental data with the theoretical background of spatial representations, spatial strategies, and the theory of locations.

### 6.1. Review and Interpretation of Results

The presented results indicate that spatial performances are highly depended on the applied cognitive strategies. The validity test in Chapter 5.2. shows that out of the four presumed spatial strategies, three has significant relation to spatial performances. Wall-touching, enfilading and pacman strategies act as strong predictors for overall performance changes and affect the level of spatial behaviour success. So the part of the first hypothesis that considers the visually observed motion patterns being functionally interconnected to the spatial performances is verified. This finding further strengthens the existing assumption in the research literature that performance could be analysed in terms of the motion pattern strategies observed on the path maps (Astur et al., 2003; Thinus-Blanc, 1996).

In the second hypothesis, I presumed some turning-points in both platform finding times and in the distribution of the applied motion patterns throughout the ten trials. Theories describing the various levels of spatial representations underlie the second research question (e.g. O'Keefe and Nadel, 1978; Siegel and White, 1975). Some qualitative changes happen either in terms of spatial construction and representation, and as a consequence, these appear on a behavioural level. These reorganizations entail the variation of performance along with subsets of trials may emerge.

It revealed from the statistics that there are indeed significant shifts in the temporal distribution of performance data around the third (T3) and the sixth (T6) trials. In the post-hoc examination of the trial-to-trial changes of the variable three homogenous subsets could be created precisely at these turning-points.

The first subset includes only T3, which is separate from other trials in terms of strategy-use and the relatively high platform finding time. This trial represents the first real encounter with the spatial task, as this is the first time when the target platform is invisible. The distinctive position of the T3 trial is an outcome of the novelty of the situation and the difficulty of the task.

The two emerging strategies in the T3 trial are pacman and wall-touching. The latter one creates the egocentric linkage to the boundary (see Chapter 1.2.1.) that may give the feeling of safety via the notion of being contacted to something firmly existing. In contrast, pacman is rather a strategy for active exploration of distal cues and the shift from one cue to another. Therefore the reason for applying pacman in the early phase of spatial learning process should be curiosity about the surrounding spatial attributes.

However, it is not surprising to find the dominance of two seemingly opposite strategies in the same trial. One extends the limit of space and the other reframes it. During our everyday exploratory activity in novel situations these categories are being utilized likewise (O'Keefe, 1991).

Trial 4, 5 and 6 were clustered into the second subset. The spatio-relational changes in this phase are being represented by the unstructured spatial movements and the beginning of object anchoring as a consequence of early map structuring initiatives. Subjects slowly start to get on with their environment, although these early representations are highly fragmented and landmarks are not constructed into a coherent map.

Low platform finding latency trials (T7, T8, T9 and T10) were grouped in the third subset. By now, the subjects have acquired the basic configuration of the space and constructed a mereotopological notion of the objects. In these trials they have become able to represent the space in an allocentric reference frame and perform mental computations concerning their actual position and the target place. The object relations are relevant spatial and temporal categories in their cognitive maps and therefore goal-driven navigations or alternative route-findings are carried out confidently.

The turning-point between the second and third subsets (around T6) interestingly involves the same two strategies – pacman and wall-touching – as in the first case. The post-hoc analysis revealed a significant increase of these strategies in both cases. It seems that for a qualitative change in spatial representation there is an intensified need for a more active exploration of the environment (pacman) and at the same time, a constant need for fixed reference with the boundary of the space (wall-touching). The in-time appearance of the turning-points and the proportional distribution of the applied strategies in these key stages of the spatial learning process are likely to be responsible for individual differences in performance.

Enfilading strategy is present in all the ten trials of spatial learning. In Chapter 4.2.4. I am introducing this motion pattern as an ambiguous behaviour that either can represent a cognitively loaded activity or a non-strategic search. Although the variation of enfilading is predictive to spatial performance – due to its unclear function – it can only be considered as an indicator of the level of exploration activity and virtual self-motion. Further experimenting is needed to clarify the basis of this motion pattern.

On the other hand, circling strategy (see Ch. 4.2.3.) was not found relevant in any aspects of spatial performance or temporal shifts. It is strange that although the proportional occurrence in my database is in accordance with the study of Astur et. al (2003), they state that “circle strategy is a completely reliable method of finding the platform, and it usually results in only a few more seconds of swim time” (i.m. page 10.). Unfortunately, Astur et. al do not provide any further argument for their statement of circling’s reliability and it seems that they accepted this motion pattern as reliable only upon the relatively frequent observations (i.e. circling is mentioned in almost every such virtual tasks). Except Astur et. al’s ad hoc statement, the effort to find a study describing circling strategy failed so as the attempt in this thesis to find a functional relevance for it. One possible explanation for circling not reaching the statistical validity might be that this motion pattern is predictable to spatial performance only through a secondary effect with some other factors, but not by itself.

Finally, the third research question aimed the understanding of the differences between good and poor spatial performers. There is an obvious conceptual problem concerning the distinction between the two groups of individuals. In most cases, the time of completing the task is a good indicator of spatial performance and therefore this method was followed in this thesis but with restrictions to excessive path lengths.

The dominant spatial strategy was different between good and poorer performers but only around the turning-points. Good performers rather preferred the pacman strategy around T3, T6 and T10, while poor performers applied wall-touching significantly more at these points (see *Diagram 3.*). The functional differences of the strategies is liable for this finding, as the primary aim of wall-touching is the formation of spatial context and to grab the reference settings of the environment, while for an effective exploration there is a need for active visual monitoring, which can be found in the pacman strategy. If this latter motion is less intensive, than the probability of a successful trial is much lower and it increases the subjective feeling of uncertainty.

So poor performance is a consequence of a recurring need of safety referencing from the most stationary element of the surrounding space that is the circular boundary of the arena maze. This behaviour rises the platform finding time hence the performance will be low. On the other hand, good performers can better refine their concepts of spatial relations with the more active pacman strategy without the need for returning to the context references all the time.

The one-shot increase of wall-touching in the case of good performance group at T5 and T6 may be linked to the early construction of the allocentric positions, as these representations are related to each other and to the boundaries. The fact that both groups (i.e. good and poorer spatial performers) have wall-touching around this second main turning-point demonstrates that the beginning of cognitive map formation happens around this trial.

### 6.2. Limitations of Results

After drawing the final conclusions above, I would like to point out some possible limitations of the results that need further research to clarify. It is important to emphasize, that I have been arguing for the method of path map analysis and the functional relevance of spatial motion strategies through the whole thesis and even taking the following remarks into consideration, these concepts are valid and noteworthy aspects of spatial orientation research.

First of all, the role of virtual reality (VR) as an environment in spatial orientation may generate some questions regarding spatial motion strategies. Is it the same phenomena in two different media (real or virtual) or shall we expect separate mechanisms in the computer generated reality and therefore the results have to be restricted only into this domain? The answer is not simple. One branch of scientists dealing with virtual spaces state that total immersion is possible, so we experience the same cognitive and other processes as in reality (Jansen-Osmann, 2002; Waller, 2000; Ruddle et al., 1999). According to them, transfer of abilities from one world to another is possible and efficient. Successfully applied VR techniques of desensitisations (Rothbaum et al., 2000; Wald and Taylor, 2000) and simulation devices (Osman et al., 2000) support this assumption. However, there are some sceptical approaches as well emphasising the importance of those modalities (e.g. vestibluar, self-induced locomotion, effects of gravity) that are being omitted in virtual reality tasks (Lambery et al., 2002; McNaughton et al., 1996). The present state of our knowledge does not cover all aspects of the relationship between real and virtual world. Although it can be confirmed that many studies have revealed shaded details of the transfer processes, from which the actual rate of learning can be determined. The settings and detailed features of the environment must play an important role also in the formation of spatial performances and the application of different spatial motion strategies. In the present instance it is enough to think of the distortions coming from individual computer practice (Waller, 2000) that was carefully controlled during the preparation for the experiments with selecting subjects of the same computer expertise.

Another limitation may result from the Morris maze structural features that include only distal cues. Morris (1981) demonstrated that extramaze positioning of orientation points are sufficient enough for place learning even for rats. In the virtual equivalent of the Morris maze task (Jacobs et al., 1997) humans also rely solely on distal, abstract visual cues. Some studies concluded that abstractness of cue-points decreases the efficiency of spatial performances (Ruddle et al., 1997). More realistic arena settings and proximal cues may increase the rate of immersion that is very likely to modify the usage and the distribution of the motion strategies.

Finally, I would like to emphasise the question of causality in strategy usage. It is a well-established fact based on the experimental results that there is a relation between motion patterns and spatial performance. Although it is not easy to say, which is the cause and which is the reason. Is it behaviour that determines strategy or inversely, strategy forms the measurable performance? It is also interesting to examine causal relations in the case of the third hypothesis (difference between good and poor performers): is strategy a consequence or a determinant for the differences between the two groups? Further detailed experiments are needed to answer this question.

## References

Anderson, J. R. (1982). Acquisition of cognitive skills. *Psychological Review,* 89, 369-406.

Astur, R. S., Ortiz, M. L., Sutherland, R. J. (1998). A characterization of performance by men and women in a virtual Morris water task: A large and reliable sex difference. *Behavioural Brain Research,* 93, 185-190.

Astur, R. S., Taylor, L. B., Mamelak, A. N., Philpott, L., Sutherland, R. J. (2002). Humans with hippocampus damage display severe spatial memory impairments in a virtual Morris water task. *Behavioural Brain Research,* 132, 77-84.

Astur, R. S., Tropp, J., Sava, S., Constable, R. T., Markus, E. J. (2003). Sex differences and correlations in a virtual Morris water task, a virtual radial arm maze, and mental rotation. *Behavioural Brain Research.* (in press)

Burgess, N., King, J. A. (2002). Navigation in virtual space: Psychological and neural aspects. *International Encyclopaedia of Social and Behavioral Sciences.* Elsevier

Burgess, N. (2002). The hippocampus, space, and viewpoints in episodic memory. *The Quarterly Journal Of Experimental Psychology*, 55A (4), 1057–1080.

Burgess, N., Maguire, E. A., O'Keefe, J. (2002). The Human Hippocampus and Spatial and Episodic Memory. *Neuron,* 35, 625-641.

Casati, R., Varzi, A. C. (1999). *Parts and Places. The Structures of Spatial Representation.* A Bradford Book, The MIT Press, Cambridge.

Choi, J., Silverman, I. (2002). The relationship between testosterone and route-learning strategies in humans. *Brain and Cognition,* 50 (1), 116-120.

Dabbs, J. M., Chang, L., Strong, R. A., Milun, R. (1998). Spatial Ability, Navigation Strategy, and Geographical Knowledge Among Men and Women. *Evolution and Human Behavior,* 19, 89-98.

Farell, M. J., Arnold, P., Pettifer, S., Adams, J., Graham, T., MacManamon, M. (2003). Transfer to Route Learning From Virtual to Real Environments. *Journal of Experimental Psychology: Applied.* 9 (4), 219-227.

Gaunet, F., Thinus-Blanc, C. (1996). Early blind subject's spatial abilities in the locomotor space: Exploratory strategies and reaction to change performance. *Perception*, 25, 967-981.

Gaunet, F., Vidal, M., Kemeny, A., Berthoz, A. (2001). Active, passive and snapshot exploration in a virtual environment: influence on scene memory, reorientation and path memory. *Cognitive Brain Research,* 11, 409-420.

Golledge, R. G. (1999). *Wayfinding Behavior: Cognitive Mapping and other Spatial Processes*. Johns Hopkins University Press, Baltimore, MD, USA.

Grön, G., Winderlich, A. P., Spitzer, M., Tomczak, R., Riepe, M. W. (2000). Brain activation during human navigation: gender-different neural networks as substrate of performance. *Nature Neuroscience,* 3 (4), 404-408.

Hamilton, D. A., Driscoll, I., Sutherland, R. J. (1995). Human place learning in a virtual Morris water task: some important constraints on the flexibility of place navigation. *Behavioural Brain Research,* 129, 159-170.

Hartley, T., Burgess, N. (2002). Models of spatial cognition. In *Encyclopaedia of Cognitive Science.* L. Nadel (Ed.). London: Palgrave MacMillan.

Hartley, T., Maguire, E. A., Spiers, H. J., Burgess, N. (2003). The Well-Worn Route and the Path Less Travelled: Distinct Neural Bases of Route Following and Wayfinding in Humans. *Neuron,* 37, 877-888.

Held, R., Hein, A. (1963). Movement produced stimulation in the development of visually guided behaviour. *Journal of Comparative and Physiological Psychology*, 56, 872-76.

Hill, E. W., Rieser, J. J., Hill, M. M., Halpin, J. (1993). How persons with visual impairments explore novel spaces: Strategies of good and poor performers, *Journal of Visual Impairment and Blindness*, 87 (8).

Hite, T. R. (2003). Gender, Spatial Learning Trials, and Object Recall. *A thesis presented to the faculty of the Department of Psychology East Tennessee State University.*

Jacobs, W. J., Laurance, H. E., Thomas, K. G. F. (1997). Place Learning in Virtual Space I: Acquisition, Overshadowing, and Transfer. *Learning and Motivation.* 28, 521-541.

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

Janzen, G., Schade, M., Katz, S., Herrmann, T. (2001). Strategies for detour finding in a virtual maze: The role of the visual perspective. *Journal of Environmental Psychology,* 21 (2), 149-163.

Kállai, J., Kerekes, Zs., Osváth, A., Makány T., Járai R. (2002). Korai navigációs tapasztalatok, valamint a szorongás és félelmek hatása nők és férfiak tájékozódási stratégiáinak alakulására. *Magyar Pszichológiai Szemle,* LVIII. (3), 319-340. [Wayfinding strategies, childhood navigation experiences, adulthood fears and anxiety in women and men.(in Hungarian)]

Karádi, K., Kállai, J., Kovács, B. (2001). Cognitive subprocesses of mental rotation: way is a good rotator better than a poor one? *Perceptual and Motor Skills,* 93, 333-337.

Kimura, D. (1992). *Sex differences in the brain.* Readings from Scientific American Magazine, 79-89.

Kimura, D. (1999). *Sex and cognition.* Cambridge, MA: MIT Press.

King, J. A., Burgess, N., Hartley, T., Vargha-Khadem, F., O'Keefe, J. (2002). Human Hippocampus and Viewpoint Dependence in Spatial Memory. *Hippocampus,* 12, 811-820.

Klatzky, R. L., Beall, A. C., Loomis, J. M., Golledge, R. G., Philbeck, J. W. (1990). Human navigation ability: Tests of the encoding-error model of path integration. *Spatial Cognition and Computation,* 1, 31-65.

Lambery, S., Viaud-Delmon, I., Berthoz, A. (2002). Influence of a sensorimotor conflict on the memorization of a path travelled in virtual reality. *Cognitive Brain Research,* 14, 177-186.

Lawton, C. A. (1994). Gender differences in way-finding strategies: Relationship to spatial ability and spatial anxiety. *Sex Roles,* 30, 765-779.

Lawton, C. A. (1996). Strategies for indoor wayfinding: The role of orientation. *Journal of Environmental Psychology,* 16, 137-145.

Lawton, C. A., Kállai, J. (2002). Gender differences in wayfinding strategies and anxiety about wayfinding. A cross-cultural comparison. *Sex Roles,* 47 (9/10), 389-401.

Loomis, J. M., Klatzky, R. L., Golledge, R. G., Cicinelli, J. G., Pellegrino, J. W., Fry, P. A. (1993). Nonvisual Navigation by Blind and Sighted: Assessment of Path Integration Ability. *Journal of Experimental Psychology: General*, 122 (1), 73-91.

Maguire, E. A., Burgess, B., Donnett, J. G., Frackowiak, R. S. J., Frith, C. D., O'Keefe, J. (1998). Knowing Where and Getting There: A Human Navigation Network. *Science,* 280, 921-924.

Makány T., Karádi K., Kállai J., Nadel, L. (2002). Interference between verbal concept formation and spatial mental rotation in female subjects. *Perceptual and Motor Skills*, 95, 227-232.

Makány, T., Kállai, J. (2003). Strategy and memory. Different levels of spatial representation. *Poster presentation at the 6$^{th}$ IBRO World Congress.* Prague, Czech Republic.

Makány, T., Kállai, J. (2004). Human spatial orientation and way-finding analysis with Ethovision in a real arena maze. *Noldus News User Report,* 11 (1).

McCourt, M. E., Mark, V. W., Radonovich, K. J., Willison, S. K., Freeman, P. The effects of gender, menstrual phase and practice on the perceived location of the midsagittal plane. *Neuropsychologia*, 35, 717-724.

McDonald, T. P., Pellegrino J. W. (1993). Psychological Perspectives on Spatial Cognition. In *Behavior and Environment. Psychological and Geographical Approaches.* T. Gärling, R. G., Golledge (Eds.). Amsterdam: Elsevier. 47-82.

McNaughton, B. L., Barnes, C. A., Gerrard, J. L., Gothard, K., Jung, M. W., Knierim, J. J., Kudrimoti, H., Qin, Y., Skaggs, W. E., Suster, M., Weaver, K. L. (1996). Deciphering the hippocampal polyglot: the hippocampus as a path integration system. *The Journal of Experimental Biology,* 199, 173-185.

Moffat, S. D., Resnick, S. M. (2002). Effects of Age on Virtual Environment Place Navigation and Allocentric Cognitive Mapping. *Behavioral Neuroscience,* 116 (5), 851-859.

Moffat, S. D., Hampson, E., Hatzipantelis, M. (1998). Navigation in a “Virtual” Maze: Sex Differences and Correlation With Psychometric Measures of Spatial Ability in Humans. *Evolution and Human Behavior,* 19, 73-87.

Morris, R. G. M. (1981). Spatial localization does not require the presence of local cues. *Learning and Motivation,* 12, 239-260.

Nadel, L., Thomas, K. G. F., Laurance, H. E., Skelton, R., Tal, T., Jacobs, W. J. (1998). Human place learning in a computer generated arena. In *Spatial Cognition. An Interdisciplinary Approach to Representing and Processing Spatial Knowledge.* C. Freska, C. Habel, K. F. Wendel (Eds.). Berlin: Springer.

O’Keefe, J. (1991). The hippocampal cognitive map and navigational strategies. In *Brain and Space.* J. Paillard (Ed.). New York: Oxford University Press. 273-295.

O’Keefe, J., Nadel, L. (1978). *The Hippocampus as a Cognitive Map.* Oxford: University Press.

Oman, C. M., Shebilske, W. L., Richards, J. T., Tubré, T. C., Beall, A. C., Natapoff, A. (2000). Three dimensional spatial memory and learning in real and virtual environments. *Spatial Cognition and Computation,* 2, 355-372.

Paillard, J. (1991). Motor and representational framing of space. In *Brain and Space.* J. Paillard (Ed.). New York: Oxford University Press. 163-182.

Parsons, T. D., Larson, P., Kratz, K., Thiebaux, M., Bluestein, B., Buckwalter, J. G., Rizzo, A. A. (2004). Sex differences in mental rotation and spatial rotation in a virtual environment. *Neuropsychologia,* 42, 555-562.

Pazzaglia, F., De Beni, R. (2001). Strategies of processing spatial information in survey and landmark-centered individuals. *European Journal of Cognitive Psychology,* 13, (4), 493-508.

Rizzo, A., Buckwalter, J. G., Larson, P., Rooyen, A., Kratz, K., Neumann, U., Kesselman, C., Thiebaux, M. (1998). Preliminary findings on a virtual environment targeting human mental rotation/spatial abilities. *Proc. 2nd Euro. Conf. Disability, Virtual Reality & Assoc. Tech.,* Skövde, Sweden.

Rose, D., Foreman, N. (1999). Virtual Reality. *The Psychologist,* 12 (11), 550-554.

Rothbaum, B. O., Hodges, L., Smith, S., Lee, J. H., Price, L. (2000). A Controlled Study of Virtual Reality Exposure Therapy for the Fear of Flying. *Journal of Consulting and Clinical Psychology,* 68 (6), 1020-1026.

Ruddle, R. A., Payne, S. J., Jones, D. M. (1997). Navigating buildings in "desk-top" virtual environments: Experimental investigations using extended navigational experience. *Journal of Experimental Psychology: Applied*, 3, 143-159.

Ruddle, R. A., Payne, S. J., Jones, D. M. (1999). Navigating large-scale virtual environments: What differences occur between helmet-mounted and desk-top displays? *Presence: Teleoperators and Virtual Environments*, 8, 157-168

Sandstrom, N. J., Kaufman, J., Huettel, S. A. (1998). Males and females use different distal cues in a virtual environment navigation task. *Cognitive Brain Research,* 6, 351-360.

Siegel, A. W., White, S. H. (1975). The development of spatial representations of large-scale environments. In H. W., Reese (Ed.). *Advances in Child Development and Behavior*, 10, 9-55. New York: Academic Press.

Silverman, I., Eals, M. (1992). Sex differences in spatial abilities: Evolutionary theory and data. In *The adapted mind: Evolutionary psychology and the generation of culture*. J. Barkow, L. Cosmides, J. Tooby (Eds.). New York: Oxford University Press. 487-503.

Thinus-Blanc, C. (1996). *Animal spatial cognition: Behavioral and neural approaches*. Singapore: World Scientific Publishing.

Thinus-Blanc, C., Save, E., Buhot, M. C., Poucet, B. (1991). The hippocampus, exploratory activity, and spatial memory. In *Brain and Space*. J. Paillard (Ed.). New York: Oxford University Press. 334-352.

Tolman, E. C. (1948). Cognitive maps in rats and men. *The Psychological Review*, 55 (4), 189-208.

Varzi, A. C. (1997). Boundaries, Continuity, and Contact. *Noûs,* 31 (1), 26-58.

Wald, J., Taylor, S. (2000). Efficacy of virtual reality exposure therapy to treat driving phobia: a case report. *Journal of Behaviour Therapy and Experimental Psychiatry,* 31, 249-257.

Waller, D. (2000). Individual Differences in Spatial Learning From Computer-Simulated Environments. *Journal of Experimental Psychology: Applied,* 6 (4), 307-321.

Wang, R. F., Spelke, E. S. (2000). Human spatial representation: insights from animals. *TRENDS in Cognitive Sciences,* 6 (9), 376-382.

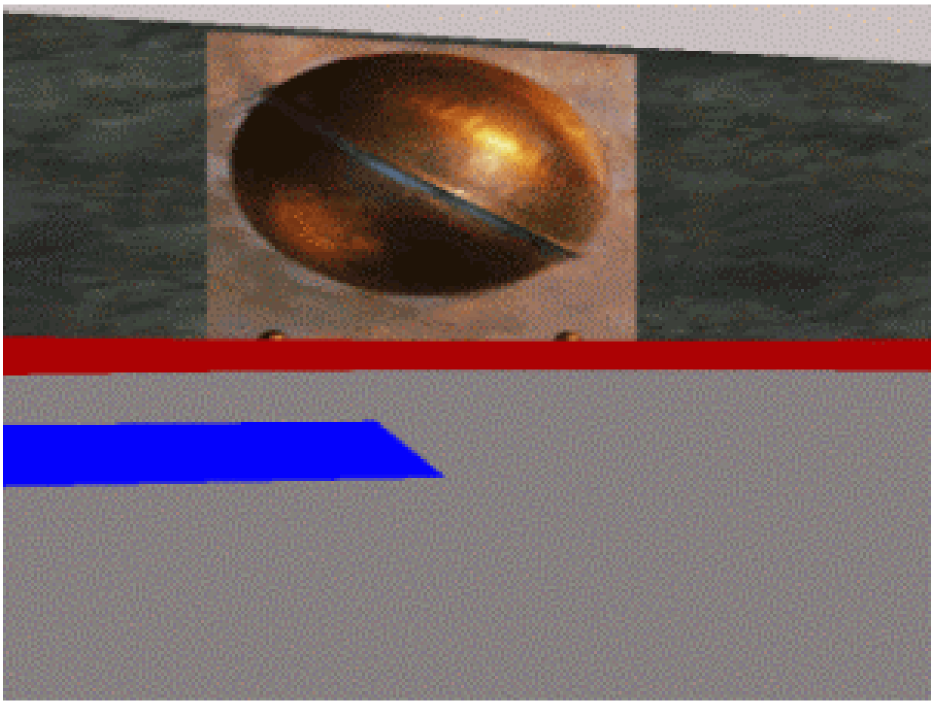
Wishaw, I. Q. (1998). Place Learning in Hippocampal Rats and the Path Integration Hypothesis. *Neuroscience & Biobehavioral Reviews*, 22 (2), 209–220.

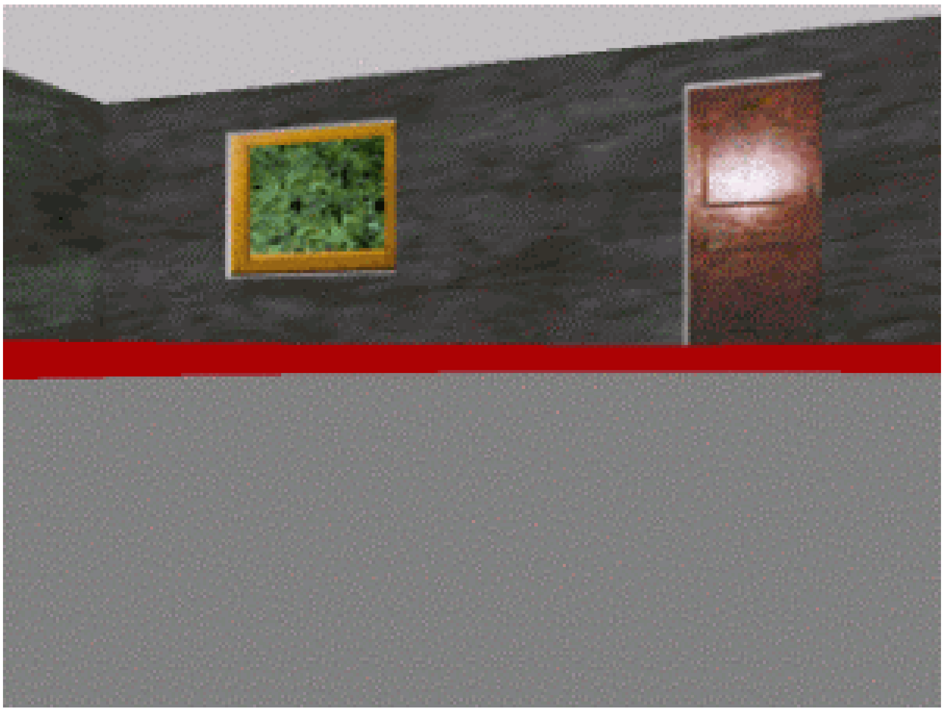
Zalta, E. N. (Ed.) *The Stanford Encyclopedia of Philosophy* (Spring 2004 Edition), forthcoming URL http://plato.stanford.edu/archives/spr2004/entries/mereology/ (accessed 27/02/2004)

## **Appendix A –** Instruction for the C-G Arena Software

*“As you can see on the screen, you have just entered to a room. You can move freely with the joystick in any directions inside this space. Try it! This is a practice room, where you can exercise how to operate the joystick and have a rest if you feel like. Now, press space, and you’ll find yourself in the test room. Here you can see some objects on the walls and a blue rectangle on the floor. Your aim is to navigate onto this rectangle and as a feedback you’ll hear a sound. If you have found this blue platform, look around on it and try to remember your position. It is important because from the third trial, the destination platform will become invisible. It’ll be still there only not visibly. Every object remains its place so as the platform in all the ten trials. Remember, try to find the invisible platform and step on it as quick as you can. Good luck!“*

**Picture 1. –** Snapshots from the C-G Arena program





**Scatterplot 1. –** Linear regression showing that spatial performance can be predicted by spatial motion strategies with a $R^2 = 0.8645$ probability

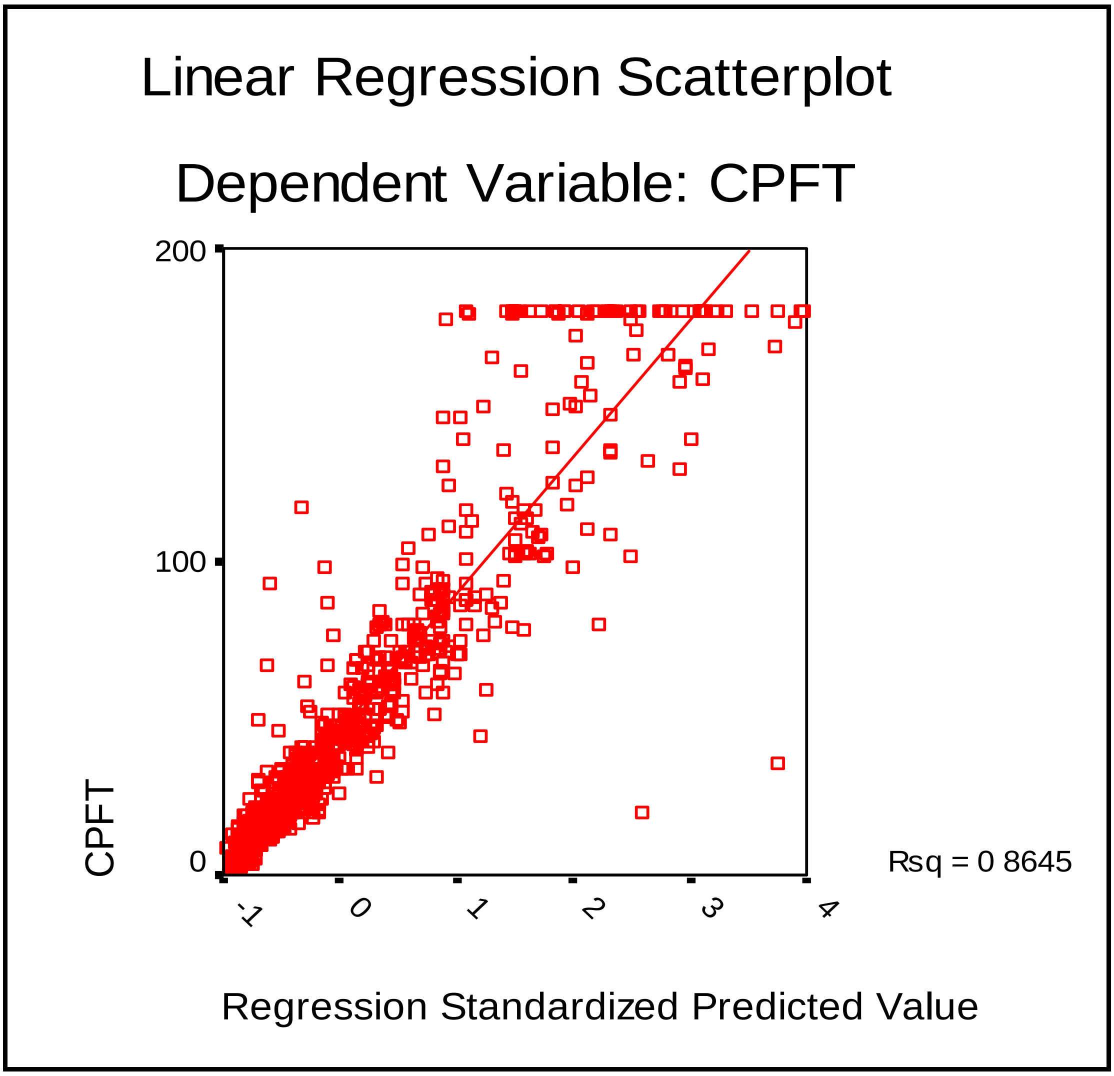


**Diagram 1. –** Temporal decrease in the estimated marginal means of spatial performance (CPFT) and strategies

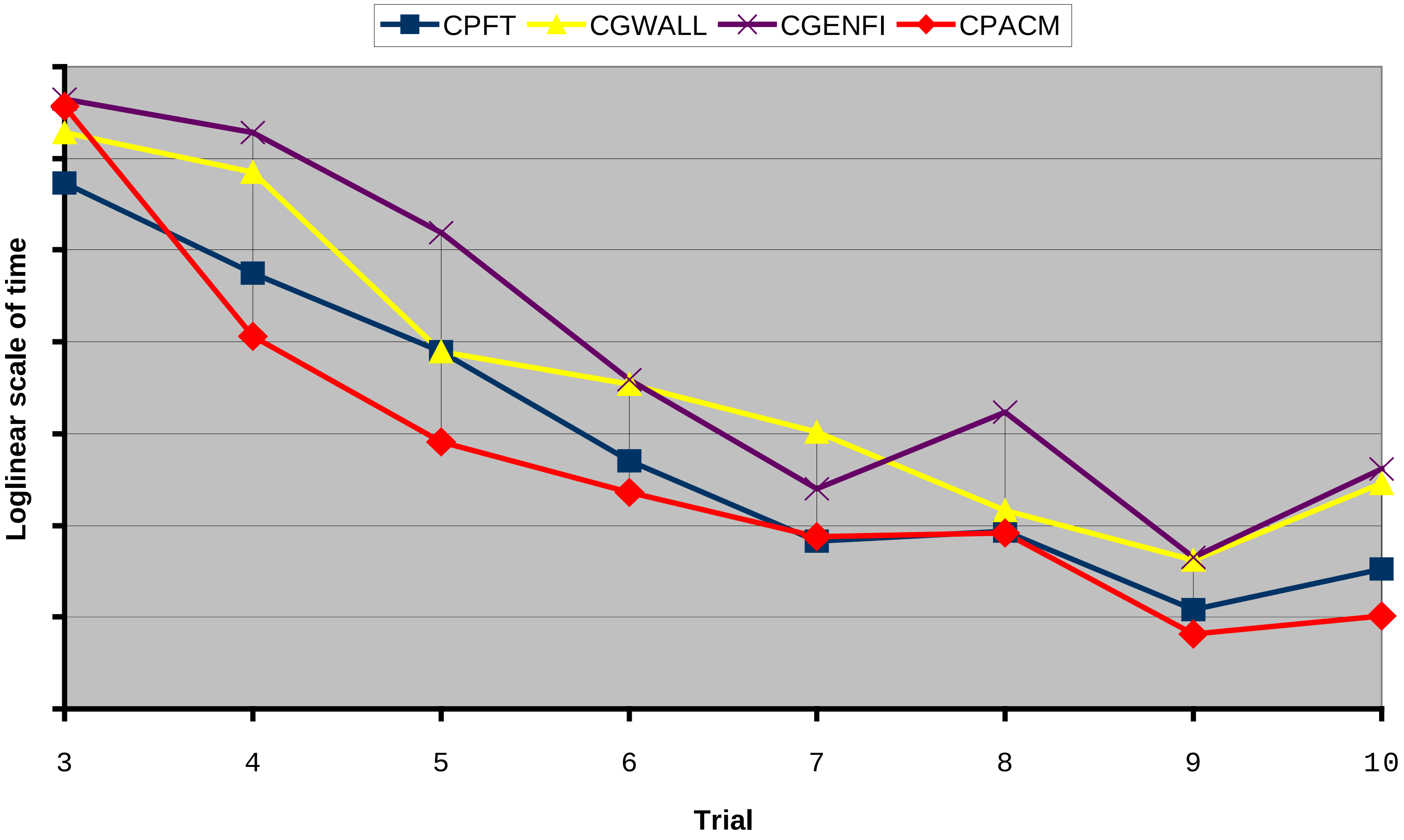


**Diagram 2. –** Subsets of performance based on the strategic shifts and the turning-points around T3 and T6

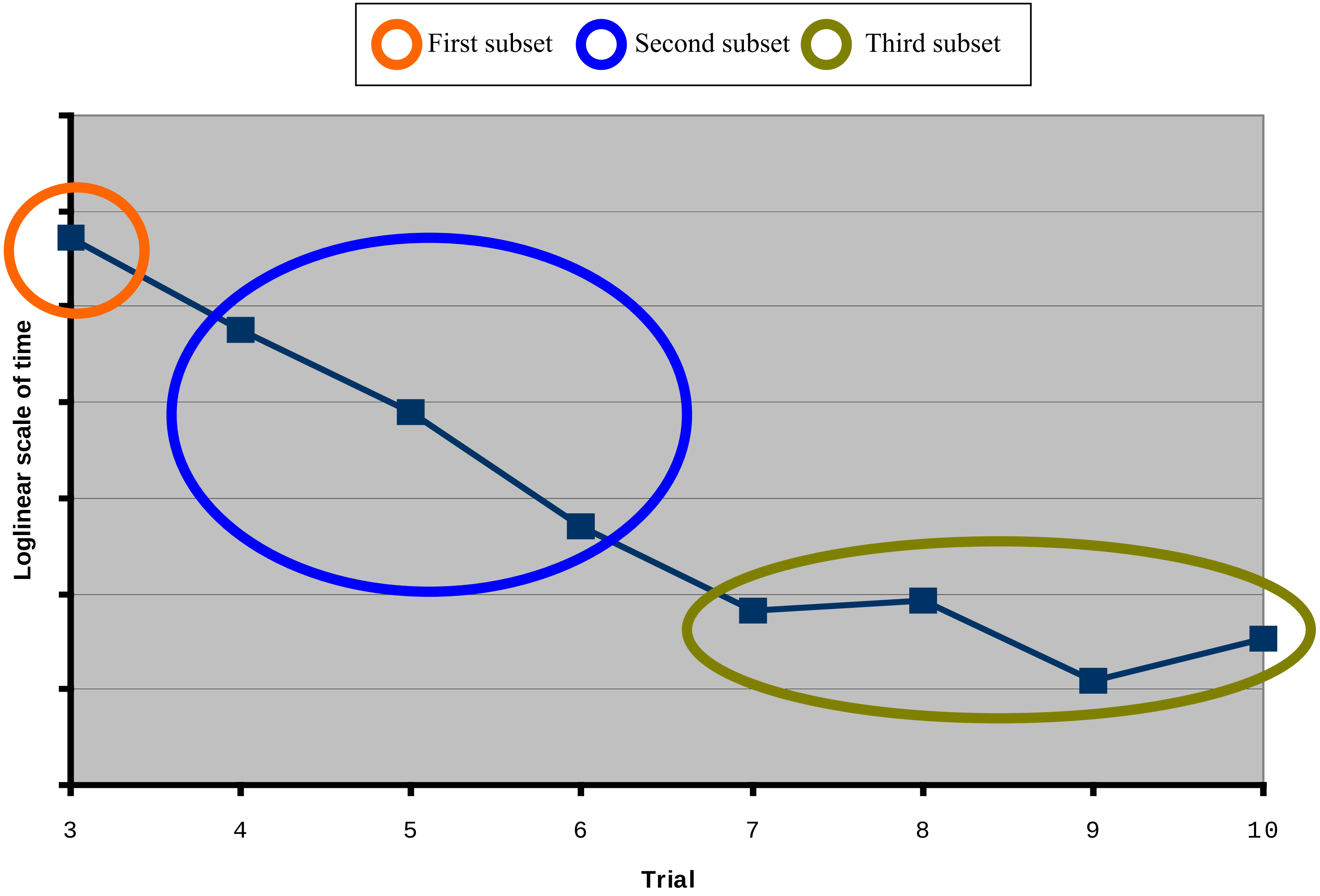


**Diagram 3. –** Temporal distribution of pacman and wall-touching strategies between good and poor spatial performers