VALIDITY AND RELIABILITY OF RECORDING SPATIAL NAVIGATION STRATEGIES IN VIRTUAL REALITY

Master Thesis

Psykologi Aalborg, Neuro.
10. semester
Dato: 1. August 2018
Studienummer: 20134218
Antal tegn: 130.615
Antal sider: 54,5
Vejleder: Nikita Kharlamov

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Abstract

The scientific literature within psychology and cognitive science has been increasingly interested in the fundamental scientific ideals of reliability and validity of methods, data, and theoretical constructs. In the wake of the “Replication Crisis”, focus has shifted to look not just the production of data, but at the method behind this production much more closely. Though not a new ideal, it was questioned whether researchers and institutions alike, had failed to critically reflect upon the methods used within psychological research.

One such area of research is spatial cognition research, which deals specifically with the study of cognition as it processes space. One study done by Kallai, Makany, Karadi and Jacobsen (2005) sought to categorize different spatial strategies from behavioral data collected within a virtual Morris Water Maze. The use of virtual methods as a test environment, the premise of deriving cognitive processes purely from behavioral data, and the method for categorizing behavioral data into strategies are all relevant to question, as they combined are key elements of this paradigm of research.

This paper has sought to explore these areas of experiment design and analysis, by replicating the original study done by Kallai et al. (2005), with the problem formulation, “Is it possible to reliably and validly record, detect and classify cognitive strategies from virtual maze methods?”

With this question in mind, this paper has sought to highlight central problems within the literature, the methodology and the method itself. An experiment replication with 20 participants were performed, using a virtual maze, and the resulting data was analyzed using an automated categorization method. Through this, it was possible to categorize all four categories from the original study, however, it is still unclear whether quantifiable methods such as these can truly capture the scope of what strategies are in praxis. In relation to this, it is also difficult to ascertain whether behavioral data reflect a specific cognitive state. New technologies are finding their way into research as well, and it is not clearly understood how virtual environment relate to real environment. This begs the question whether strategies within virtual environments are valid constructs outside of the test situation.

In conclusion, there are still many factors that play an important role in our ability to both record, detect and classify methods in a valid and reliable way. It will depend on the field gaining a better understanding of how technologies implemented in research interact with the participants and influence the data, and it will depend on the field in general adopting a praxis, that support the scrutiny and development of better and more robust methods.

Indholdsfortegnelse

1 Introduction

Cognitive research has been heavily influenced over the last 20 years by the technological advancements that have fed into many areas of study, one of which is spatial cognition. In this particular case new technologies have given new opportunities for researchers, especially in creating human studies that either align with previous animal models, or that provide easier access or more ecological and complex environments than previously possible within a controlled setting. The reason is fairly simple, as studies of spatial cognition is dependent on rather large areas of dedicated space, when testing on humans, many practical limitations constrain the research possibilities and thus the opportunity to explore a variety of scientific questions within spatial research have been limited by the amount of space available, as well as the (in)opportunity to control variables across large environments. Virtual methods have therefore provided a unique opportunity for researchers to perform studies that are not limited by environment size and event-control problems, as it gives scientists full control of a test environment.
With these new technologies are born a new paradigm of spatial cognition research, which builds its models on technologically supported experimental designs. In virtual environments, very precise data can be collected about actors every move. Their precise placement within a maze, their heading direction, their view, all of this can be collected to point precision, several times a second. This means that within these types of studies, researchers can collect a hoard of data, that then needs to be processed for further data analysis.

One study done by Kallai, Makany, Karadi and Jacobs (2005) used path information to isolate and categorize specific strategies their participants used in a virtual maze, through behavioral definitions. These studies spring from the logic, that performance differences within spatial settings, may depend on particular strategies applied within the navigation setting, and therefore, that certain strategies may result in better performance (Hill & Rieser, 1993). The question then becomes, with the amount of data that studies like these collect, and with the complexity of this data, can we classify behavior from these data sets in a reasonable way?

A study done by an Open Science Collaboration (“An Open, Large-Scale, Collaborative Effort to Estimate the Reproducibility of Psychological Science,” 2012) noted, that psychology research was quite disadvantaged both in their opportunity for replication, and in the subsequent replicated results. This has brought the methodological consideration within current research to the forefront, and pointed out the relevancy of examining, not only the results of studies, but also their design and central logic to improve the current scientific body of knowledge within the field.

This was popular termed “the Replication Crisis”, and it raised the question on one hand, if the current scientific environment encouraged and enabled replication studies, and on the other hand, whether studies that now form most of our fundamental understanding of psychology actually hold up to scrutiny, and perhaps most importantly, how we can strive to create better, and more well founded methods and methodologies within the respective fields. This has led to the question that is presented as this paper’s problem formulation.

2 Problem statement.

Is it possible to reliably and validly record, detect and classify cognitive strategies from virtual maze methods

3 Spatial Theories

Most would agree that common for the majority of behavior cross-species is that they need space, and are as such spatially bounded. Space in this sense includes all areas that can be inhabited by organisms, from large habitats, to environments at the cellular level. Similarly then, behavior which is spatially bounded includes not only movement of the whole body from one discrete position to another, but also other more minute types of behaviors such as reaching for you coffee, stretching your legs, curling into a ball in your nest, or shaking your fur. All these types of behaviors, in the broadest sense of the term, are spatial. They require that your whole body, or parts of your body, occupy a different place in space, if only momentarily. Not only that, but spatial processes are also perceptual, and just as we do things in space so too do we perceive space.

Some central concepts are the notions of cues, routes, and cognitive maps on the one hand, and navigation and wayfinding on the other. The former refer to objects or mental representations that serve as some kind of spatial information, the latter two instead denote spatial behavior. Wayfinding and navigation in particular is often used interchangeably within the literature with no general consensus of how to use these as terms, however within this paper, navigation will refer to the specific act of performing a route, whereas wayfinding will instead refer to the broader processes related to route execution, such as route learning, a concept introduced below.

The following section will introduce the central concepts within spatial cognition though between the various theoretical perspectives on how spatial behavior is organized there is no general consensus. This paper will assume the same intuition as the study by Kallai, Makany, Karadi and Jacobs (2005), that cues are paired with actions to form routes, and routes are then organized into maps, and as such these concepts will be introduced in that order.

3.1 Cues. As fundamental building blocks of space.

Basic inputs assumed within spatial theories are divided into two different groups, though the actual distinction between these can still be discussed, they are often divided into *idiothetic cues* and *allothetic cues*.

Idiothetic cues refer in general to cues from within the body, such as proprioception and vestibular cues, but it is often within the theoretical context conceptualized as cues of self-position, that are assumed to derive from self-motion cues integrated from a plethora of idiothetic cues (Jeffery & O'Keefe, 1999; Knierim, Kudrimoti, & McNaughton, 1998; Mittelstaedt & Mittelstaedt, 2001). It is thought of as an organization of cues that with the information somatic cues provide, temporally denote a sense of the body being moved. They can as such both be seen as an organization of cues that interrelate (Jeffery & O'Keefe, 1999), or as a group of different cues that serve an idiothetic function (Mittelstaedt & Mittelstaedt, 2001).

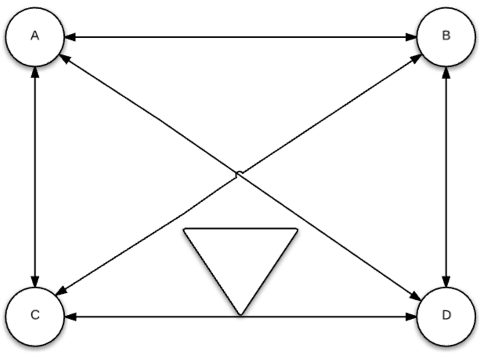
Allothetic cues are on the other hand extra-personal, and are often summarizes as landmarks or spatial objects that serve as constant environmental coordinates from which spatial navigation can be executed (Rogers, Churilov, Hannan, & Renoir, 2017). Some theories however have argued that low level cues, such as a basic geographical module (Cheng & Newcombe, 2005), inform spatial processing through stable cues that denote some spatial consistency. Similarly it is argued that basic information of a geometric nature related to depth perception, perspective lines, and topographical information within the environment are underlying informational structures that serve as allothetic cues (Cogné et al., 2017; Rusconi, Morganti, & Paladino, 2008). In relation to this, a distinction is often made between features of the environments, the object of a given environment and geometric cues such as the angles within the environments, the size of the wall, open or closed spaces etc. (Sturz, Bell, & Bodily, 2017; Sturz, Forloines, & Bodily, 2012). These can be further divided into local and global geometric cues, where local cues are corner angles, wall height and the like, and global cues are the principal axis of space (Sturz, Forloines, Bodily, 2012).

Many models assume that spatial cognition integrate idiothetic and allothetic cues in navigation (Byrne, Becker, & Burgess, 2007; Wang & Spelke, 2000), though research tries to isolate effects of idiothetic or allothetic dependent navigation (Jeffery & O'Keefe, 1999). Idiothetic navigation in particular has been of interest in studies focusing on navigation in blind people, as humans are assumed to navigate primarily from sight based information (Iachini, Ruggiero, & Ruotolo, 2014).

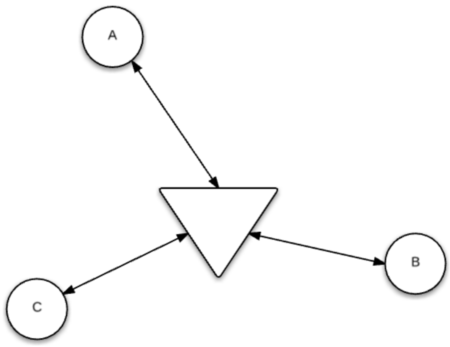
Models from the tradition of computational theory and information-processing theories assume that spatial cognition progress in complexity of integrated knowledge and behavior (Kitchin & Blades, 2002). In other words, just as we can see representational information as either more or less complex and in that sense related to each other hierarchically through their level of integration, so too can we consider behavior as organized as more minute, and therefore simpler behavior within more complex behavior. There is an assumed relationship between the complexity of behavior and the complexity of processing, and so too are idiothetic and allothetic cues assumed to be processed in some interrelated fashion. Theories on spatial cognition have since its early beginnings derived from a notion of input-output relationships (Tolman, 1948). Earlier theories assumed input to be sensory stimuli only, but later, as the field have broken from behaviorism, input has extended to include higher internal processes, such as memory, which are assumed to impact perception and behavior in a top-down fashion (Kitchin & Blades, 2002). This configuration of cognition as integrated levels of increasingly higher levels of processing is central to many fields, and can both be applied to our understanding of space, as in the perceptual and encoding process (Byrne et al., 2007), and in spatial behavior, like goal-directed navigation and exploration (Erdem, Milford, & Hasselmo, 2015). Some studies support the hierarchized models at the neural level (Felleman & Van Essen, 1991), and building from bottom-up integration, spatial models like the one introduced by Byrne, Becker and Burgess (2007) assume that different representations of spatial information are translated back and forth as derivative computations. While it may be true that sources of input can both be considered to be top-down and bottom-up driven, emphasis is often put on initial sensory processing as the fundamental instigator of spatial cognitive processes.

3.1.1 Spatial information

Spatial cues and landmarks have been a major conceptualization of spatial stimuli that afford navigation in specific ways. In the most general term, a landmark is simply some environmental cue that holds some salience to the individual either by virtue of its physical



Model 2: Allocentric reference of space. Objects are related to each other.



Model 1: Egocentric reference frames. Objects are related to the moving subject.

characteristics or by its functional salience (Kitchin & Blades, 2002). It is however not clearly understood what exactly defines a landmark (Cohen & Schuepfer, 1980; Yoder, Clark, & Taube, 2011), if landmarks are processed in a holistic way (Kitchin & Blades, 2002) or as hierarchized cues (Tom & Tversky, 2012), and if landmarks necessarily need be defined by discrete objects or if they also can be areas (Steck & Mallot, 2000). In short, the bounds of what can be considered a landmark as it is processed cognitively depends upon the particular theory. Nevertheless, these are considered fundamental to human navigation. Cues and landmarks are often used interchangeably with each other, and with spatial objects, though landmarks at times are used to denote spatial objects in large environments specifically (Pazzaglia & De Beni, 2001). Cues on the other hand often refer to the general concept of something in the environment that is *cuing* the individual to certain behaviors.

Spatial cues are often considered as relational properties that are relevant spatially by their relative position either to other objects in space or in relation to the individual, or as paired cues that bind action to specific spatial points, also called route learning (Tom & Tversky, 2012). One way that this has been conceptualized is through what is called spatial reference frames (Burgess, 2006; 2008), which are often divided into two theories that differ in how objects are spatially related in cognition.

These are the *egocentric* and *allocentric* reference frames (Burgess, 2006, 2008; Wang & Spelke, 2000). Within the egocentric model, spatial objects are processed relative to the individual. In a computational perspective, this is explained as vectors that are cast from the individual to surrounding landmarks, and are updated as the subject moves through the environment (Burgess, 2006; Wang, 2016).

The allocentric reference frame, unlike the egocentric one, assumes that objects are processed in their relation to other objects (Gramann et al., 2010; Holmes & Sholl, 2005). In other words, whereas the egocentric reference frame assumed a constant updating of relative vectors between the subject and objects, allocentric reference frames are instead constant relationships between static objects within the environments. The allocentric reference frame assume that navigation to unseen goals is done from these enduring representations of surrounding objects (Burgess, 2006).

Wang and Spelke (2000) argue that these two types of spatial representation assume two different understandings of navigation strategies. They consider these two models to be exclusionary, and as such argue that navigation either is purely based on allocentric or egocentric representation, of which they argue the latter has sufficient explanatory power. Egocentric navigation then is akin to navigation observed in insects, based on dead reckoning strategies and homing. Whereas allocentric navigation assumes that navigation happens upon a symbolic system of spatial representation, much like navigation from an actual map.

Burgess et al. (2006) and Byrne, Becker and Burgess (2007) however, argue that these two reference frames both inform behavior. Byrne, Becker and Burgess (2007) introduced a computational model wherein egocentric and allocentric information is essentially derivatives of each other. Based on certain types of cells that have been shown to code spatial properties such as head direction (Taube, 1998), environmental grids (Doeller, Barry, & Burgess, 2010; Giocomo, Moser, & Moser, 2011; Moser & Moser, 2013) boundary vectors (Lever, Burton, Jeewajee, O'Keefe, & Burgess, 2009) and place in space (Lever, Wills, Cacucci, Burgess, & O'Keefe, 2002), egocentric and allocentric reference frames are translated back and forth through computational processes. Their overarching argument is that the transitional nature of an egocentric representation makes this information hard to store, whereas allocentric reference frames lack informational complexity as they are static and as such are more ideal for memorization. In this way, they relate spatial processing also to a notion of spatial memory and representation of space across the temporal and immediate spatial context.

3.2 Routes. Behavior and Representation.

Another type of fundamental spatial structure are routes. Routes at the core are assumed to be sequences of goal-directed actions that can either be viewed as constructed from learning landmarks or as the basis on which landmarks are coded (Kitchin & Blades, 2002). The exact organization of these, and how these are hierarchized depend on the model, and in the model presented by Kallai et al. (2005) it is assumed that route learning is a sequence of paired associations of cues along a path, that do not have a direct relational representation of start or end points. Actual navigation on this type of knowledge is seen as procedural, and therefore focused on discrete action when meeting a paired cue, as opposed to navigation related to cognitive map navigation, that would instead depend on the relative positions of cues to each other.

Egocentric and allocentric reference frames are often related to what is termed goal-directed spatial knowledge and survey knowledge or configurational knowledge (Kallai et al., 2005). Survey knowledge is sometimes defined as "map" knowledge (Kallai et al., 2005) which bears its relation to the original differentiation introduced by Tolman (1948) that spatial knowledge was either organized in strips or in survey structures, depending on the particular need of the individual. According to Kallai et al. (Kallai et al., 2005), survey knowledge are interrelated route structures that have formed into maps. They define survey knowledge as an integration of the topological relationship between landmarks and routes that are represented in a coordinate system and that route knowledge are acquired representations from previous learning.

Route navigation is also considered to be a specific type of spatial navigation, where sequences of ordered behavior is executed between a given start position and a given end position, at its most basic definition (Tom & Tversky, 2012). A related concept to this is *path integration*, which is often considered very basic form of wayfinding strategy (Harris & Wolbers, 2012).

Path integration is both considered a fundamental spatial process, as well as a function working in relation to non-mapping or mapping typed navigation. The basic process is also known as dead reckoning, and consists of continually updating an estimated self-position within space from an integration of idiothetic cues and directions (Zhao & Warren, 2015). It is a mechanism proposed to keep track of a moving individual's changing position and orientation, in other words tracking movement on a very basic scale simply from an estimated difference between a previous position and direction to a current position and direction (Wiener, Berthoz, & Wolbers, 2011).

In computational models path integration is thought to involve three major components: (1) a self-motion estimation system, (2) a spatial representation of the home location (i.e. the homing vector), and (3) a integrator module which combines the two former components into a new homing vector (Wang, 2016). As such, path integration is considered a vector which is constantly updated with the estimated current position and a direction towards and estimated salient position. In this model, distortion happen, when estimations are fallacious for various reasons. As such, it is also considered highly susceptible to distortions and disruptions. As it is continuously updated on estimated directions and positions, it will inevitably lead to errors, and for the same reason, as it is continuously updated from the prior state, errors will carry over from one homing vector to the next, making these accumulative. It is a sequential process, which entirely relies on the step before, which means it is also easily disrupted. If the animal becomes confused or disoriented at any point during this sequence, the entire system could fail if it is disruptive enough to disable the possibility of continuing the sequential processing (Wang, 2016). Path integration is also assumed to be a process within non-mapped navigation. It is argued that path integration computes a homing vector based on motion estimation derived from the animals movement and processed direction. In other words, it is a system that translates transitional information into a general estimation of a home direction, *home* being some assumed salient starting position (Wolbers, 2015). This particular navigation strategy is also called "homing", and have been studied extensively cross-species, in both insects, rodents and humans mainly (Maaswinkel & Whishaw, 1999).

What this highlights is a conceptual disagreement that relates to what is assumed to be a viable vector position and/or direction. From the conceptualization that imply that path integration is a type of navigation where a vector is formed directing to and from a home position, path integration is not considered a universal function, but instead specifically related to “homing” type behavior, and thus is relevant when the animal is traveling outward from or returning to home. It can then be discussed how this process would change if an organisms have several homes, like different nesting places and similar. On the other hand, path integration can also be viewed as a general function that apply the general process of estimation of self-position relative to various types of positions in space.

Route knowledge and navigation figure in to this conceptualization of path integration, as it denotes the general relationship between the behavior of executing a planned set of navigational tasks, and how mental representations may allow this specifically. However, where path integration has often been used to conceptualize navigation behavior in relation to two points, route knowledge integrate both positional cues and sequential ordering towards navigating more complex environments (Cohen & Schuepfer, 1980; Tom & Tversky, 2012)

3.2.1 Orientation and reorientation

Similar to path integration, reorientation is also considered a fundamental function for successful navigation. Reorientation is dealt with in many different theories, and is most broadly assumed to occur by measuring and continuously updating one’s heading direction with an assumed position in space or a previous heading direction. One example of this is Wolbers (2015), who considers reorientation processes to be reliant on a realignment of two different direction vectors. One would be one’s own heading direction and then an estimated direction of a given goal. Newcombe and Huttenlocher (2007) on the other hand assume a probabilistic model, where multiple sources such as cues and geometric cues, by weight are combined to localize a target.

One often used method of research in this area is a task where participants are trained to locate a corner in a rectangular room, after which selective aspects of the enclosure are changed to isolate what kind of cues are used for orientation within an environment (Cheng & Newcombe, 2005). Through this method it has been shown that individuals not only use cue objects within the environment, but that orientation also can be derived from geographical cues (Cheng, 2005), as even in conditions where cues were absent, participants still performed at above chance level. By controlled variation of different features of enclosures, such as the shape and size, it has been determined that orientation depend differently on either objects of geographical cues in larger or smaller environments respectively (Miller, 2009). All in all, these processes imply some lower level processing wherein external and internal spatial information in combination are used to estimate a position within space. Whereas path integration refers to a general concept that position estimation is maintained throughout movement as a fundamental process to keep track of self-position, orientation refers to a basic process of keeping track of environmental features, and specifically the ability to reorient, as a basic premise to account for erroneous spatial processing, either by circumstance or some computed error.

3.3 Cognitive Maps

Though already alluded to in the earlier chapters, one central concept within the field of spatial cognition is *the cognitive map*. Research on spatial navigation has been broadly influenced by the conceptual metaphor of a map. Often cited as the instigator of this understanding, Tolman (1948) differentiated wayfinding into two separate process types he termed strip-maps and survey-maps. The general idea is that organisms, and humans specifically, use map-like constructions to organize spatial information, and that this type of knowledge is either arranged toward a specific spatial position (i.e. a goal) or a general knowledge of the surrounding area (i.e. a survey type of knowledge). He broke with an understanding of spatial navigation, which was informed mainly by a pure response-stimuli mechanism. Like many fields of cognitive research, spatial cognition was defined by a move from behavioristic theories towards an inclusion of cognitive models to build from simple stimulus-response theories. This framework had heavily emphasized goal-oriented navigation by virtue of the basic mechanism, that spatial information be memorized in relation to a specific reward, however Tolman (1948) argued that such a framework could not account for the many types of flexible use of spatial knowledge that spatial navigation theory would have to explain in natural life. A purely behavioristic model could not cover questions such as how novel navigation occurs, and could not appropriately explain how long stretches of navigation could occur over long a time period. Since Tolman's (1948) time, the cognitive map has been used either as an abstract metaphor, or as a specific model, to explain how complex areas are memorized, organized and acted upon in cognitive processes.

According to O'Keefe and Nadel (1978), maps refer to a structuring of interrelated information, though it does not necessarily include any specification of guides. They argue, that the ability to represent the world in an objective, referential way is an innate ability.
Wang (2015) argue that cognitive maps should meet three criteria, to overcome limitations of other functions of spatial processing such as path integration. First, it should be comprehensive enough to include information about several locations. Secondly, it should support travel over long distances as well as flexible route planning. Third, it should be a persistent representation, so as to overcome weaknesses mentioned within sequential processing, and it should be able to recover from disruptions. Gillner and Mallot (1998a) argue, that the terminology within cognitive maps imply that they are separate storages of cues and landmarks that can later be flexibly referred to when an individual is planning behavior. As such, it is similar to Wang's (2015) theoretical consideration, where "snapshots" of spatial updating systems are stored in long-term memory for later recall. Within both theories, the maps are not themselves considered to prompt behavior, but instead are passively referred to. O'Keefe and Nadel (John O'Keefe & Nadel, 1978) similarly introduce what they call *place representation*, which can be seen as a hierarchized substructure within a cognitive map, and a cognitive map then, as an organized collection of places. These representations can be either derived externally, through the occurrence of two or more sensory inputs providing appropriate spatial coordinates, or internally as coupled input of another place representation, with the motor system informing on the magnitude and orientation of movement.

Gillner and Mallot (1998a) describe 3 different categories of cognitive map theories, which they consider central aspects to a comprehensive map. The first they consider is the cognitive map as a spatial reasoning stage, which according to them, allows for novel shortcutting behavior, as planning and reconfiguration of possible routes are made possible through a process of logical reasoning of the environment. Secondly is maps as a cue integration stage, in other words, as a process of integrating cues and actions into a structure, this being similar to the theoretical framework of spatial organization theories, and cognitive *encoding* of spatial information. They argue that this as well is a fundamentally necessary process for any cognitive map, as it is the process of integration between complex information structures into one coherent system. Thirdly, they consider map theories as a goal-independent memory of space. As mentioned earlier, Tolman (1948) argued that maps would need to have a passive mechanism of knowledge acquisition if it were to support flexible behavior, which Gillner and Mallot (1998a) also consider to be a fundamental function. Their argument is, that later goal-oriented behavior can be reasoned from an existing map (hence the reasoning stage), but that for goal-oriented behavior to be adaptable, there would need to be a general map which itself is not oriented towards specific goals.

O'Keefe and Dostrovsky (1971) and O'Keefe and Nadel (1978) note, that cognitive maps not only enable the individual to solve tasks within an environment, but to also provide a sensitivity towards novelty introduced into the environment, for example from changing seasons etc. In other words, that cognitive maps allow the animal to behave consistently within a changing environment.

What can be gathered from this is, that the cognitive map have had different emphasis depending on the assumed function it serves. Cognitive maps are either viewed as a level of knowledge representation such as O'Keefe and Nadel (1978) propose, or as a process of acquisition as within Gillner and Mallot's model (1998), or a combination of the two.

Kallai et al. (2005) argue cognitive maps to be survey knowledge, that are in part constructed of routes. The cognitive map is in this sense a Euclidian coordinate system within which topological relationships of cues and routes are encoded. It is an allocentric representation of spatial objects that serve navigation by providing the individual with global knowledge of the environment. Allocentric reference frames have been argued to be mapping type structures, as they are in some cases considered to be a near-Euclidean type representation (Burgess, 2006, 2008). From a computational standpoint, Burgess (2006) argues mapping, as in objective representations of space are necessary for the sake of storage to be economical.

Siegel and White (1975) present space as organized along 3 levels, those being landmarks, routes and configurational levels. This both assumes how spatial information is processed and learned as well as how spatial objects are related to each other. First landmarks are learned, then these along with related actions (like choice points) are encoded into a route. These are in turn grouped with other routes to form small configurations of map, that are then combined with other small maps to form larger, coherent map types (Siegel & White, 1975). This inherently assumes that spatial information is atomic, in the sense that it can be deconstructed into increasingly smaller fractions. These levels in turn denote different levels of knowledge available. Higher level organization for example, allows for survey knowledge, which in turn is conceptualized as complex information relying on the integration of information at all 3 levels of organization. Siege and White (1975) assumed from this, that individuals would have an objective representation of space available to them, which would enable them to estimate direction and distances independent of the actual direct perception of a given area.

Golledge (1978) on the other hand, argued that different environments accrued different salience levels, which structured spatial representation. He argued that landmarks are organized according to their given importance, and that *primary landmarks*, a type of landmark that had high salience (such as your home, your workplace, your favorite shop) served as anchor-points to which other landmarks could be connected to. Golledge (1978) arrives at spatial behavior from a different outset that most other theories mentioned in this paper. While this paper has mainly focused on spatial behavior as a field of psychology, geography, which is the field Golledge (1978) comes from, is much more concerned with the actual physical organization of space, something that is often not dealt with within psychological theory. As such, spatial representation according to Golledge (1978) consist of a node map, which relate primary anchor-points to smaller, less significant landmark types that themselves are organized hierarchically according to salience (i.e. secondary and tertiary landmarks). Salience could be influenced both by the actual areal size of a landmark, but perhaps more notably, by the amount of times it was visited (Golledge, 1978). From this, he argued that landmark availability influenced the ease of which a given environment could be learned (R. G Golledge, 1991). This not only proposed that certain environments, by virtue of how they were structured, could be more difficult to navigate, but also that certain types of landmarks would be better for the sake of navigation, independent from the individual and by virtue of its actual physical structure. In that sense, Golledge (1978; 1991) makes a direct connection between the physical organization of space following certain heuristics that directly relate to the encoding of said environment into cognitive representations, as opposed to other models with high abstraction of the actual physicality of spatial structures into cognitive representation. He argues that landmarks with high differentiability would incur easier processing, on the other hand, environments with an abundance cues of would negatively influence the processing, as there would be high competition for the limited processing of cues (Golledge, 1991). Gärling (1981) on the other hand argues that routes are learned before landmarks, and that routes then anchor landmarks onto a given sequence of action.

As such, there is not a consensus on the structure, acquisition or function of cognitive maps; however the map metaphor has been used to highlight several aspects of navigation as representation and dependent on information or higher order processes. This leads to the introduction of spatial strategies, which considers how navigation then is implemented as behavior in specific situations, and how complex navigational tasks are executed within the environment.

3.4 *Spatial Strategies*

To discuss spatial strategies, we must first consider cognitive strategies, as that is broadly what they are. Cognitive strategies are mainly the method people use to problem solve or learn, and therefore has been of interest in much of research in regards to how these processes can be optimized through instruction (Pressley et al., 1990). One often used example of cognitive strategies is simple arithmetic, for which most people will remember as children having learned an explicit method for adding and subtracting numbers, dividing and multiplying and so on.

Broadly speaking, spatial strategies are considered a set of organized behavior, narrowing this down if only slightly, it is structured behavior with some intended goal (Kallai et al., 2005). It has also been related to modes of planning, where certain people, or certain contexts are assumed to afford different strategy use (Hölscher, Tenbrink, & Wiener, 2011). When talking of a spatial strategy then, it is often related to performance in navigation tasks (Kallai et al., 2005), and more or less efficient methods of navigation (Hill & Rieser, 1993). The crux of the problem here is that when we assume that behavior is organized and structured according to some logic, these underlying assumed structures are themselves only latent to that which is actually performed, in other words the behavior. Studying strategy, is trying to derive the plan, when you only have the outcome of it, and in the case of spatial strategies specifically, it is watching people walk in circles and assuming that they have a reason for doing so. Include in this, that we cannot assume all behavior to be organized or planned (Kallai et al., 2005).

The main focus of Kallai, Makany, Karadi and Jacobs (2005) is what they term *search strategies*. The underlying idea is, that exploratory behavior is structured in a more or less efficient way to create spatial representations (Kallai et al., 2005). As it is assumed that learning an environment is contingent on the specific search strategies that an individual deploy when navigating an unfamiliar area, performance is often considered a dependent variable of search strategy use (Kallai et al., 2005). The outcome of strategies then, is that the subject do better or worse at certain tasks. The conceptualization of these search strategies assume that these are expressed as discrete, uniform types of behavior that are executed more or less in a sequential manner (Hill & Rieser, 1993; Kallai et al., 2005), and therefore we can describe patterns of behavior that are coherent by virtue of their underlying function. Kallai et al. (2005) themselves test for four different search strategies. First is *thigmotaxis*, which is a well known strategy within both cognitive as well as biological study. It is a type of structured behavior, which is observed within different species when introduced to novel environments. It refers to how animals will stay close to walls or area boundaries, specifically when exploring an open space (Walz, Mühlberger, & Pauli, 2016). Thigmotaxis however, has also been considered a way of orienting oneself within space through touch (Creed & Miller, 1990). As such, it is heavily implied to include a sense of "touch" and the constant contact with a stable element, such as a wall, is argued to be a stable of defining one's position in a bordered environment (Kallai et al, 2005). Especially rodents have been noted to present this type of behavior in early environment exploration, and it is a behavior which has been linked to anxiety in mice (Simon, Dupuis, & Constentin, 1994), and humans (Walz, Mühlberger, Pauli 2016). Walz, Mühlberger and Pauli (2016) therefore highlight thigmotaxis as an adabtable behavior, which allows the individual to stay hidden, just as much as it allows orientation. Kallai et al. (2005) argue, that thigmotaxis serves a process of egocentrically linking the boundary of the environment, possibly by being in contact with something tangible, in other words, making it a particular way where we through touch anchor representations of space to the body.

Circling, the second strategy, is instead identified as arc like paths, that are independent from the wall, and instead figure closer to the center of the maze (Kallai et al. 2005). In the article itself, they conclude that circling isn't actually relevant for spatial performance, which they argue, may be because the strategy influences performance indirectly (Kallai et al., 2005) They derive the notion of circling from another strategy described as perimeter search (Hill & Rieser, 1993), a strategy assumed to scope out the general outlay of a given area before more specific, sequential strategies are enforced.

Visual scan is the third strategy introduced within the article, and behaviorally it is described as cases where the subject stands still, rotating around either one's view by moving one's head, or by turning on the spot (Kallai et al., 2005). They argue, that the visual scan strategy is directly related to active exploration, namely of cues in the environment and the relations between these cues (Kallai et al., 2005). Unlike the other types of strategies described, this one takes into account non-transitional movement, in other words head rotation or body rotation. In the case of visual scanning it relies on the individual actually having visual information available, in other words not being blindfolded, in the dark, or blind, meaning that it is a strategy that is made redundant under specific circumstances

Enfilading on the other hand is defined in the article as repetitive walking back and forth within a smaller area (Kallai et al., 2005). In simpler terms, it denotes a "zig zag" pattern within a small area (Kallai et al., 2005). From their study, Kallai et al. (2005) questions whether these actually counts as strategies, and instead only consider it to be ambiguous behavior, either related to some cognitive processing or non-strategic search (Kallai et al., 2005).

Kallai et al. (2005) subset the 10 trials of their experiment into 4 types of trials, from the temporal distribution of performance (Kallai et al., 2005). Trial 3, the first trial without a visible platform typically has long latencies, according to their study, and the search strategies used in this is assumed to relate to the novelty of the environment. Trial 4, 5 and 6 are of the second subset, and here the subject transitions into a phase with unstructured spatial movement. They hypothesize this to be a result of early map structuring, relating to their definition of landmark knowledge being constructed into route knowledge (Kallai et al., 2005). Trial 7, 8, 9 and 10 were instead defined by shorter latencies, and they argue that subject typically by Trial 7 have acquired a basic cognitive map as well as a topological idea of the objects. They note that in the transition between the second and third subset, thigmotaxis and visual scan became high predictors of spatial performance, which they argue indicates a "qualitative shift" in the spatial representation. While strategies here are focused on as molar structures, Kallai et al. (2005) also argue the point that strategies change dynamically over time, and are themselves structured (even if that structure is dynamic). What they found in their study was that search strategies were contingent to specific points in the process of learning the maze, which arguably indicates that spatial strategies themselves are not isolated, in the sense that they carry over in a broader sequence of behaviors. These arguably could be conceptualized as strategies that instead span a greater amount of time.

In this as well lies a central assumption, that strategies are more or less efficient, and therefore that strategies make adaptable behavior. In this particular view point of strategies, they are linked to what is called cognitive flexibility (Malá et al., 2015), and denote that in the process of deploying a specific strategy to a task, cognition must both choose strategies suited for the context, and perform these strategies well. The notion that circling specifically influence performance indirectly, really derives from a second problem within the cognitive strategy literature. Namely the difference between the strategy, the implementation of the strategy, and then the outcome or performance of behavior. Several possible conclusion could be drawn from so-called ambiguous behavior being present in a study. It could be that there was a formulated strategy in the situation, but that it was itself poor, or it was implemented poorly. It may also be, that the strategy was implemented, and then aborted during its execution. Within the conceptualization itself, strategies are not one to one, in a way that any one strategy is necessarily implemented in behavior, or that any one implementation is necessarily executed as it was intended to, or that any given successful strategy use and subsequent successful implementation necessarily yield the intended result. A proposed solution to this problem is by looking at strategies through the lens of the direct feedback of the individual performing navigational tasks (Taylor & Tversky, 1996). If either we can acquire the rational from the individual at the time of navigation, or retrospectively, it could support the hypothesis that certain strategies underlie our behavior.

4 Methodological and epistemological considerations

Cognitive research have since its beginning been informed mainly by experimental methods, and therefore it is positioned rather firmly within positivism. Experimental methods in psychology have root in the general movement towards what was originally seen as a more "scientific" study of human behavior by emphasizing ideals within natural science of inductive and deductive reasoning towards formulating and confirming theoretical standpoints (Pedersen, 2011). It was therefore the center of discussion throughout most of psychology's history, what can feasibly be observed and measured of the otherwise unobservable "psyche". Historically, experimental methods derive in part at least, from physiological studies done originally by researchers such as Weber and later Fechner (Pedersen, 2011). As many of these studies worked with the perception of physiological stimuli the trouble became, what actually differentiates physiological studies from psychological studies. It was still not considered possible to study psychology scientifically by most physiologists, as the "psyche" was understood as mainly metaphysical, and perception was understood as more a principle of physiology than psychology (Pedersen, 2011). This was however reconsidered by Wundt (Farr, 1983), who instead argued that perception was a fundamental quality of psychology, and one of the few that could be studied through experimentation (Pedersen, 2011). Wundt (in Farr, 1983) argued, that understanding and scientific progress would come through experimental methods, but in this he introduced a new methodological concept, as a tool for studying the mind, namely *introspection* (Danziger, 1980). Introspection was the conceptualization of our ability to reflect, examine and subsequently report on our own internal state (Questienne, van Dijck, & Gevers, 2018). This however could only cover the immediate experience, and could not arrive at what Wundt considered the "higher functions" such as language and memory (Pedersen, 2011).

This limitation in the applicability of the experimental methods however were later contested, by Ebbinghaus (Pedersen, 2011). He formulated a method by which he studied his own memory, thus showing that even these “higher functions” can be subjected to systematic, experimental study (Pedersen, 2011).

Development of a new understanding of what we can observe through experimentation, mainly by the inclusion of inference measures, have thus moved psychology from a field of metaphysics, to a field of experimentation. As such, when discussing the methodological underpinnings of cognitive psychology, it is often taken as a given, that these experimental fields derive from a notion of positivist ideals. One question when it comes to introspection as a tool for research however has been the problem of how sensitive it actually is to details and specific states (Questienne et al., 2018). Accuracy of self-report measures have been heavily criticized from within psychology, as they are necessarily filtered through the individual perception (Schwitzgebel, 2002). In relation to this, introspection and how it relates to consciousness has also been a point of discussion throughout the literature (Overgaard & Mogensen, 2017), as the fundamental problems within consciousness in research extend to the problem of introspection as it refers to mind turning its attention towards itself.

4.1 Positivism, critical rationalism and hypothetic-deductive reasoning

When researching any subject from a hypthetico-deductive standpoint, it is important to keep in mind, what condition or result would be necessary for a theory to be falsified (Popper, 1935). Given the nature of spatial strategies, that both depends on simple pattern description, but also on some assumed underlying process that organizes this behavior, if there is any qy to actually falsify this theory.

Positivism really describes a variety of different philosophical traditions, but is commonly associated with what can be considered the traditional scientific theory of the natural sciences (Boolsen & Jacobsen, 2010). Outside of the natural sciences however, positivism has been widely adopted as the ideal for modern research, for better or for worse, and has defined methodological procedures that seek to quantify the object of research (Boolsen & Jacobsen, 2010). It is not within the scope of this paper to discuss the intricate relationship between the positivist positions as they have developed from different areas, however some general points can be drawn:

First of all, the world is natural. Reality, even the societal or mental one, exist and can be studied with the same methods as used within the natural sciences (Boolsen & Jacobsen, 2010). Secondly, everything can be reduced to sensory data. Phenomenon does not contain more than what can be experienced. Only that which can be experienced can be studied scientifically. Thirdly, any scientific statement concerning totalities can only refer to factual, individual or concrete objects. In other words, there is no collective, eternal ideas, entities or other, as those cannot be observed. Fourth, knowledge is either determined *a posteriori* or *a* priori. It is a differentiation that distinguishes between the type of knowledge that we have *agreed upon* and therefore is true (an example could be, we have *agreed* that the symbol 2, reflect the numerical value of 2), as opposed to the type of knowledge that we typically deal with in research, knowledge that need proof and elaboration to be determined as true (Boolsen & Jacobsen, 2010). Fifth is the search for precise and well-founded knowledge through the continued application of skepticism. Sixth is the scientific monism, which means that all scientific knowledge and praxis should have the same philosophical perspective. Seventh is the search for causal relationships and general laws that can describe these causal relationships. Eighth is the idea of social responsibility. Knowledge does not exist in a vacuum, and the pursuit of knowledge should always seek to better the lives of humans, and never the opposite. Ninth, and perhaps the most often referred to characteristic is the idea of researcher objectivism. It refers to the ideal that research should be divorced from personal opinion and values.

A core idea within positivist methodology is the hypothetic-deductive reasoning (Boolsen & Jacobsen, 2010). This relates directly to what is termed the *verification criteria* in logical positivism which stated, that any statement regarding the world can only considered true when it has been supported by empirical evidence (Boolsen & Jacobsen, 2010). The central idea in the hypothetic-deductive reasoning is that we formulate testable statements, so called hypothesis, that we then test (Boolsen & Jacobsen, 2010). Unlike the inductive method, which is said to be theory producing, it is theory-testing (Boolsen & Jacobsen, 2010). It is at this point important to mention Popper (1935) and perhaps part of largest critique of positivist theory that have challenged the scientific understanding *within* its field. Within the positivist ideal research would follow the logical progression from (1) observing the world and gathering data, (2) forming a theory based on this data, (3) verifying that the theory corresponds to the world. Karl Popper however criticized this concept of verification, and instead proposed a new concept of *falsification* (Popper, 1935).

Popper's main issue was that, though verification is arguably necessary for the sake of a theory to be held true, actual scientific endeavor should be put into disproving a theory, as a theory could be verified a thousand times over, and none of it would matter if we at any given point could disprove it (Vengsgaard, 2010). His critique was not aimed at the practical execution of falsification necessarily, but at the possibility. Any theory, if it were to be considered scientific, should be possible to falsify. There should be some possible outcome of a test that would disprove any given scientific theory.

The question then is, whether it is actually possible to formulate a falsifiable hypothesis of spatial strategies. As noted above, particular branches of research have dealt with strategies as indicators of better performance, however performance is also used as exclusionary criteria between what is and isn't a strategy (Kallai et al., 2005). While this may seem the intuitive step, a theoretical conundrum lies in how well a strategy is performed actually excludes the possibility that a strategy was there in the first place. Part of the problem here is that strategy is not defined in terms of performance really, but in terms of intentionality in the subject, and in this way falls dangerously close to the problem of how we measure consciousness and whether such properties are actually accessible through scientific study (Chalmers, 2010). A central question is, how we determine whether any seemingly organized subset of behavior was performed with that intention in mind, and how do we determine whether any seemingly unorganized behavior wasn't the result of a strategy, though it may have been a bad one.

4.2 *Objectivism and subjectivism.*

One core ideal within experimental methods is the adherence to objective results. Most choices within experimental methods are done on the consideration of what makes that particular design more "objective", and therefore it is important to consider what this actually means, and how those choices are made both in general, and within this specific study.

Objectivism is, as stated above considered a norm to either strive for or achieve, depending on the initial assumption. It is generally the idea that data and research should not be influenced by individual opinions and values. Though many studies argue that their design and analysis are “objective”, implying that it is a state that they have reached wherein their study have been completely devoid of any personal influence, it is a heated discussion whether actual objectivism is possible.

According to Gelman and Hennig, (2017) objectivism and subjectivism is often not well-considered within actual research, arguing that objectivism have become such an extreme ideal, that it is has made it impossible within scientific discourse to rationally discuss the influence the individual researcher has on design and data, effectively making studies less objective in their lack of self-awareness. Gelman and Hennig (2017) instead propose that the field of research in general substitute the “objective” versus “subjective” terminology for more specific values that instead inform of the context of any given study.

It is not possible to circumvent the fundamental limitation that any observation is done by an observer. Independent of whether or not we agree that there is one world or one truth to any phenomenon; we cannot magic away the fundamental reality that is that observation of any scientific phenomenon is filtered through the biased lens of a human being (Gelman and Hennig, 2017). The best way for research to tackle this problem is through honesty about the limitations of any study, through consideration of the methods, analysis, and conclusions we arrive at, the critique posed by Gelman and Hennig (2017) implying, that this is too often overlooked entirely.

As they argue, statistics are often simply assumed to be objective (Gelman & Hennig, 2017), and though not necessarily wrong, simply using statistics does not safeguard any researcher against subjectivity, the same way that eating copious amounts of kale does not safeguard you against obesity. Instead researchers must understand how they make judgements in their choice of methods, theoretical assumptions, and data to include or exclude (Gelman & Hennig, 2017).

De Finetti (2017) notes, when research handles knowledge of the world, as well as claims of truth, they also deal with uncertainty. When describing the world through statistics, we in other words deal with probability, as it is the gradation of what is possible, from impossible, improbably too probable, with varying degrees in between. He argues that probability does not belong to the domain of certainty by its inherent nature, and he therefore argues that it is instead specific to the domain of subjectivity. Gelman and Hennig (2017) propose seven values to substitute the traditionally used concepts of subjectivity and objectivity.

Transparency, they argue, is the fundamental idea that choices within any design, study or statistical procedures should be done on the basis of externally verifiable information and transparent criteria. Transparency is the idea that the central choices, often simply argued as being more "objective" or simply taken for given for the experimental design, should instead be made on transparent criteria. As there is no uniquely "objective" analysis, and different stakeholders will differ in their decisions we must instead aim at transparency through clear communication and justification of our analysis. Criteria, decisions, unverifiable assumptions, prior knowledge etc. should be communicated in a way that beckons scrutiny first, and consensus second (Gelman and Hennig, 2017).

Consensus is the second attribute which Gelman and Hennig (2017) propose. It is both the need of the individual study to communicate clearly the rationales, motivation and the general argument of how a study relates to already existing knowledge, and the way in which scientific communities build best-practice rules, that can avoid some of the individuality in design and analysis choices. It relates to the general condition that observer-independent reality is inaccessible, and therefore to try and avoid the potential bias of the individual observer, multiple observers must serve as a filter through

We must be impartial, the third value, and in order to do this, we must consider how different theoretical standpoints compete within any subject of study (Gelman & Hennig, 2017). We must seek to minimize personal bias when possible through careful consideration of factors that may influence consensus and interpretation of the results. In turn, we must be open to criticism and ready to evaluate the soundness of our own position (Gelman & Hennig, 2017).

Correspondence to observed reality is the fourth core concept that Gelman and Hennig (2017) introduce, in reference to the fundamental realist assumption that there is an existing world outside the individual observer's perception that science can determine general rules about. In praxis, this means that we must verify our theories in accordance with reality. If we cannot verify them, we must falsify them. Validity denotes an evaluation of whether a study, a concept, measure, or conclusion is in correspondence with the real world (Kukull & Ganguli, 2012). There are two major questions within this however: whether any measure actually measures what is intended, and then whether the results can be generalized beyond the specific context of the study (KuKull & Ganguli, 2012). These are termed internal and external validity respectively, and they make the difference between having a thermometer that actually measures noise, and then realizing that it only measures the noise of tabby cats and nothing else. Or a more relevant example, we should consider in the case of mazes and their design whether they actually produce strategies that we then can measure, and then whether that is true outside of the specific study, and whether the behaviors described within the different strategies denote the assumed underlying cognitive process, and then whether these exist outside of the experimental condition. Both of these relate to the theory of sample and hypothesis testing (KuKull & Ganguli, 2012).

Reliability on the other hand refers to the notion of whether a measure is consistent, producing the same results in the same context (Kukull and Ganguli, 2012). In other words, does a person performing this specific measure produce the same results? The problem here, when we are dealing with measures that involve a learning-curve, is that the state of the participant is assumed to change over time as that task is being performed. The same is true for the maze design used within this paper. This is also what makes it difficult to assess reliability. Instead we should assume that performance will vary according to some stable measure. Finally, generalizability refers to the question of whether any given study or data sample is representative of the broader population.

To reach the above stated values, which are categorized as the “objective” values of science, we must also consider our own subjective position and any influence that we as researchers pose to our work. One way to do this is to accept and reflect on the multiple perspectives present within any one field of study. This relates to the idea of correspondence, while it is the scientific ideal it is not always the practical reality that the theoretical foundation within a field is organized around one accepted theory. Even if there is, it is not a given that this dominant position is not dominant for reasons other than the above stated foundations of correspondence. Therefore it is always important to recognize the decisions we make as researchers that are dependent on the particular perspective we have ourselves, and then how others perspectives would make these choices differently (Gelman & Hennig, 2017).

Another point towards this is the sixth value, that Gelman and Hennig (2017) introduce, awareness of context dependence. The specific context of the study should be accounted for (Gelman and Hennig, 2017) both including the physical and theoretical context that a study is placed in, as well as context-dependent goals and needs specific to the topic or areas of research. Researchers should be aware of how different choices and assumptions would affect the analysis and subsequent conclusion of a study, as well as the researchers own position (Gelman & Hennig, 2017).
The seventh and last value is that of stability and the investigation thereof (Gelman & Hennig, 2007). Again, this refers back to the point that any one study is limited by the researcher’s perspective, so in considering the stability of a study, by its reproducibility of conclusions given a new data set, or in documenting the influence of different choices on the data outcome we approach more objective conditions for research.

In sum, subjectivity and objectivity have both med hated and glorified by the scientific community respectively, however if we are to actually build a scientific hoard of theoretical knowledge we must, as a community, critically discuss the studies being done through honest communication (Gelman & Hennig, 2017). Honesty and clarity - transparency - are all aspects of a scientific endeavor that means facing the aspects of our scientific inquiry that we cannot at present time determine to be perfectly objective, perhaps even more than the need to communicate the areas of our work where we can claim objectivity.

The study done by Kallai et al. (2005) arguably lacks essential information both in terms of its maze design, as well as specific definitions of their categories. It is a study that is 13 years old currently, and therefore, focus may have been different at the time, however, for the sake of replicability, the lack of precise information about categorization criteria as well as the design of the maze procedure has made it a difficult process to recreate their study design. When essential information is lacking, replications have to guess at what choices were made within the original study, resulting in differences between study contexts that are left unaccounted for.

4.3 Maze studies and related considerations.

The use of mazes in cognitive studies were first developed on rodents specifically, and animal models more broadly speaking (Paul, Magda, & Abel, 2009). Mazes are purpose-built, and the different paradigms of mazes (T-maze, radial-arm maze, Morrison Water Maze etc.) have been designed for specific types of objectives. This can be conceptualized in terms of limiting or affording choices, such as multiple route choices, restricted choices, serial or complex choices, all being specific to different maze types. Mazes are designed as controlled environments wherein we can control variables and choices available and systematically study a range of cognitive functions (Bertholet et al., 2015).

The central logic within maze methods have depended on the premise that reward-systems in the maze will motivate animals to perform learned tasks within the different maze paradigms (Paul et al., 2009). Rewards are not equal, or rather, there are many different ways to implement a reward system. Radial arm mazes for example often use, in the case of rodents studies, a period where animals are food deprived, and therefore are motivated through hunger (Hodges, 1996). In the Morris water maze, on the other hand, the reward is simply being allowed to climb out of a large pool of water (Rogers et al., 2017). Comparing the two, one is receiving a meal, and the other is the reward of not drowning.

As mazes are designed particularly towards rats, they are also designed towards a rodent's specific behavior (Paul et al., 2009). A central problem within animal models is how these relate to humans, if and how we can generalize from animal models to human studies (Mogensen, 2011). It should also be considered that maze models like these are designed towards the specific purpose of use on rodents, and how artifacts of these models carry over into human studies should then be considered.

As noted above, spatial strategies are implicitly assumed to relate to the type of environment, individuals happen to find themselves in. Thigmotaxis as an example is assumed to be particularly frequent to open spaces (Walz, Mühlberger, Paulli, 2016), supposedly because those are the places where this type of strategy makes the most sense. The question that this raises then, in terms of discussing the validity of these strategy constructs, is how environments promote certain types of strategies and discourage others.

The use of virtual mazes technologies in research

Virtual methods have given us the advantage, of making it possible to do maze type studies on humans, which has otherwise been impractical (Lingwood, Blades, Farran, Courbois, & Matthews, 2018), and through the increased availability to both control variables and stimuli (Gillner & Mallot, 1998b), it has given the opportunity to study more complex environments (Vidal, Amorim, & Berthoz, 2004). Virtual methods also pose the opportunity to study aspects of cognition under unusual circumstances (Tarr & Warren, 2002). With all these advantages however, comes a number of difficulties when it comes to both how these technologies relate to our real-world cognition, how personal differences such as technology positivity and experience influence participant's interaction with these technologies, and also how we communicate clearly what complex software and technology do in studies.

When it comes to considerations of ecology in virtual methods, two arguments persist through out the literature. The first argument is that VS lack ecology, as they are dependent on simulation technology that can be better or worse at simulating aspects of sensory input (Sanchez-Vives & Slater, 2005). This deals with VS as a tool that appropriates real-world experience by increasingly integrating levels of different aspects of normal human behavior and perception, visual and auditive being the most common level of simulation, and proprioceptive and vestibular inputs being introduced to more complex systems. This has often been related to a concept of *immersion* and *presence* (Bowman & McMahan, 2007;

McMahan, Gorton, Gresock, McConnell, & Bowman, 2006) which generally denote a concept that VS increase in ecology as the subject becomes surrounded by technology.

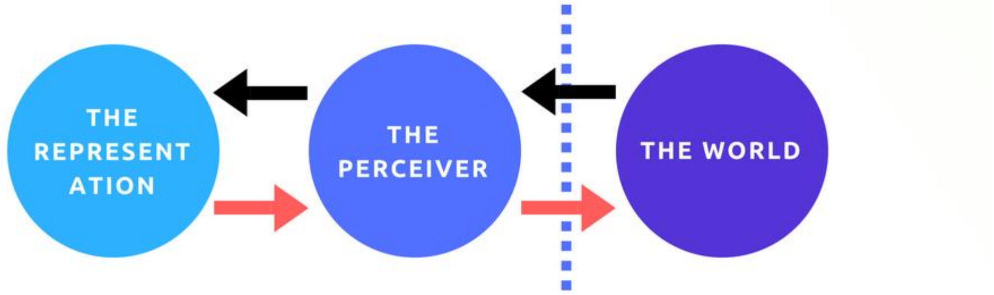
Interaction devices or input devices also play an important role in how these technologies influences behavior within the system (Lapointe, Savard, & Vinson, 2011). In general, different types of input devices rely on different strategies of movement (Lapointe et al., 2011). When considering research then, and especially the transparency of data, different devices may introduced noise to data due to technological issues such as delay times (Shimizu, 2002), or because different input methods produce differences in the execution of virtual behavior (De-Marchis, 2013). When there is an increasing choice between different types of interaction devices, it only becomes ever more important for researchers to consider how these choices may indirectly influence the data.

4.4 The Problem of Mental Representation

When we talk of the cognitive map as a process or a representation of spatial knowledge, what does that actually mean? As mentioned above, the idea of the cognitive map has saturated most, if not all, of the literature on spatial cognition (Bennett, 1996). A central question to this, is what the cognitive map actually means. The use of the map as a term within spatial cognition therefore begs 3 questions. What is the actual nature of a cognitive map? Is it symbolic or more analogous to the maps that we know of? Are cognitive maps mental representation? Do cognitive maps need to be representations to be useful for navigation?

O'Keefe and Nadel (1978) proposed that the hippocampus is a physical implementation of an actual map, an idea that has been prevalent within neuroscientific research ever since (Burgess, Jeffery, & O'Keefe, 1999), with place cells being proposed as the particular neural basis for mapping (Lever et al., 2002). When it comes to the actual nature of the cognitive map, an interesting nuance in this question is that maps themselves (the cartographic kind you use on your standard road trip across Germany), are symbolic representations. Maps are not "naturally" occurring, they are actually representational constructs (Kitchin, 2014). So do we cognitively represent this representation of space? Avoiding the digression inevitable to the question of how mental representation represent representation themselves, what this instead poses as a viable question is how spatial theorists understand the relationship between the cognitive and the non-cognitive maps. Maps are not universal tools, as a navigation praxis, in fact various different cultures have used a multitude of ways to organize navigation beyond using actual maps (Heft, 2013). It raises the question of whether actually representing things in a map form, as the original metaphor eludes to, is really a natural way for us to represent space, as opposed to a system in itself that has developed over the decades and years (Kitchin & Dodge, 2007). And even then, there are a variety of map types used within cartography, and a well of theoretical positions on the 2D representation of space, that poses the question, what do we talk about when we talk about maps? This critique is specific to maps, and the map as a useful metaphor to describe the how's and why's of how humans navigate, however several questions regarding representations that are relevant to our understanding of cognitive maps are general questions within cognitive science (Glenberg, Witt, & Metcalfe, 2013).

Considerable discussion within psychology has dealt with the problem of representation. It's a fundamental question of how the external world relates to the internal state of the mind (Fodor & Pylshyn, 1988), and it relates to some of the early theories of cognitive psychology that built from concepts within computer science, where behavior structures acted upon internal models of the external world. It should be noted however, that some theorists make the distinction between mental representation and mental models (Morgan, 2014). Largely theories can be divided into two, the ones that include some assumption of a mental representation underlying mental processes, and those that don't (Churchland, 1981; Fodor & Pylshyn, 1988). These are otherwise known as the representative and eliminative positions, and between these, the representational standpoint has been heavily favored within psychology in general (Fodor & Pylshyn, 1988). Part of the argument for theories depending on mental representations lay in the logical division between the so called inner and outer world, in other words in differentiating between the object itself and then the perception of that object as being independent of each other (Skovlund, 2011). Later theories have dealt with mental representation however as instead semantic abstractions that interface between the perception and the cognitive and neural processing (Fodor & Pylshyn, 1988).



So when we talk of mental representation, on the one hand we are dealing with a question related to, at the extreme end at least, the difference between the realist position versus a solipsistic assumption where thoughts are the same as the object themselves. On the other, it is dealing with a variety of questions on how mental processes and physical processes deal with information from the external world.

In relation to the cognitive map then, how these relate to the external world is both a question of how they relate to maps as the object, and to the environment itself. Though the question of mental representation has been framed as a categorical question of either being there or not being there (Skovlund, 2011) the distinction is more often framed along the line of a spectrum of mental representation, ranging in terms of how much perception stimuli is assumed to be "processed" (Field, 1978), in other words in terms of its abstraction. Now, as have been noted, the map itself is not a uniform existence itself. Speaking from the point of cognitive science solely, the cognitive map is often used as a general shorthand for a variety of different viewpoints on how spatial cognition is organized, arguably to the point that it threatens the meaningful use of the term (Bennett, 1996). The conceptualization of a map in the mind ranges from more literal interpretations that understand the cognitive representation of space as actually being cartographic in style (Giocomo et al., 2011; John O'Keefe & Nadel, 1978), to more figurative conceptualizations where the maps is a metaphor denoting the relational way that information is stored (Tversky, 1993). Between these, there are differences in terms of their general form, their structure and their function (McNamara, 1986).

There are no broadly accepted way of organizing mapping theories into coherent paradigms, however Kitchin and Blades (2002) have tried to outline some overarching differences between theoretical traditions. Gibsonian theories build on the theory of *direct perception* (Kitchin and Blades, 2002). Spatial models deriving from these theories assume that in situations where we act upon stimuli in front of us, no interfacing model exists between the perceived and behavior (Kitchin and Blades, 2002). There are varying degrees of Gibsonian theories, some claiming no representation at all (Glenberg et al., 2013), and other instead placing mental representation as more or less a function of memory and recall (Kitchin & Blades, 2002). These theories do not assume that objects do not exist outside of the individual, however they still "do away" with at least some of the generality of mental representations. To many cognitive theories, and information-processing theories in particular, mental representations are structures that hold information that cognitive processes can act upon (Nørby, Kyllingsbæk, Harms & Larsen, 2011).

It is not irrelevant when we consider mental representation, whether we assume it to be an analog of the object it is representing, or instead an abstract propositional relation (McNamara, 1986). This is in relation to its assumed form, as the difference lies in an analog and a symbolic representation (Fodor & Pylshyn, 1988). In this regard as well, the metaphor of the cognitive map is of importance. It has absolutely saturated the spatial literature, and to its credit, the use of cognitive maps gives us a ready available vocabulary to contextualize how relational information can become spatial, and then how that spatial information can be processed towards behavior as it is in its original symbolic form. There is in other words, not a big leap in assuming that we use maps to navigate from, as we already do. Problematic to this however, in the context of mental representation, is the question of how these maps actually are represented then in the cognitive and neural structure. Again, as related to the question within direct perception theory, do we act directly upon the stimuli that happens to be before us, or do we first construct a model of the surrounding world that we then act upon. And then in terms of cognitive maps, do we analogously construct Euclidian type maps in our heads when navigating, this being concrete to the object but the object itself being a symbolic structure. Do we instead create more symbolic maps, in other words maps more abstracted from what we traditionally consider maps to be.

The analog assumption have been criticized for not accounting for the ambiguity, or the non-material lack of specificity inherent to the internal experience (Dennett, 1987). Mental representation does not follow the same rules as a physical representation would have to, most importantly the amount of information that would have to be accounted for in the physical representation is much greater than when we mentally construct or recall something

(Dennett, 1987). As an example think of the cognitive map. Disregarding whether or not we actually use maps as a mental representation, imagining a map and the necessary information we can assume to do in a variety of ways, though the one most often implied is that of a visual or pictorial map, like a land map. We do not have to specify the metric relationship when mentally picturing this relationship, we do not even have to specifically picture how the locations look, whereas if we had to draw it out, even if we did not particularly care about the accurate metric relationship, we would still have to explicitly make a choice in this regard (Dennett, 1987).
A rather analogous view of spatial representation could be the egocentrically oriented theories, where representation is in some cases argued to be of the viewpoint of locations and routes (Wang & Spelke, 2000). On the other hand, allocentric representations can be considered more symbolic, as theories that rely on this type of representation assume that some cognitive process have derived relational information between viewed objects (Burgess, 2006; Chersi & Burgess, 2015), therefore giving the representation a higher level of abstraction from the original perception. In this sense however, symbolic versus analogous come to mean more or less processed. In relation to cognitive maps specifically, it could instead be conceptualized as more or less like cartographic maps.

Information-processing theories claim that the objects we perceive are instead objective information and facts made available to us through our senses (Kitchin and Blades, 2002). Though it depends on the specific theory, this paradigm of theories generally states that information is existing independent of the perceiver. In other words, the metric relationship between objects, their placement in space, their texture, heat signature and so on, all different aspects of the particular object exists independent of whether an individual is able to perceive it. Arguably, within these theories, information does not happen as a representation within the mind, but are instead inherent to the environment. Later theories on the other hand, instead described the perceiver as an interacting agent, that actively perceives the world around it, and representation or modeling happening then in this interaction, where information is filtered through individual and personal factors that sort and model information into meaningful behavior (Kitchin and Blades, 2002). The central argument here is that what is spatial information in the environment is not the same as what is spatial to the organism, as that is both limited by the individuals perceptual perimeter as well as individual factors. Though modeling is included in the later theories, the general understanding is, that the information, that which is often seen as the first semantic representation is not inherent to the cognition as a representational value, but instead is inherent to the object itself, changing the relationship slightly between the object and the assumed representation. These theories derive from computer methods, so part of their ecological difficulty is in the difference between the input/output relationship within computers and humans. There are no clear conceptualization of what the limits of an input is in humans, and similarly our output is not so easily categorized either, as both explicit behavior, emotional and cognitive response could all be seen as "output", and "input" in and of themselves. This begs the question: when is a task concluded and new input is interpreted. Another problem in this regard, is how we fit such things as our own consciousness and intentionality into a model, that reduces many mental processes to computation and information structures in the same way that computers deal with intput and output (Searle, 2009).

Transactional theories on the other hand critiqued this approach to perception and processing, as it assumed that humans process stimuli in a sequential manner, clearly denoting an end and start point of an input and a subsequent output. The transactional theories instead argued that the boundary between the act of doing and the act of perceiving was in constant interaction with the surrounding world, and therefore couldn't be clearly distinguished themselves (Kitchin & Blades, 2011). This notes an important difference in the function of mental representation, as it defies the idea that representations are passively acted upon, instead of active components in our engagement with the surrounding world. Though some theories make a clear distinction between what is being represented, and the processes that act upon the representation, it is not as clear a distinction within human cognition (Glenberg et al., 2013).

Computational models on the other hand derive from a central idea, first introduced as the cognitive sciences took their inspiration from computer science. It follows the general principle that thoughts can be expressed as algorithmic calculations (Kitchin & Blades, 2002). Initially these were purely symbolic systems that dealt with specific inputs and outputs that were then fed into a computer. Neural computational theories however has put an emphasis on representation as neutrally founded (Clark & Toribio, 1994). In general, there has been a movement towards embodiment theory, where cognition and body have been much less seen as two planets circling the same sun, and more like two sides of the same coin (Glenberg et al., 2013). Not all neural computational theories align with the idea of embodiment, but treat the neural layer as a natural progression of rooting the cognitive functions in a physical system (Byrne et al., 2007) whereas others take the idea of embodiment further into consideration, top-down modulating the neural networks on the process of perception (Glenberg et al., 2013).

5 Method

In the following section it the method used in this paper will be described. The section will first introduce the overall experimental procedure, followed by the specifics of the maze and categorization method.

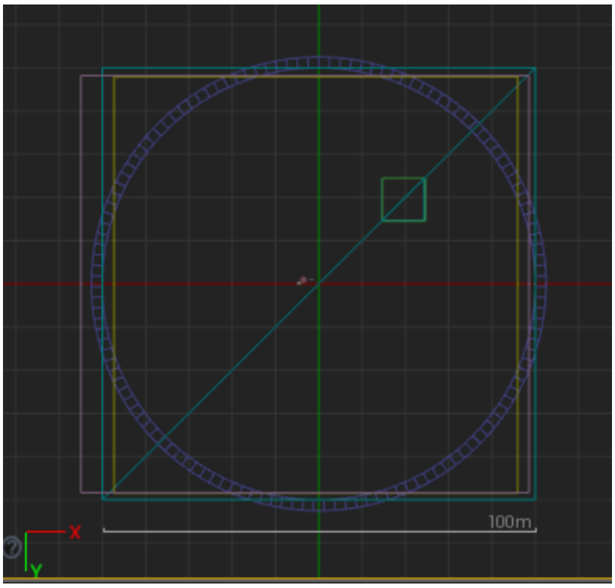
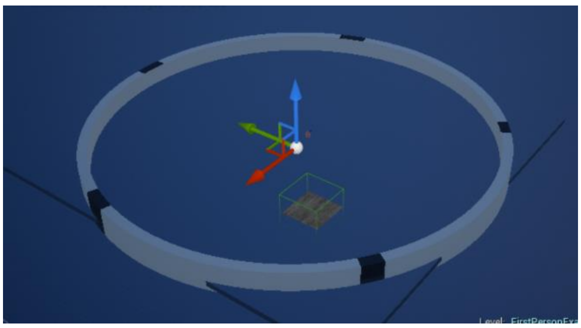


Figure 1: Picture of the maze design from within the unreal engine.

5.1 *Experimental procedure.*

The study included 20 participants, of which 6 were male. All participants were students, ranging from the age of 21 to 43 A virtual Water Morris Maze was used to explore spatial strategies, specifically related to the validity and replication of these types of experiments. Participants were placed within a virtual environment setting, with a platform in the northeastern corner, which was visible for the first two trials, and then was made invisible. The task was to find the platform as quickly as possible. At each trial, participants had 3 minutes to find the platform or they would be transported to a new starting point in the maze.



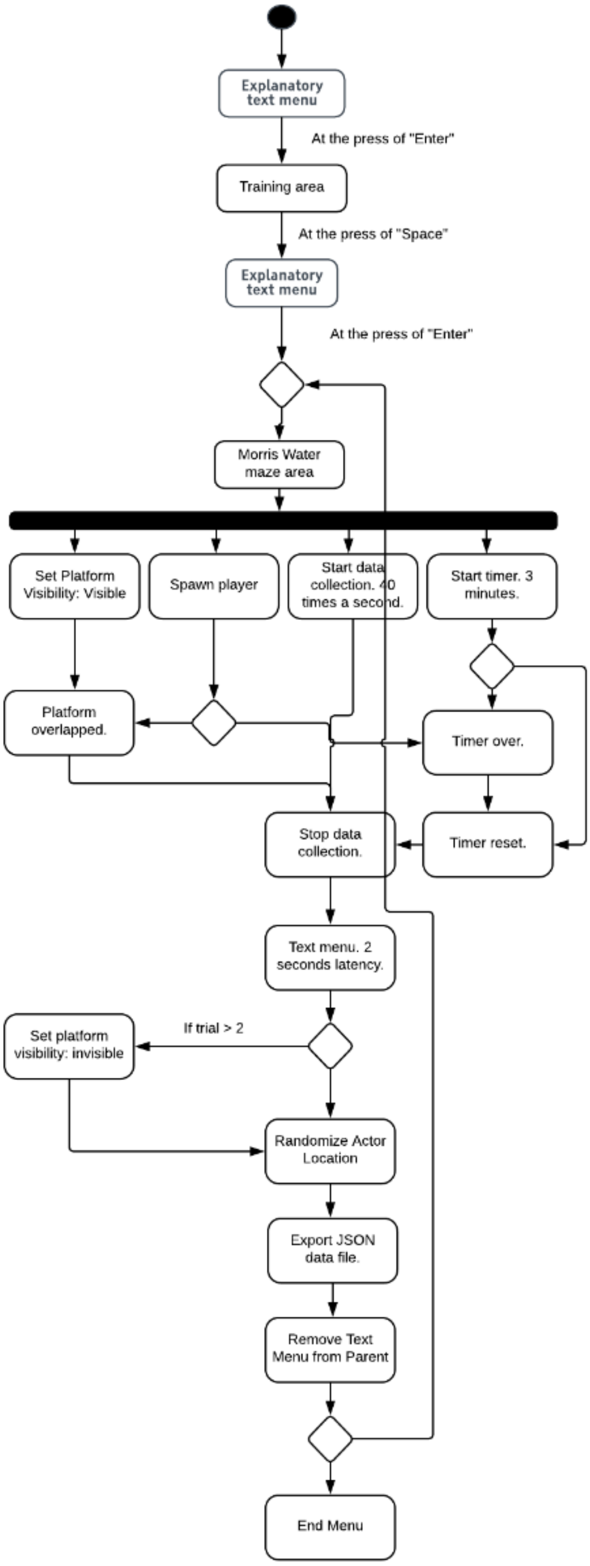
The participants were first given free range to move around a training area, with the purpose of making them comfortable with the controls in the maze, and the participants were instructed prior to initiating the study to spend as much time as they needed in the training area. Instructions for the controls were given both as a text screen which preceded the virtual environment as the opening screen, and orally as an introduction to the study. Instructions of the specific task objective in the maze were given orally and via text as well, with a text screen between the training and maze environment.

The participants chose themselves how long they spent both within the training area and on reading the text, however they were instructed prior to starting the test to read descriptions in the study thoroughly before continuing.

At the end of the trial, if the trial ended because the time ran out, participants would be shown a screen with a text explaining that they had not found the platform within the allotted time, and therefore would begin a new trial. If they found the platform, as text screen would appear, explaining to them that they had found the platform and that they would be placed a new place to start again. These description menus were added to avoid confusion during the test session. There were 10 trials in all, 2 of which were priming trials and the remaining 8 being testing trials.

Training Trial	Priming Trials	Testing Trials
No time limit.	3 min. time limit	3 min. time limit
Participants were instructed to familiarize themselves with the controls.	Participants were instructed to find the platform as quickly as possible	There was no intermission between priming trial and testing trial.
Participants were placed in a simple, square room	Participants were placed in Morris water maze environment, platform visible.	Morris Maze. Participants were placed in Morris water maze environment, platform invisible.

Model 3: Overview of the trial composition in the experiment



Model 4: Sequence diagram of Maze Algorithm

The experiment was done using a Lenovo Y700 laptop with an externally attached 17" screen, a Logitech Bluetooth Keyboard and a Logitech G700 mouse. The maze was programmed and modelled using Unreal Engine, which handled both the simulation and data collection.

5.1.1 Pilot

A small pilot test was performed on two participants, from which adjustments were made to the simulation. Upon feedback from the participants, adjustments were made to latency timers in the maze, to avoid unnecessary confusion, and light setting were adjusted to allow better contrast. Texture was also added to the outer wall to improve contrast.

5.1.2 The Maze

The maze and the related virtual environment was developed on the Unreal Engine platform. The Virtual Morris Water Maze was 50 meters in diameter, as in the original study done by Kallai et al (2005) and surrounding the maze was built a larger room with the dimensions.

The camera view was placed at 1.70 meters, giving participants an eyeheight of 1.70 meters.

Figure 2: View from within the maze.

Cues were as described in the original study a distinctive set of arches and windows arranged around the room. As there were no pictures of the maze, simple holes were formed in the wall around the maze in the size and shape of doorways and window arches around the room, and then sequenced in a particular order for each wall. Texture was added to the room wall, resembling brick walls, mainly to increase the contrast between the maze wall and the wall of the surrounding room, but there were no specification in the original study of how the maze was textured, and it could possibly serve as an additional cue to the participants.

Model 5: Dimensions and specifications

Room	
Room dimensions	512x512X128
Morris wall radius	m
Morris wall height	50 m
Target dimension	3.5 m
	10x10 m
Player Pawn	
Eye height	1.70 m
View angle	50
Motion	
Acceleration	2048.0

In Model 4, the algorithm of the maze is described using standard UML activity script. As can be seen from the diagram, intervals of 2 seconds were given at the end of each trial when the trial end screen was displayed. This interval was adjusted during the pilot, from 1 seconds due to expressed confusion and disorientation from the participants in the pilot. As there are no general guidelines for latency setting, and Kallai et al. (2005) did not inform on the between-trial transition, latency was instead set from feedback from the two pilot participants.

A randomizing algorithm was used to place participants between trials. It was unclear from the study whether participants were replaced in a limited order of placements, or their placement was randomized. In the end, it was decided in this project, to randomize placement with a check to ensure that participants did not overlap with the trigger area on the platform. It should be noted however, that some placements were still quite close to the platform, and some participants started a trial right next to the platform which could possibly skew certain trials.

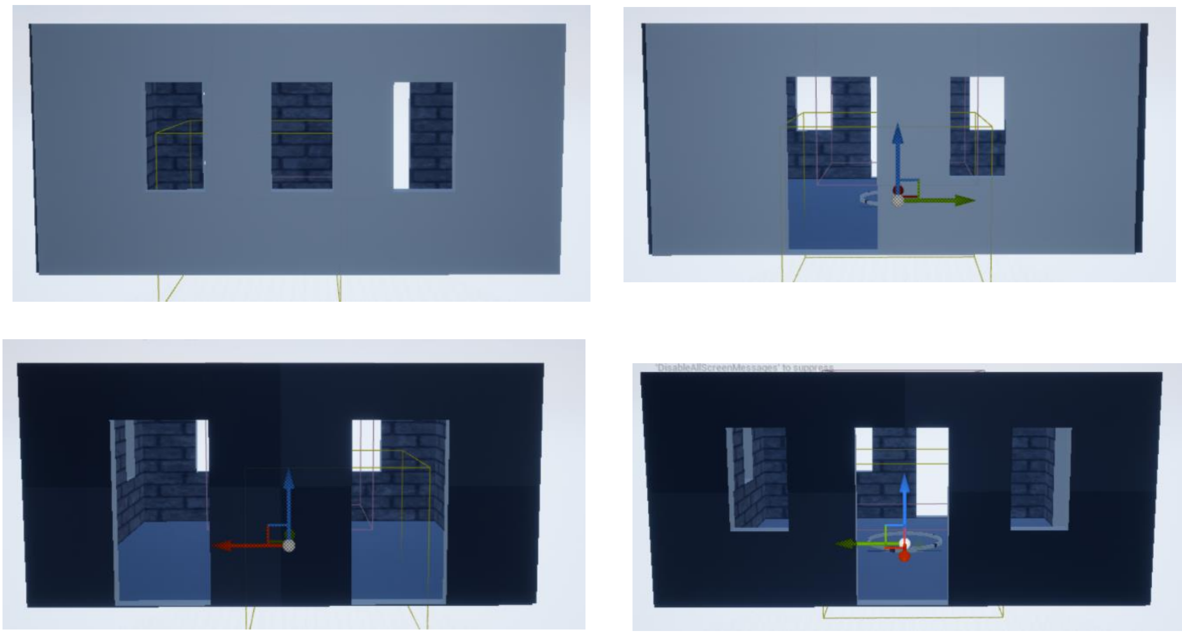


Figure 3: The cue arrangement on all four walls.

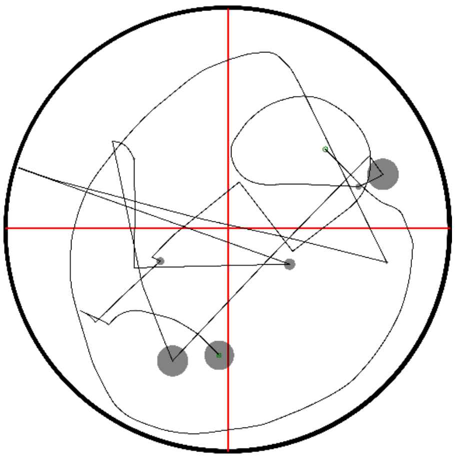
5.2 *Data collection*

A data point was gathered from the maze 40 times a second, and the following raw data was collected from the maze:

1. X, Y and Z coordinates of the participants in the maze. This meant that their location was recorded 40 times a second.

2. Roll, Pitch and Yaw direction of the camera heading vector. This is a measure of the direction of the viewpoint.
3. Hour, Minute, Second and Millisecond. Giving a timestamp for every data point.

5.3 Data processing and Mapping.



Collected data was processed into bitmaps to give a visual overview of the paths in general, similar to the original study. The maps are 1:2 scaled to the actual maze, meaning that half the data points are sorted out for the visual representation. All other processing of data included the total amount of data points.

In the original study, qualitative evaluations were made of the strategies in the maze that were then measured for length (in the case of circling, thigmotaxis and enfilading) or counted on occurrence (as with visiual scan). In this project 4 categorization algorithms were coded to sort through the path data an check for conditions for enfilading, thigmotaxis, visual scan and circling. As a point of comparison however, qualitative categorization was made similar to the original study as a point of reference towards the difference between analyzing the data through qualitative and quantitative descriptions.

Strategy Criteria and Categorization

Visual scan is possibly the easiest of the strategies to describe. Kallai et al. (2005), define it as places where the participants stand still and do a turn above 20 degrees. The latter condition was in the original study meant to exclude small changes in trajectories. With outset in this definition, the following algorithmic check was formed:

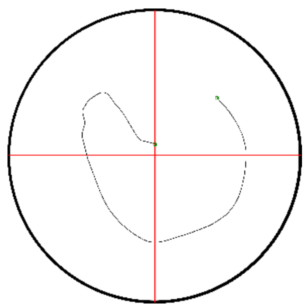


Figure 4

If point A and point A+n are equal to each other AND Yaw changes with more than 20 degrees consecutively, that interval of data describes a visual scan strategy.

For the second strategy, circling, Kallai et al. (2005) describe these as “arch like” patterns that follow the curve of the wall. It is unclear whether this means that the slope of the curve matched the slope of wall as would be the case in Figure 4, in the southeastern area, or if it means to exclude curved paths that within a subsection does not follow the slope of that subsection, as in the case of Figure 5, in the southwestern subsection. As their circling was derived from Hill et al.’s (1993) concept of perimeter search, the latter notion was assumed to be the intended meaning., why the following algorithmic check was formed.

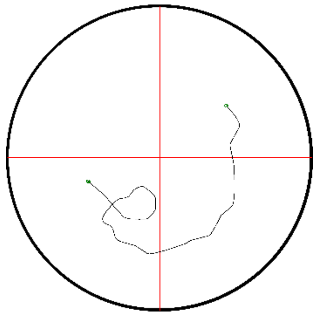


Figure 5

If the vectors between point A and point A+n are all at an angle to each other in the same direction it is a curve.

In the case of thigmotaxis, it was defined within Kallai et al. (2005) it was defined as paths that touched the perimeter wall. This was described algorithmically as,

If point A and point A+n are all within X point distance of the maze wall, it is a thigmotaxis strategy.

Similar to circling, a lower limit was set for how short a thigmotaxis strategy must be, to exclude paths that simply hit the wall.

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Lastly, enfilading was described in the original study as movement back and forth within a limited area (Kallai et al., 2005). It was also related to a definition of a strategy, called “zig zag”. This was interpreted in this study to mean a certain amount of movement, within a limited amount of space, and thus described within the algorithm as:

If the point distance from the first point P1 to the next point is less than the max radius add this as a possible part of an enfilading pattern, and do this for each P1+n, until this is no longer true. If the resulting path is longer than the minimum length of enfilading, categorize this path segment as enfilading strategies.

The automated categorization was done using an algorithm programmed in C# (see appendix). In a few examples, categorization was also done qualitatively to illustrate how certain maps were categorized differently using different methods.

Strategies were categorized on the assumption that they were molar. Strategies were therefore processed as exclusionary, which meant that a path section could only be defined with one strategy. They were categorized in the order of visual scan, enfilading, thigmotaxis and circling.

6 Results

All strategy types were identified within the sample data. The results of this will be presented for each strategy in turn in the order of visual scan, enfilading, thigmotaxis and circling.

6.1 Visual Scan

For the qualitative evaluation, visual scans were isolated by adding grey dots to the bitmaps, which indicated that the person stood still. Larger dots indicate longer periods of standstill. These were then cross-referenced with the path information, to see if the person did an above 20 degree turn.

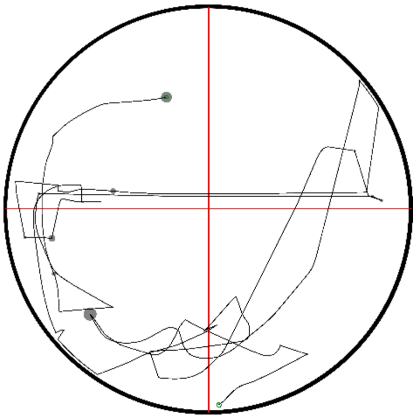


Figure 6: Test subject 7, trial 8 with the qualitative analysis condition.

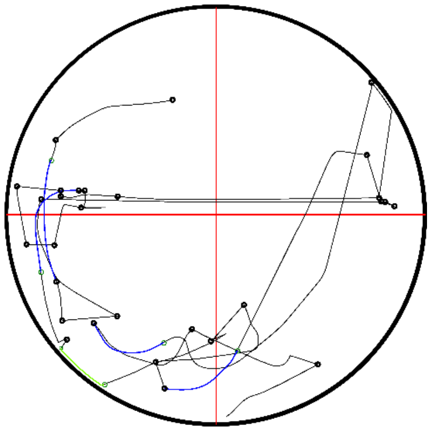


Figure 7: Test subject 7, trial 8 with the quantitative analysis condition.

In Figure 6 is shown 10 possible visual scan strategies, and after cross-referencing the strategies with the path information, it was confirmed that they all lived up to the second criteria. The quantitative analysis of the same trial yielded 29 visual scan strategies. This means that there was a difference of 19 strategies between the qualitative and quantitative condition in this trial, when the lower boundary for latency was 1 point, meaning a fortieth of a second.

Adjusting the lower boundary for the latency visual scan strategy by a fourth of a second meat changed the amount of visual scan strategies by down to 27, in this particular case, and 22 if the boundary instead is set to 1 second or 40 points.

6.2 Enfilading

Figure 9 and Figure 8, are two examples of paths that were identified with a qualitative condition. In Figure 9, the right-side path displays a zig-zag like pattern at the bottom, which then broadens at the ends was categorized as an enfilading pattern as were the pattern to the left that also diplays a back-and-forward motion in the same direction. In Figure 8 in the bottom left corner of the map were an enfilading pattern identified, as were there one in the bottom right corner, where there also is a movement back and forward in the same space.

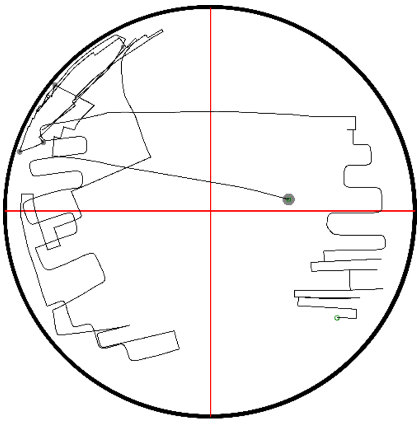


Figure 9: Test subject 10, trial 8. Enfilading strategy identified on the right, but excluded on the left.

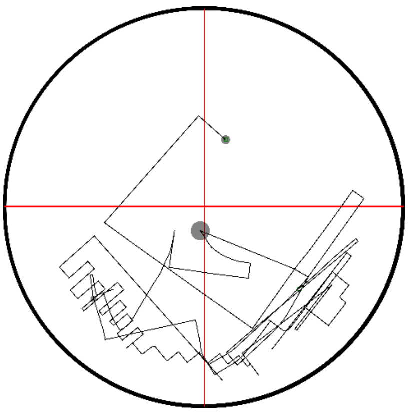


Figure 8: Test subject 10, trial 6 with the qualitative analysis condition.

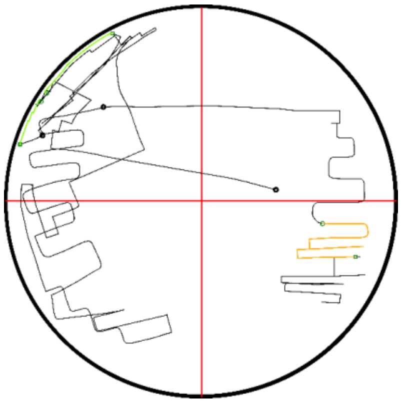


Figure 10: Test subject 10, trial 8. Enfilading strategy identified on the right, but excluded on the left.

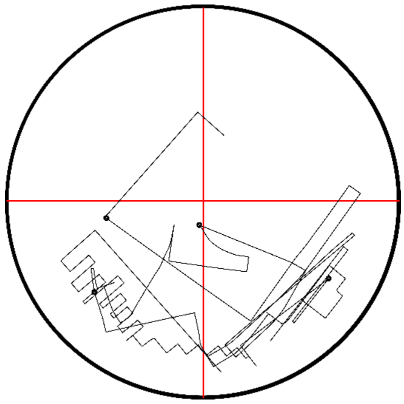


Figure 11: Test subject 10, trial 6 with the automated analysis condition.

In comparison with the automatic categorization results from the same two trials, we can see that within the trial in Figure 10 there were no enfilading categories identified to the left of the center and only part of the path on the right that would otherwise be categorized as enfilading within the qualitative condition was categorized as enfilading strategy. Figure 11 on the other hand which presents trial 6 from the same subject had no enfilading conditions.

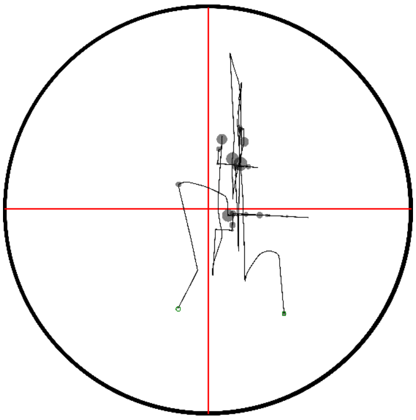


Figure 12: Test participant 8, trial 3.

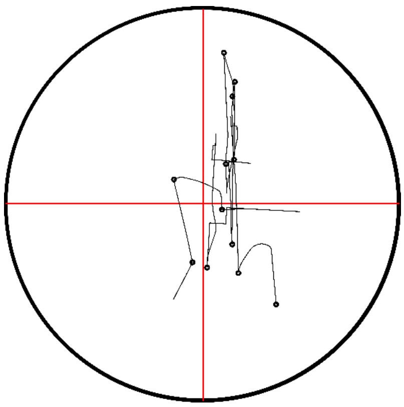


Figure 13: Test participant 8, trial 3 with the automated analysis.

Another identified enfilading strategy was found in the right upper corner of Figure 12, which again wasn't identified within the automated condition. This was most likely because the area was too large for the automated condition to count as enfilading.

One identified enfilading strategy had parts of its path following the perimeter wall, like an thigmotaxic strategy (see Figure 14). This strategy as well, shows that the enfilading strategy in the automatic categorization is identified hallway into a set of movement that from the qualitative analysis was identified as enfilading because of it's zig-zag like pattern. Other paths were identified as a strategy within the automatic condition that wasn't considered a strategy within the qualitative categorization (see Figure 15)

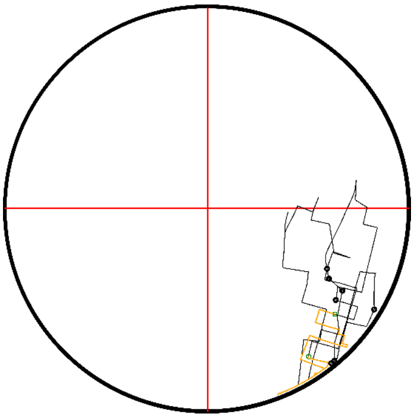


Figure 14: Test subject 8, trial 9. Enfilading strategy identified with part of its path following the perimeter wall.

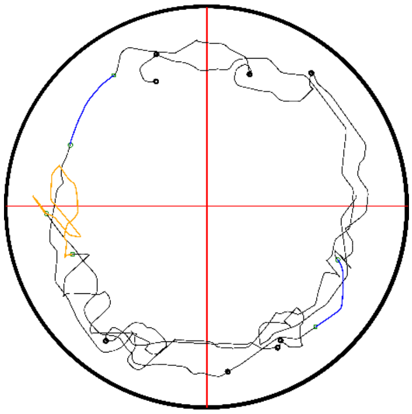


Figure 15: Test participant 15, trial 5.

6.3 Thigmotaxis

The thigmotaxic strategies were observed both in the qualitative and quantitative condition. They consisted of paths that followed close to the wall. There were no notable differences in the strategies categorized by the qualitative and the quantitative measure. Figure 16 and Figure 17 were two of the longest cases of thigmotaxis strategies spaced so close to each other. Test participant 10 (see Figure 18 and Figure 19) showed some irregularties along the path, which means that the participant didn't touch the wall at all times during this navigation.

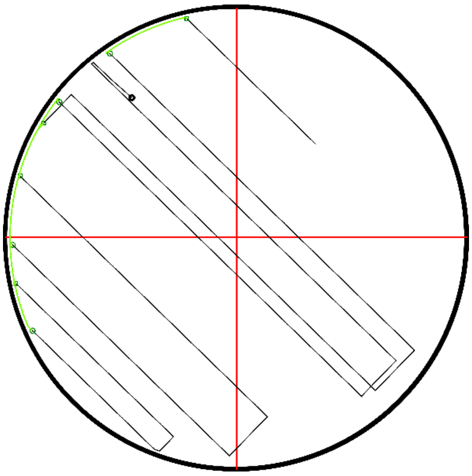


Figure 16: Test subject 2, trial 10.

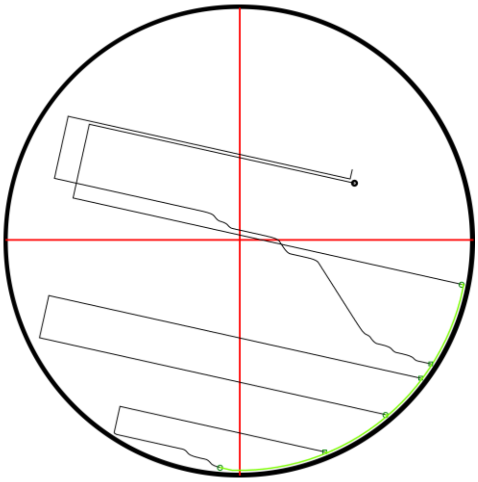


Figure 17: Test participant 2, trial 7

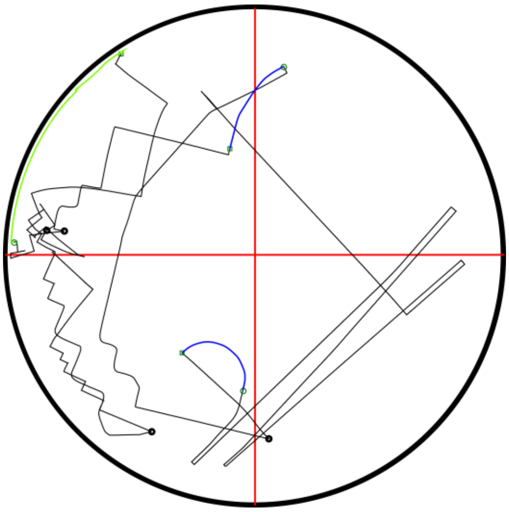


Figure 18: Test participant 10, trial 7.

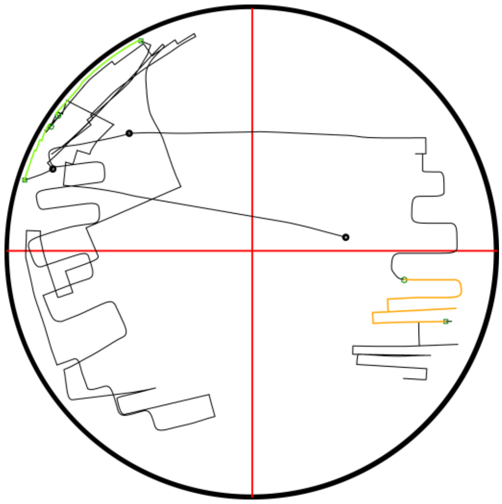


Figure 19: Test participant 10, trial 8

6.4 Circling

Circling was identified both within the qualitative and the automated analysis. In Figure 20 are shown four examples of identified circling strategies, all of which had identified circling strategies in both the automated and qualitative categorization. In test participant 2, trial 3 (first to the right) we see that the circling strategies are separated by smaller line segments in the automated analysis. These segments were included in the qualitative analysis. Similarly, in participant 3's trial 7, the whole line segment, excluding the very straight path going from the start point in a north-west direction, was all considered circling strategy. While the trial was included as a circling strategy, in the automated condition, only a small segment of path lived up to the criteria in the algorithm.

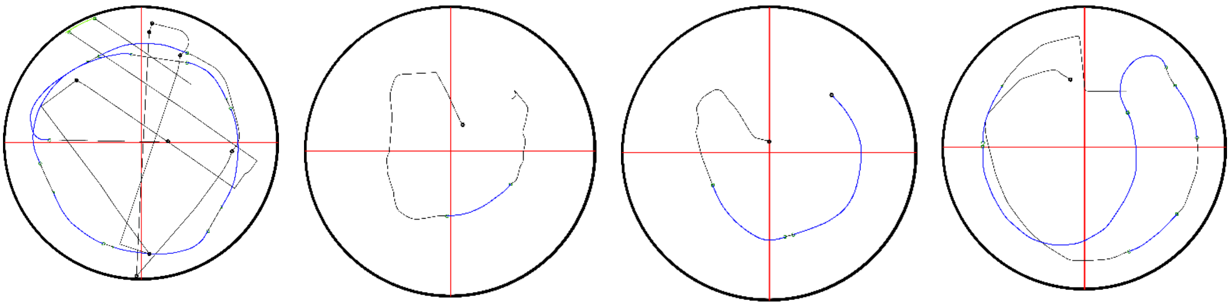
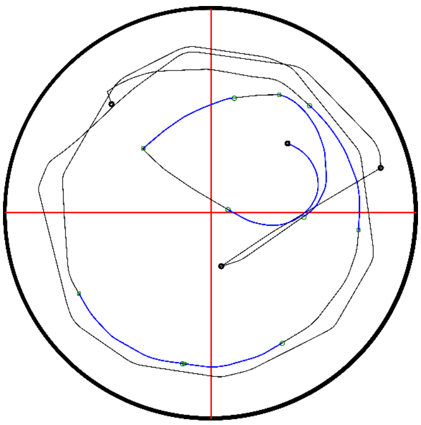


Figure 20: A number of automatically identified circling strategies, starting from the top right corner: Test person 2, trial 3. Test person 3, trial 7. Test person 3, trial 8. Test person 5, trial 8.

The automated categorization was less forgiving for irregularities in the general path than the qualitative analysis here. This can also be seen in the two trials to the right in Figure 20. The qualitative analysis included more or less the whole of these path segments as circling, whereas the automated categorization has excluded segments as not being curved.



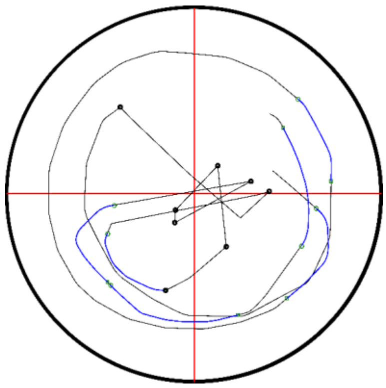


Figure 21: Test subject 13, trial 9. Circling strategies are highlighted with blue from the quantitative analysis.

Figure 22: Test subject 13, trial 7. Circling strategies are highlighted with blue from the quantitative analysis.

Figure 17 and Figure 18 showed a marked difference between the qualitative and the automated analysis. While the path that follows the circumference of the maze in these two trials were categorized as circling strategies within the qualitative method, the automated method does not include a large part of these paths as strategy. The person here has moved in a straight line, adjusted direction, then moved in a straight line again, which overall forms a something close to a circle, put the individual segments themselves are not arched and therefore are not included by the automated categorization.

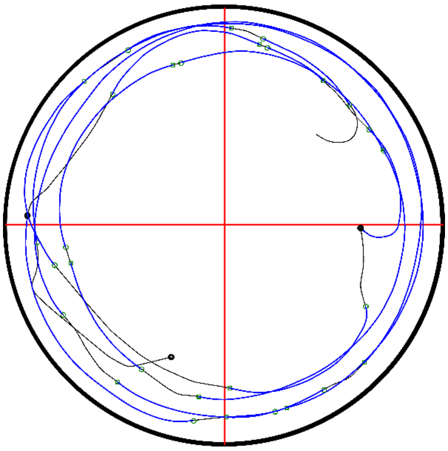


Figure 23: Test participant 7, trial 6.

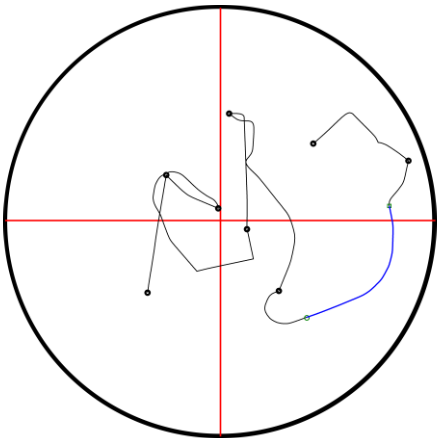
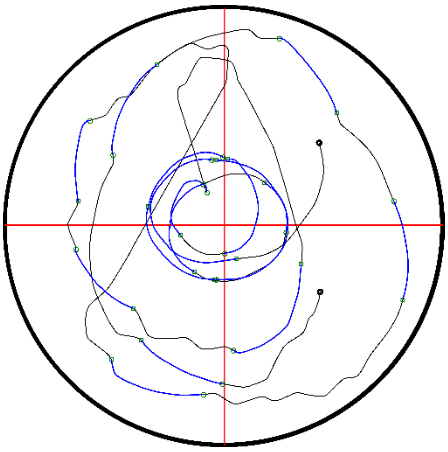


Figure 24: Test participant 20, trial 3.

Comparing the above-mentioned examples with the trial in Figure 23, the participant walked in a circle surrounding the circumference that was included in the automated process because the curve was more regular. The automated categorization also included some path segments that were not considered to be circling strategies in the qualitative analysis. In the case of Figure 24 they were not considered circling because the arch was too short.

Some trials were categorized with circling, where the arches themselves were tightly wound, relatively to the other circling strategies, as can be seen Figure 25 and Figure 26. It should be considered whether these should be categorized as such, and what the different then is between enfilading and circling in these examples.



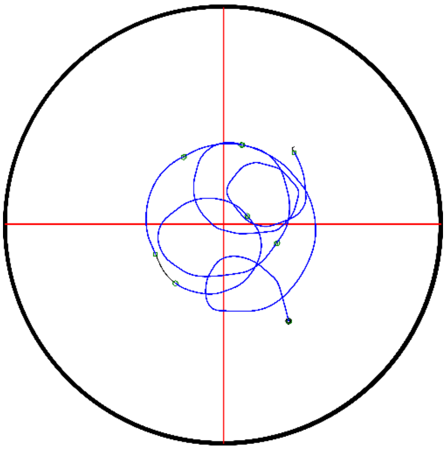
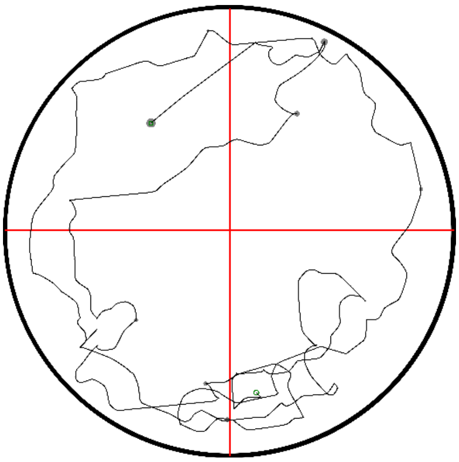


Figure 25: Test participant 19, trial 5.

Figure 26: Test participant 19, trial 6.

6.5 *Other patterns.*

There were some paths that approximated a circling strategy, but inconsistencies in the path excluded them as a pure circling strategy. In Figure 27 the lower part of the path looked quite close to a circling strategy, however the general path in the arch looked like the person had been pressing the controls right and left, making the path almost “bumpy”. On the other hand, Figure 28 was not considered to the same extend as a possible circling strategy, because of how irregular it was, however it was still noted as a strategy that spanned the perimeter.



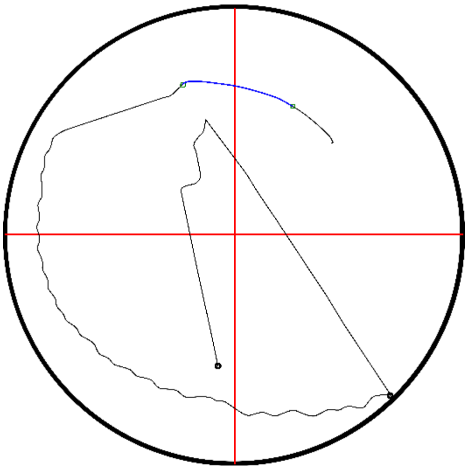


Figure 28: Test participant 15, trial 6.

Figure 27: Test participant 19, trial 3

There were participants that displayed seemingly consistently used strategies, and particular ways they interacted with the environment. One participant consistently crossed back and forth across the span of the maze, similar to a zigzag pattern (see Figure 29 and Figure 30). A repeating pattern of behavior with a type of zig zag like movement, similar to the one described by Kallai et al (2005). Generally, it consisted of movement that went from one wall to the other along one axis, and then a movement upwards or downwards in the same direction.

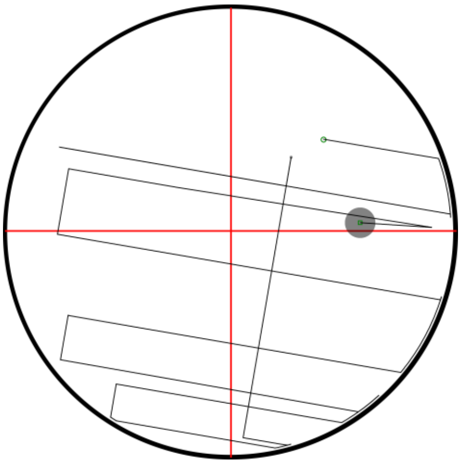


Figure 29: Participant 2, trial 4.

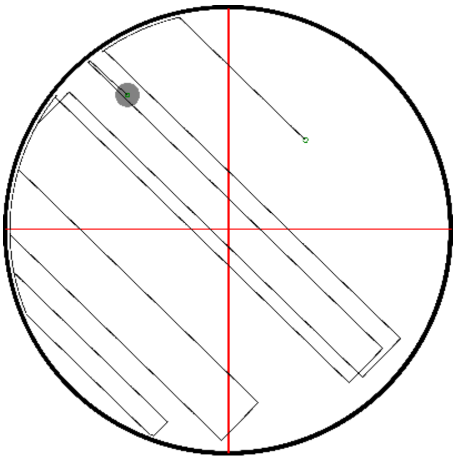


Figure 30: Participant 2, trial 10.

Participant 10, as can be seen in Figure 31, showed a similar pattern. The participant consistently crossed the maze in a pattern, where the person went back and forth with an arched turn at the end. Participant 18 on the other hand seemed to have a particular pattern as well, where the user often retraced the previous path (see Figure 32). Participant 1 had a path that was generally very square, in the sense that many of the turns made were at an approximately 90-degree angle, indicating that they had a particular way of interacting with the computer.

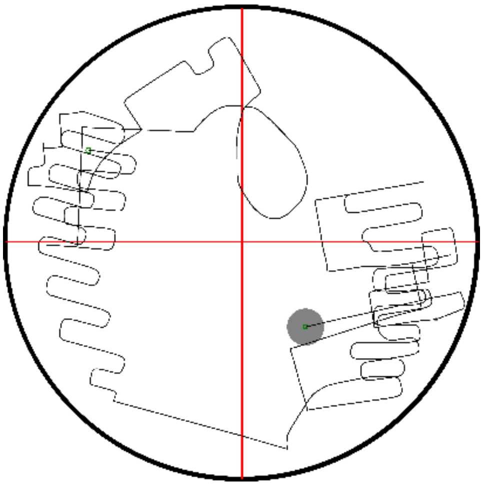


Figure 31: Participant 10, trial 8.

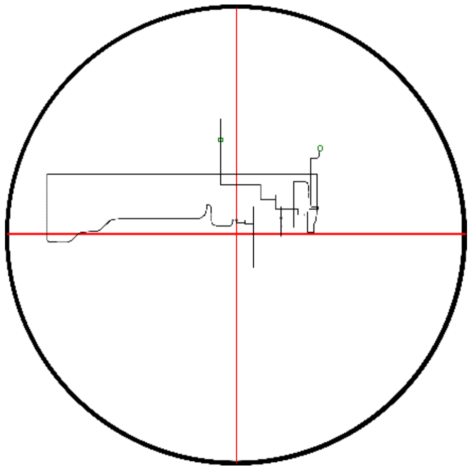


Figure 32: Participant 18, trial 3.

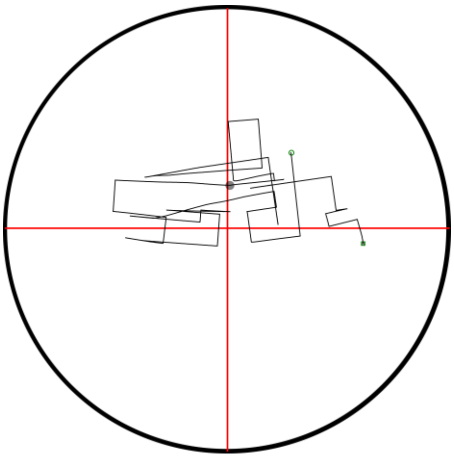


Figure 33: Tests participant 1, trial 6. Displayed at particular pattern where change in trajectory was done at close to a 90 degree angle

7 Discussion

This study was able to identify all of the mentioned strategies within the original study by Kallai et al. (2005), and by comparing a method of qualitative categorization with an automated, quantitative categorization method it has attempted to highlight some conceptual difficulties within categorization of spatial strategies, and intentional behavior in general. These difficulties will be discussed in the following section.

7.1 Categorization of paths

It was possible to identify the presence of these strategies defined within the original study, however, it required the specification of the categories and defining specific perimeters to evaluate the patterns against. It should be discussed, whether the strategies align with the ones identified within the original study, both when it comes to the qualitative and automated condition.

With virtual maze methods, it is possible to collect very accurate, and very complex data on individuals' behavior within the virtual environment. The problem after collecting all this data then becomes how we can accurately process it and evaluate it. A study like Kallai et al.'s (2005) depend on the premise that we can accurately, and with some degree of objectivity, categorize strategy types from collected information about individual's movement within a maze. As the result show however, how accurately this categorization is can depend a lot on a variety of factors.

One major factor that influences the ability to categorize consistently and transparently is the initial category description. The more specific and precise a category description is, the easier it is to transfer and replicate. Enfilading for example, was a strategy that was rather difficult to identify, even within the qualitative description, as the category definition was rather vague. It was both defined as a zig-zag like pattern, though it was not explicated just how like a zig-zag pattern it had to be to actually be considered enfilading, and as a pattern where you had a certain amount of movement within a limited amount of space. In the case of both definitions, no measurable criteria was given that made it possible to evaluate if a pattern was enough of a “zig-zag” to be considered a pattern, or if the area was too large, or the amount of movement too small to be considered enfilading. Given that, the definition itself seemed unclear, and the theoretical argument for the enfilading pattern, it was assumed within this study that the strategy itself was a clustering problem, in other words the latter definition, that subjects performed a certain amount of transitional movement within a bounded area. This definition also made it possible to describe it with transparent parameters such as a radius of the area and minimum path length within the area. The lack of specification from the original study makes it particularly difficult to secure that analysis is done on the same premise as the original study, and that categories are applied in a consistent way to the original study. An algorithm was used to analyze the majority of data, which forced the need to explicitly state some specific criteria for the analysis. Qualitative analysis allows for broader inclusion, and analyzing data like these allows for greater variability in face of how curves and similar forms may vary in in their slope and general progression.

The challenge with the qualitative evaluation of strategies is also its strength in many ways. As we are trying to identify somewhat complex behaviors, it follows that not all categories lend themselves easily to simple definitions and criteria, and even if we try to describe these strategies within rigid parameters, we may lose what was otherwise the essence of the behavior. At least, what is assumed to be the essence. This relates to the problem of inferring intention from behavior, and the central problem within most of psychological study of how we cannot directly observe cognitive processes, and instead are left with behavioral data to assume some internal process from.

Circling strategies was an example of a pattern, where the qualitative analysis categorized patterns as being within this strategy, and the case could certainly be made that the general progression of the overall path was in a curve like form. In the automated analysis however, some of these patterns that otherwise looked circular were not categorized as such, because the minute relationships between points did not follow a curve. One path section for example (see 6.4) overall looked like a curve, but the person had walked in a straight line, then adjusted her trajectory, and then continued in a straight line. While overall, the pattern became circle like, the person mostly walked straight. It could be argued that this path section should still be considered a curve, and that it was a flaw to the automated categorization method that it did not include it, however that again falls to the definition of that category. Conceptually, patterns may be more or less pure in that way, in terms of how well they fit within the specific category; however it is difficult to determine what is the "true" strategy, as it entirely depends on how specifically we evaluate its validity. Is it dependent on the behavioral coherence, or on its reflection of some cognitive process?

A related problem to this is how we isolate minute or molar behaviors from a sequence of behavioral data. Again, the example with the circling strategies illustrated the problem that in the case where, for example, a person has shifted from a circling strategy to simply walking straight and then shifting into a circling strategy again, due to the nature of curves, a situation like this would be considered one circling strategy within the qualitative analysis (see 6.4). There are no objective and clear ways to identify where one behavior begins and one ends, as it all depends on the perceived coherence of that particular part of a long string of behavior.

To this point as well arises the problem that the different strategies are very alike in two cases, and in the other two, very different. There is a big difference between Visual Scan strategies, where the only real criteria is that a person stands still and does a turn above 20 degrees, and circling where transitional movement follows in an arc like path. Compare this to the difference between circling and thigmotaxis, however, where the difference especially in this small enclosure size and type is quite small. One particular problem in designing the algorithm for identifying these strategies automatically was how closely related thigmotaxis and circling was to each other in terms of the general behavior. If the enclosure size was changed, and the person was performing the exact same route, what would have previously been thigmotaxic strategies would now be circling strategies instead, because of the particular design of the maze. This would not be true if the maze was square. A broader point is that different strategies depend on different relational factors. Enfilading for example is defined in such a way, that classifying it would not depend on the specific space it was performed in. Whether the maze was round, square, start-shaped or any other feasible shape you would still be able categorize enfilading according to the same criteria. The same could not be stated for thigmotaxis, as stated above, because the category relates specifically to the design of the environment. Thigmotaxic behavior in a square maze would therefore be a square path, whereas it here is round. Circling can also be discussed whether this really is universal to all open field maze types or if it instead would have to be adapted to include behaviors that traversed the span of the maze environment in a similar way to circling in a round maze. This of course depends on whether one considers the act of walking in a circular motion specifically to be important, or whether circling instead is essentially a behavior about moving around the maze within a trajectory that follows the shape of the space. Therefore, strategies are not the same, or defined in the same way, and therefore they may have descriptions and perimeters that are quite context specific, but are treated as essential categorical descriptions. This also begs the question of how we can generalize across different studies that perhaps rely on other types of maze designs, and how contextually driven these behaviors are.

It is important to note, that there is a difference between a categorization method that is quantified and then one that is automated. Automated categorization necessitates quantifiable parameters that data points can be evaluated against, however, quantitative evaluation does not necessarily need to be carried out by a computer. For example, the premise set for visual scan can be analyzed by hand, though the process would without a doubt take quite a long time. Enfilading on the other hand in its original definition fails to be quantified, because the original study does not specify measurable criteria, such as the how small the area needs to be, or how much movement there needs to be. A computer cannot readily deal with this, and while it can be done in a qualitative fashion, the specific criteria is left to the intuition of the individual. Without consistent criteria to evaluate these patterns against, even if we use qualitative methods, the analysis would be incredibly variable in their outcome.

7.2 Strategies and their underlying construct.

There is an assumed relationship between the mentioned strategies, and some cognitive process, and it is therefore relevant to discuss the strategies that have been identified, not just in terms of their behavioral description, but also in terms of their assumed, underlying process.

The different strategies have as mentioned, been related to assumed underlying processes, which infers ultimately, some cognitive purpose for these specific types of behavior. Visual scan for example, while the definition may be rather simple, as it only involves a standing still and then making a turn, as a construct denotes the underlying strategy to be a way for assessing the surroundings and assessing its input (see 3.4). Similarly, it is argued that circling strategies and thigmotaxic strategies serve the purpose of surveying the parameter, and possibly linking this to a stable spatial cue, which would be the wall, in the case of thigmotaxis (see 3.4).

What should be considered then is the difference between evaluating a strategy from the outset of an underlying cognitive process, and then evaluating a strategy from its behavioral coherence, as they are two different premises for that evaluation. In other words, there is a difference between describing the behavior and then the underlying construct. Say a participant walked, then stopped did a 20-degree turn, then walked on. One person may have used that 20-degree turn, and actively looked around the surrounding area; another may simply have focused on making a turn to avoid a wall. Some may have been distracted from the surrounding room, though this scenario was sought minimized by placing individuals in a soundproof room during testing. The point is for all these examples, the behavior may be the same, but the underlying process and the general context will be very different. This is a fundamental problem in inferring cognitive processes or mental states in general purely from behavioral data. One option that could give researchers a better idea of the cognitive processes, is the use individuals' self-report on their own behavior, either live during testing, or retrospectively after a test is done. This would not be perfect necessarily, if we assume that some underlying strategies are not consciously reflected upon, however it would be additional data that could give a better idea of the context of that person in that situation.

Another thing to consider in relation to this is that there may be a plan in the mind of the participant, but between thinking of a strategy, implementing that strategy, and then executing it into actual behavior, things could go wrong in that process. Strategies could be poorly executed, or poorly conceived, and in addition to this, behavior may just be random or accidently fall into these strategy types. We are not machines and do not execute code without failure, not only that, humans are notoriously good at changing their minds halfway through an action. That is to say, cognition and behavior may not be as directly linked as spatial strategies imply them to be.

There is a difference between asking the question “can this specific type of behavior be recognized” and “can this type of cognitive strategy be recognized”. Visual scan was a particular concern here for the above-mentioned reasons. Since there were no real criteria set for what counted as standing still, it was left as an intuitive decision what that lower boundary would be. Setting up criteria inevitably leaves you with the question of whether those criteria are too high or too low. If set to high, in the case of visual scan, it would sort out people who had been looking around for a good period of time, on the other hand, if set too low, the criteria would also include individuals who simply take slow turns.

Similarly, in the automated condition, come paths were left out of the circling strategies, either because they were too straight, or because the overall path was irregular. This method has no guarantee that these paths were not the same, in case of the cognitive strategy, only that they did not fit with the predefined behavioral definitions. This is the major challenge, which does not necessarily come from the process being automated, but rather through the formalization of category definitions.

7.3 Design and method

This study tried to recreate the maze procedure used in the original study from scratch, and therefore much consideration was put into the process of replicating the experimental design. The following section will discuss the implications of this, as well as the measures taken in the original study to communicate in a transparent way.

7.3.1 The maze

As previously stated, this paper tried to recreate the design of the original study to the best of ability from the information provided within the article, and this included programming and designing the virtual maze that was used in the original study.

For a study to be replicable, information about the practical implementation of a study must be clearly and precisely communicated, as far as the details are relevant to a replication. In a study like this, which relies on a complicated piece of software and 3D model, that executes a large part of the actual practical implementation of the study transparency becomes only more important. In this replication, many decisions in regards to how the maze was designed, both in terms of its 3D model, and in terms of its algorithm were decided arbitrarily as a best guess, since there was limited available information in the original study, and no general guidelines exist for determining latency specifications between trials or general behavior within maze settings. In this study, participants were shown a 2 second latency window between trials, both to communicate that they had completed a trial, and that they were about to start a new one. One concern was that too long a latency would feel frustrating to the participants, and on the other hand, too short a latency would perhaps cause some test subjects to feel disoriented. The structure and nature of cues as another example, was only described as a distinctive set of arches and windows, which in this study was interpreted as holes in the outer wall area in the shape of doors and windows, that were arranged in distinctive sequences in each wall. Details such as the design of cues in these types of studies can have an influence on the resulting performance, as it has been noted before that cues and landmarks are not necessarily equal in their level of salience (see 4). To only be able to approximate what was done in the original study then in this case can influence performance in unpredictable ways.

When such things as how the maze was textured, and how the design was arranged are not explicitly detailed, it can be difficult to argue that a replication is pure to the original study, and it becomes hard to both verify and falsify any given hypothesis, as we cannot account for this difference. The study is from 2005 (Kallai et al., 2005), so it would only be fair to point out that the use of simulation tools in research was not as broadly available, meaning that the method for communicating clearly about simulation dependent studies were not as developed either. Endeavors towards sharing more of the information surrounding the context of a study are fairly recently become a concern within the scientific community (see 23), and the field in general have moved a long way over the past 10 years. Nevertheless, these are important details to any researcher that would seek to replicate a study of this form. In this paper, an attempt has been made to communicate the choices in terms of the maze design, both by documenting through pictures of the maze, the specifications of the maze, as well as the maze algorithm, in an attempt to transparently illustrate what was done in this replication study. The difficulty with transparency is that communicating a context is near impossible to do in full detail. Naturally, any author of a study must select what details are relevant and which are not. When developing a program however, as opposed to doing a design in real life, there are many things, even if they seem small, that the developer or researcher actively has to make explicit decisions on. In real life, this may depend on a variety of different factor we cannot account for. In the environment on the computer, however these are decision, as it cannot be left to chance how long the program takes between ending and starting a new trial, or the exact sequence of events that should happen when a participant crosses the platform. Of course, one argument for the benefit of computer-supported studies like these is the added control of even minute details within the environment, however this also means that even the minute details to some extend become part of the experimental design.

A detail such as what exactly is going to happen once the person finds the platform has to be specifically designed. In the case of this maze, the platform was revealed when the person stepped over the platform, and if the person then stood on the platform for more than 5 seconds, the trial end sequence was started. It was not clear how the original study tackled this situation. Two initial models were considered within the design of this maze, the first being the one described above, the second using a commonly implemented choice button, or activation button, which would be pressed when individuals thought they had found the platform. This second model was discarded, because it setup the condition as a guess that the test participants had to make, as opposed to the original maze from the animal models, where the platform was submerged and rodents found the platform by bumping into it more or less. It illustrates however, that small changes in the maze may change the premise of the study, and therefore change the study to such a degree that it is no longer replicating the same processes as the original study.

Input design and artifacts in data.

In the Kallai et. al.'s (2005) study, a joystick was used to perform the behavior within the maze, whereas in this study, a standard keyboard and mouse was used instead. The reason for this choice was two-fold: joysticks are not widely available, and not widely used. It is currently a niche product that few participants would actually have tried using for any extended period of time, and people who would be familiar with it, would possibly be people who play games on a regular basis. It was therefore of concern that joysticks may provide unfair advantages to people coming from a particular background and interest. A computer mouse and keyboard on the other hand are common consumer products that most have experience using today, and therefore, test subjects would not have the same need to familiarize themselves with the controls, as they already would be familiar, with at least the general premise of using these devices. In retrospect, this may have influenced the data, as there were many path sections within this study that displayed a perfectly straight path. This was perhaps due to the particular way that navigation works on keyboards relative to joysticks. On keyboards, you typically have the choice of four buttons that will transport your viewpoint in one of four direction: Forwards, backwards, right or left. Combining these buttons will adjust this trajectory. On joysticks however, users are often moving a pin in any of 360 degrees, and the upkeep of the path direction is dependent on whether you hold this pin in the same direction for the extent of the movement. It is arguably more difficult with a joystick to create perfectly straight paths than with keyboard, and it may be an artifact of the particular input design that particular paths look the way they do.

Another particularity, which may have been influenced by the use of a specific input device, is visual scan. In the original study, as it used a joystick, it is reasonable to assume that all movement was mapped onto the one device. In other words, transitional movement and movement around the personal axis would depend entirely on the global movement of the joystick. Some joystick types have local, smaller analog sticks on top however, so it is not clear whether this is the case. If movement and turning was mapped without an analog stick, pushing the joystick ahead would most likely cause movement whereas pushing the stick in either the left or right direction would cause a turn. In other words, there is no separation between head-movement and body movement, as there is with a keyboard and mouse. Mapping transitional and head-rotation to different devices would give more freedom in terms of walking and looking around at the same time. With the category of visual scan, this may have influenced how useful the category description is, as the mapping on the keyboard and mouse afforded turns in the viewpoint in very different ways, and possibly gave the opportunity to do 20-degree turns in a very short time, due to the turning not fitting accurately to the original study's. It could be questioned whether the need for specific visual scan strategies are more dependent on the input device as well. If you cannot readily adjust your viewpoint without also influencing the trajectory of your movement is may force visual scan strategies to be used differently than if you can walk and look around freely within the maze.

All in all, it should be considered in designing studies like these, whether certain input devices afford behavior within the environment in different ways, which could mean that certain strategies as they are described in the original study, may be a result of the interaction with the technology rather than cognitive processes. This is not conclusive evidence to either discredit or support this hypothesis, however it is a topic that would be highly relevant to elaborate on through further study in the future. Comparison between input types and understanding how input devices, and the technology at large, influence the person's ability to act within the environment could help future researchers isolate effects of the specific design, and effects of the specific process being studied.

7.4 Ecology of virtual methods

One concern related to the use of virtual methods is whether they can be considered ecologically viable and representative of real life processes. It should be noted that this is a relative question, as that really depends on what we compare the specific method to. The evaluation of virtual methods, especially in lending from virtual reality literature, highlights a variety of factors that must be considered when evaluating a system's realism in and of itself. There is a major difference between a method such as this, where individuals are placed in a room that they then can navigate in freely, and virtual methods where, that may not allow free movement, or may have more encompassing output technologies such as head-mounted displays. Virtual methods as a concept is an umbrella term that includes a variety of different software and hardware models of differing quality and level of realism. With that being said, there are still some overarching considerations that hold true for most virtual methods.

Moving beyond the specific study and its method, it should be considered whether virtual methods in general simulate real life experience, or if they are instead contingent on specific processes themselves. Research using virtual methods implicitly assume that the processes that are engaged in the virtual environment mimics the processes of the real-life situation that the virtual environment tries to simulate. This is not a given however, there may very well be specific processes that are engaged when performing behavior within a virtual environment.

Another thing to consider is whether adjustments in the rendering of graphics, or the implementation of different types of hardware may increase or decrease the overall ecology of a method. Say for example if this study implemented a head-mounted display, would that make the method more ecological? Or are head-mounted displays a separate thing from regular displays? There seems to be some agreement that realism, places software and hardware implementations along a scale of more or less realistic, which increases or decreases, depending on both the sheer quantity of sensory inputs that are simulated, and the quality of each category of simulation. In the case of this study then, we simulated visual input mainly, and to some extend motor action. Comparing these to the extremes, such as head-mounted displays with motion trackers where individuals can walk around with some degree of freedom, it is clear from this assumption, that the applied method is comparatively less ecological than these newly available technologies. Similarly, if we compare to a method where the environment wasn't animated but instead stills that were shown to the subject, or where you couldn't freely move within the environment, the applied method would be comparatively better, than this thought example. It becomes rather difficult however if we were to compare what the difference in ecology between using a mouse and a joystick. Neither of these two really approach natural movement in a noticeably different way, however they are still built around different types of interaction.

Either way, we do not fully understand the extend to which virtual simulations relate to the context they try to simulate, however it would be relevant as a topic for further research, how specifically virtual methods can support research, and where we need to beware of their validity as well. Essentially, it is a question of how these methods can be used to detect behavior, and whether that behavior is meaningful beyond the context of that virtual setting.

8 Conclusion

This study has sought to elucidate whether and how it is possible to reliably and validly record, detect and classify cognitive strategies from virtual maze methods. This study has shown that given specific criteria descriptions, it is feasible to make evaluations with some degree of consistency, however, as has been discussed in this paper, many difficulties arise from unclear and non-specific category descriptions, both in the case of qualitative and automated categorization procedures. Transparency is key to assuring that categorizations of such complex data is done in valid and reliable way, and that category descriptions are correctly interpreted between researchers.

It is difficult however to ascertain whether specific behaviors relate to specific cognitive strategies, as strategies can both be poorly executed, and behavior can be accidentally strategic. This means that there are many factors still to be aware of, that simply analyzing behavioral data can't account for. One proposed method to help this is self-report, and the use of either live or retrospective feedback from participants on their thoughts during navigation tasks.

Lastly, the literature cannot currently account for how strategies from within maze methods, generalize outside of this specific context, and neither can virtual methods. There is still the question, of how much of the measured behavior is on account of environmental factors or artefacts of the virtual method used. Clarifying these relationships in the future will possibly make it easier, both for researchers to make choices that minimize these influences, and account for it in their data.

9 References

An Open, Large-Scale, Collaborative Effort to Estimate the Reproducibility of Psychological Science. (2012). *Perspectives on Psychological Science, 7*(6), 657–660. https://doi.org/10.1177/1745691612462588

Bennett, A. T. D. (1996). Do Animals Have Cognitive Maps? *The Journal of Experimental Biology, 199*, 219–224. Retrieved from http://jeb.biologists.org/content/jexbio/199/1/219.full.pdf

Bertholet, L., Escobar, M. T., Depré, M., Chavan, C. F., Giuliani, F., Verrier, P. G., … Schenk, F. (2015). Spatial radial maze procedures and setups to dissociate local and distal relational spatial frameworks in humans. *Journal of Neuroscience Methods, 253*, 126–141. https://doi.org/10.1016/j.jneumeth.2015.06.012

Boolsen, M. W., & Jacobsen, M. H. (2010). Positivisme. In M. H. Jacobsen, K. Lippert-Rasmussen, & P. Nedergaard (Eds.), *Videnskabsteori i statskundskab.* (1., pp. 55–85). Copenhagen: Hans Rietzels Forlag.

Bowman, D. A., & McMahan, R. P. (2007). Virtual Reality: How Much Immersion Is Enough? *Computer, 40*(7), 36–43. https://doi.org/10.1109/MC.2007.257

Burgess, N. (2006). Spatial memory: how egocentric and allocentric combine. *Trends in Cognitive Sciences, 10*(12), 551–557. https://doi.org/10.1016/j.tics.2006.10.005

Burgess, N. (2008). Spatial cognition and the brain. *Annals of the New York Academy of Sciences, 1124*, 77–97. https://doi.org/10.1196/annals.1440.002

Burgess, N., Jeffery, K. J., & O'Keefe, J. (Eds.). (1999). *The Hippocampal and Parietal Foundations of Spatial Cognition*. New York: Oxford Press.

Byrne, P., Becker, S., & Burgess, N. (2007). Remembering the past and imagining the future: a neural model of spatial memory and imagery. *Psychological Review, 114*(2), 340–375. https://doi.org/10.1037/0033-295X.114.2.340

Chalmers, D. J. (2010). *The character of consciousness*. Oxford University Press.

Cheng, K. (2005). Reflections on geometry and navigation. *Connection Science, 17*(1–2), 5–21. https://doi.org/10.1080/09540090500138077

Cheng, K., & Newcombe, N. S. (2005). Is there a geometric module for spatial orientation? Squaring theory and evidence. *Psychonomic Bulletin & Review, 12*(1), 1–23. https://doi.org/10.3758/BF03196346

Chersi, F., & Burgess, N. (2015). The Cognitive Architecture of Spatial Navigation:

Hippocampal and Striatal Contributions. *Neuron*, *88*(1), 64–77. https://doi.org/10.1016/j.neuron.2015.09.021

Churchland, P. M. (1981). Eliminative Materialism and the Propositional Attitudes. *The Journal of Philosophy*, *78*(2), 67–90.

Clark, A., & Toribio, J. (1994). Doing without Representing? *Synthese*, *101*(3), 401–431. https://doi.org/10.1007/BF01063896

Cogné, M., Taillade, M., N'Kaoua, B., Tarruella, A., Klinger, E., Larrue, F., … Sorita, E. (2017). The contribution of virtual reality to the diagnosis of spatial navigation disorders and to the study of the role of navigational aids: A systematic literature review. *Annals of Physical and Rehabilitation Medicine*, *60*(3), 164–176. https://doi.org/10.1016/j.rehab.2015.12.004

Cohen, R., & Schuepfer, T. (1980). The Representation of Landmarks and Routes. *Child Development*, *51*(4), 1065–1071. https://doi.org/10.1111/j.1467-8624.1980.tb02654.x

Creed, R. P., & Miller, J. R. (1990). Interpreting animal wall-following behavior. *Experientia*, *46*, 758–761.

Danziger, K. (1980). The history of introspection reconsidered. *Journal of the History of the Behavioral Sciences*, *16*(3), 241–262. https://doi.org/10.1002/1520-6696(198007)16:3<241::AID-JHBS2300160306>3.0.CO;2-O

De-Marchis, G. P. (2013). The use of key-press, voice and mouse devices in response time researches: A comparison in low conflict tasks. *Computers in Human Behavior*, *29*(5), 1960–1970. https://doi.org/10.1016/j.chb.2013.04.010

De Finetti, B. (2017). *Theory of probability : a critical introductory treatment*. John Wiley & Sons. Retrieved from http://library.books24x7.com.zorac.aub.aau.dk/toc.aspx?site=G45VZ&bookid=132680

Dennett, D. C. (1987). *Content and Concsiousness*. *Routledge* (Vol. 70). London.

Doeller, C. F., Barry, C., & Burgess, N. (2010). Evidence for grid cells in a human memory network. *Nature*, *463*(7281), 657–661. https://doi.org/10.1038/nature08704

Erdem, U. M., Milford, M. J., & Hasselmo, M. E. (2015). A hierarchical model of goal directed navigation selects trajectories in a visual environment. *Neurobiology of Learning and Memory*, *117*, 109–121. https://doi.org/10.1016/j.nlm.2014.07.003

Farr, R. M. (1983). Wilhelm Wundt (1832-1920) and the origins of psychology as an experimental and social science. *British Journal of Social Psychology*, *22*(4), 289–301.

https://doi.org/10.1111/j.2044-8309.1983.tb00596.x

Felleman, D. J., & Van Essen, D. C. (1991). Distributed Hierarchical Processing in the Primate Cerebral Cortex. *Cerebral Cortex*, *1*, 1–47. Retrieved from http://www.cns.nyu.edu/~tony/vns/readings/felleman-vanessen-1991.pdf

Field, H. H. (1978). Mental representation. *Erkenntnis*, *13*(1), 9–61. https://doi.org/10.1007/BF00160888

Fodor, J. A., & Pylshyn, Z. W. (1988). Connectionism and cognitive architecture: A critical analysis. *Cognition*, *28*, 3–71.

Gelman, A., & Hennig, C. (2017). Beyond subjective and objective in statistics. *J. R. Stat. Soc. A*, *180*, 967–1033.

Gillner, S., & Mallot, H. A. (1998a). Navigation and Acquisition of Spatial Knowledge in a Virtual Maze. *Journal of Cognitive Neuroscience*, *10*(4), 445–463. https://doi.org/10.1162/089892998562861

Gillner, S., & Mallot, H. A. (1998b). Navigation and Acquisition of Spatial Knowledge in a Virtual Maze. *Journal of Cognitive Neuroscience*, *10*(4), 445–463. https://doi.org/10.1162/089892998562861

Giocomo, L. M., Moser, M.-B., & Moser, E. I. (2011). Computational Models of Grid Cells. *Neuron*, *71*, 589–603. Retrieved from https://ac.els-cdn.com/S0896627311006507/1-s2.0-S0896627311006507-main.pdf?_tid=ec466fb4-c8bf-11e7-b939-00000aacb360&acdnat=1510611408_f008167c0aea8d1bf5641fa4beed74ea

Glenberg, A. M., Witt, J. K., & Metcalfe, J. (2013). From the Revolution to Embodiment: 25 Years of Cognitive Psychology. *Perspectives on Psychological Science*, *8*(5), 573–585. https://doi.org/10.1177/1745691613498098

Golledge, R. G. (1978). Representing, interpreting, and using cognized environments. *Papers of the Regional Science Association*, *41*(1), 168–204. https://doi.org/10.1007/BF01936415

Golledge, R. G. (1991). Tactual strip maps as navigational aids. *Journal of Visual Impairment and Blindness*, *85*(7), 296–301. Retrieved from https://sfx.aub.aau.dk/sfxaub?_service_type=getFullTxt&artnum=&atitle=Tactual+strip+maps+as+navigational+aids&aufirst=R.G.&auinit=R.G.&auinit1=R&aulast=Golledge&date=1991&epage=301&id=doi%3A&isbn=&issn=0145482X&issue=7&pages=296-301&req.language=eng&sid=E

Gramann, K., Onton, J., Riccobon, D., Mueller, H. J., Bardins, S., & Makeig, S. (2010).

Allocentric Reference Frames during Navigation. *Journal of Cognitive Neuroscience*, *22*(12), 2836–2849. https://doi.org/10.1162/jocn.2009.21369.Human

Harris, M. A., & Wolbers, T. (2012). Ageing effects on path integration and landmark navigation. *Hippocampus*, *22*(8), 1770–1780. https://doi.org/10.1002/hipo.22011

Heft, H. (2013). Environment, cognition, and culture: Reconsidering the cognitive map. *Journal of Environmental Psychology*, *33*, 14–25. https://doi.org/10.1016/J.JENVP.2012.09.002

Hill, E. W., & Rieser, J. J. (1993). How persons with visual impairments explore novel spaces: Strategies of goo...: EBSCOhost. Retrieved May 22, 2018, from http://web.a.ebscohost.com.zorac.aub.aau.dk/ehost/detail/detail?vid=0&sid=9235bd51-1fde-41c6-a3ed-6059060b7374%40sessionmgr4010&bdata=JnNpdGU9ZWhvc3QtbGl2ZQ%3D%3D#AN=9402152739&db=aph

Hodges, H. (1996). Maze procedures: The radial-arm and water maze compared. *Cognitive Brain Research*, *3*(3–4), 167–181. https://doi.org/10.1016/0926-6410(96)00004-3

Holmes, M. C., & Sholl, M. J. (2005). Allocentric coding of object-to-object relations in overlearned and novel environments. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *31*(5), 1069–1087. https://doi.org/10.1037/0278-7393.31.5.1069

Hölscher, C., Tenbrink, T., & Wiener, J. M. (2011). Would you follow your own route description? Cognitive strategies in urban route planning. *Cognition*, *121*(2), 228–247. https://doi.org/10.1016/J.COGNITION.2011.06.005

Iachini, T., Ruggiero, G., & Ruotolo, F. (2014). Does blindness affect egocentric and allocentric frames of reference in small and large scale spaces? *Behavioural Brain Research*, *273*, 73–81. https://doi.org/10.1016/j.bbr.2014.07.032

Jeffery, K. J., & O'Keefe, J. M. (1999). Learned interaction of visual and idiothetic cues in the control of place field orientation. *Experimental Brain Research*, *127*, 151–161. Retrieved from https://link-springer-com.zorac.aub.aau.dk/content/pdf/10.1007%2Fs002210050785.pdf

Kallai, J., Makany, T., Karadi, K., & Jacobs, W. J. (2005). Spatial orientation strategies in Morris-type virtual water task for humans. *Behavioural Brain Research*, *159*(2), 187–196. https://doi.org/10.1016/j.bbr.2004.10.015

Kitchin, R. (2014). From mathematical to post-representational understandings of cartography. *Progress in Human Geography*, 1–7. https://doi.org/10.1177/0309132514562946

Kitchin, R., & Blades, M. (2002). *The Cognition of Geographic Space*. I.B Tauris.

Kitchin, R., & Dodge, M. (2007). Rethinking maps. *Progress in Human Geography*, *31*(3), 331–344. https://doi.org/10.1177/0309132507077082

Knierim, J. J., Kudrimoti, H. S., & McNaughton, B. L. (1998). Interactions Between Idiothetic Cues and External Landmarks in the Control of Place Cells and Head Direction Cells. *Journal of Neurophysiology*, *80*(1), 425–446. https://doi.org/10.1152/jn.1998.80.1.425

Kukull, W. A., & Ganguli, M. (2012). Generalizability - The trees, the forest and the low-hanging fruit. *Neurology*, *78*(23), 1886–1891.

Lapointe, J. F., Savard, P., & Vinson, N. G. (2011). A comparative study of four input devices for desktop virtual walkthroughs. *Computers in Human Behavior*, *27*(6), 2186–2191. https://doi.org/10.1016/j.chb.2011.06.014

Lever, C., Burton, S., Jeewajee, A., O'Keefe, J., & Burgess, N. (2009). Boundary Vector Cells in the Subiculum of the Hippocampal Formation. *The Journal of Neuroscience*, *29*(31), 9771–9777. https://doi.org/10.1523/JNEUROSCI.1319-09.2009

Lever, C., Wills, T., Cacucci, F., Burgess, N., & O'Keefe, J. (2002). Long-term plasticity in hippocampal place-cell representation of environmental. *NATURE*, *416*, 90–94. Retrieved from http://www.nature.com.zorac.aub.aau.dk/articles/416090a.pdf

Lingwood, J., Blades, M., Farran, E. K., Courbois, Y., & Matthews, D. (2018). Using virtual environments to investigate wayfinding in 8- to 12-year-olds and adults. *Journal of Experimental Child Psychology*, *166*, 178–189. https://doi.org/10.1016/j.jecp.2017.08.012

Maaswinkel, H., & Whishaw, I. Q. (1999). Homing with locale, taxon, and dead reckoning strategies by foraging rats: sensory hierarchy in spatial navigation. *Behavioural Brain Research*, *99*(2), 143–152. https://doi.org/10.1016/S0166-4328(98)00100-4

Malá, H., Andersen, L. G., Christensen, R. F., Felbinger, A., Hagstrøm, J., Meder, D., … Mogensen, J. (2015). Prefrontal cortex and hippocampus in behavioural flexibility and posttraumatic functional recovery: Reversal learning and set-shifting in rats. *Brain Research Bulletin*, *116*, 34–44. https://doi.org/10.1016/j.brainresbull.2015.05.006

McMahan, R. P., Gorton, D., Gresock, J., McConnell, W., & Bowman, D. A. (2006). Separating the effects of level of immersion and 3D interaction techniques. In *VRST'06* (pp. 108–111). https://doi.org/10.1145/1180495.1180518

McNamara, T. P. (1986). Mental representations of spatial relations. *Cognitive Psychology*, *18*(1), 87–121. https://doi.org/10.1016/0010-0285(86)90016-2

Miller, N. (2009). Modeling the effects of enclosure size on geometry learning. *Behavioural Processes, 80*(3), 306–313. https://doi.org/10.1016/j.beproc.2008.12.011

Mittelstaedt, M.-L., & Mittelstaedt, H. (2001). Idiothetic navigation in humans: estimation of path length. *Exp Brain Res*, *139*, 318–332. https://doi.org/10.1007/s002210100735

Mogensen, J. (2011). *Handbook of Laboratory Animal Science, Vollume II, Third Edition: Animal Models*. (J. Hau & S. J. Schapiro, Eds.) (3rd ed.). CRC Press. Retrieved from https://books.google.dk/books?hl=da&lr=&id=yk7TFvsFCBcC&oi=fnd&pg=PA47&dq=animal+models+jesper+mogensen&ots=YeI-jazmPS&sig=-H2z7hH8w3oVql-U1Uo7RizPMV8&redir_esc=y#v=onepage&q=animal models jesper mogensen&f=false

Morgan, A. (2014). Representations gone mental. *Synthese*, *191*(2), 213–244. https://doi.org/10.1007/s11229-013-0328-7

Moser, E. I., & Moser, M.-B. (2013). Grid Cells and Neural Coding in High-End Cortices. *Neuron, 80*(3), 765–774. https://doi.org/10.1016/j.neuron.2013.09.043

Nardini, M., Burgess, N., Breckenridge, K., & Atkinson, J. (2006). Differential developmental trajectories for egocentric, environmental and intrinsic frames of reference in spatial memory. *Cognition*, *101*(1), 153–172. https://doi.org/10.1016/j.cognition.2005.09.005

Newcombe, N. S., & Huttenlocher, J. (2007). Development of Spatial Cognition. In *Handbook of Child Psychology*. Hoboken, NJ, USA: John Wiley & Sons, Inc. https://doi.org/10.1002/9780470147658.chpsy0217

O'Keefe, J., & Dostrovsky, J. (1971). The hippocampus as a spatial map. Preliminary evidence from unit activity in the freely-moving rat. *Brain Research*, *34*(1), 171–175. https://doi.org/10.1016/0006-8993(71)90358-1

O'Keefe, J., & Nadel, L. (1978). *The Hippocampus as a Cognitive Map*. *Journal of Chemical Information and Modeling* (Vol. 53). https://doi.org/10.1017/CBO9781107415324.004

Overgaard, M., & Mogensen, J. (2017). An integrative view on consciousness and introspection. *Review of Philosophy and Psychology*, *8*(1), 129–141. https://doi.org/10.1007/s13164-016-0303-6

Paul, C. M., Magda, G., & Abel, S. (2009). Spatial memory: Theoretical basis and comparative review on experimental methods in rodents. *Behavioural Brain Research*, *203*(2), 151–164. https://doi.org/10.1016/j.bbr.2009.05.022

Pazzaglia, F., & De Beni, R. (2001). Strategies of processing spatial information in survey and landmark-centred individuals. *European Journal of Cognitive Psychology*, *13*(4), 439–508.

https://doi.org/10.1080/09541440042000124
Pedersen, J. M. (2011). Tysk eksperimentalpsykologi of strukturalisme. In B. Karpatschof & B. Katzenelson (Eds.), *Klassisk of moderne psykologisk teori* (2nd ed., pp. 13–39). Copenhagen: Hans Rietzels Forlag.
Popper, K. R. (1935). *The Logic of Scientific Discovery*. *2005*. New York: Routledge. https://doi.org/10.1016/S0016-0032(59)90407-7
Pressley, M., Woloshyn, V., Lysynchuk, L. M., Martin, V., Wood, E., & Willoughby, T. (1990). A primer of research on cognitive strategy instruction: The important issues and how to address them. *Educational Psychology Review*, *2*(1), 1–58. https://doi.org/10.1007/BF01323528
Questienne, L., van Dijck, J.-P., & Gevers, W. (2018). Introspection of subjective feelings is sensitive and specific. *Journal of Experimental Psychology: Human Perception and Performance*, *44*(2), 215–225. https://doi.org/10.1037/xhp0000437
Rogers, J., Churilov, L., Hannan, A. J., & Renoir, T. (2017). Search strategy selection in the Morris water maze indicates allocentric map formation during learning that underpins spatial memory formation. *Neurobiology of Learning and Memory*, *139*, 37–49. https://doi.org/10.1016/j.nlm.2016.12.007
Rusconi, M. L., Morganti, F., & Paladino, A. (2008). Long-lasting topographical disorientation in new environments. https://doi.org/10.1016/j.jns.2008.06.015
Sanchez-Vives, M. V., & Slater, M. (2005). Opinion: From presence to consciousness through virtual reality. *Nature Reviews Neuroscience*, *6*(4), 332–339. https://doi.org/10.1038/nrn1651
Schwitzgebel, E. (2002). Why did we think we dreamed in black and white? *Stud. Hist. Phil. Sci*, *33*, 649–660. Retrieved from www.elsevier.com/locate/shpsa
Searle, J. (2009). Chinese room argument. *Scholarpedia*, *4*(8), 3100. https://doi.org/10.4249/scholarpedia.3100
Shimizu, H. (2002). Measuring keyboard response delays by comparing keyboard and joystick inputs. *Behavior Research Methods, Instruments, & Computers*, *34*(2), 250–256. https://doi.org/10.3758/BF03195452
Siegel, A. W., & White, S. H. (1975). The development of spatial representations of large-scale environments. *Advances in Child Development and Behavior*, *10*(C), 9–55. https://doi.org/10.1016/S0065-2407(08)60007-5

Simon, P., Dupuis, R., & Constentin, J. (1994). Thigmotaxis as an index of anxiety in mice. Influence of dopaminergic transmission. *Behavioural Brain Research*, *61*(1), 59–64.

Skovlund, H. (2011). Amerikansk funktionalisme. In B. Karpatschof & B. Katzenelson (Eds.), *Klassisk of moderne psykologisk teoril* (2nd ed., pp. 39–61). Copenhagen: Hans Rietzels Forlag.

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

Sturz, B. R., Bell, Z. K., & Bodily, K. D. (2017). Environmental Scaling Influences the Use of Local but Not Global Geometric Cues During Spatial Reorientation. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. https://doi.org/10.1037/xlm0000510

Sturz, B. R., Forloines, M. R., & Bodily, K. D. (2012). Enclosure size and the use of local and global geometric cues for reorientation. *Psychon Bull Rev*, *19*, 270–276. https://doi.org/10.3758/s13423-011-0195-5

Tarr, M. J., & Warren, W. H. (2002). Virtual reality in behavioral neuroscience and beyond. *Nature Neuroscience*, *5*, 1089–1092. https://doi.org/10.1038/nn948

Taube, J. S. (1998). HEAD DIRECTION CELLS AND THE NEUROPHYSIOLOGICAL BASIS FOR A SENSE OF DIRECTION. *Progress in Neurobiology*, *55*, 225–256. Retrieved from https://ac.els-cdn.com/S0301008298000045/1-s2.0-S0301008298000045-main.pdf?_tid=19073b1e-a50c-11e7-a010-00000aacb360&acdnat=1506685892_6ea78ca6c790eeff98555b2fa2d2c812

Taylor, H. A., & Tversky, B. (1996). Perspective in Spatial Descriptions. *Journal of Memory and Language*, *35*, 371–391. Retrieved from https://www.tc.columbia.edu/faculty/bt2158/faculty-profile/files/aylor_Tversky_Perspectiveinspatialdescriptions.pdf

Tolman, E. C. (1948). Cognitive maps in rats and men. *Psychological Review*, *55*(4), 189–208. https://doi.org/10.1037/h0061626

Tom, A. C., & Tversky, B. (2012). Remembering Routes: Streets and Landmarks. *Applied Cognitive Psychology*, *26*(2), 182–193. https://doi.org/10.1002/acp.1805

Tversky, B. (1993). *Cognitive maps, cognitive collages, and spatial mental models*. https://doi.org/10.1007/3-540-57207-4_2

Vengsgaard, K. (2010). Kritisk rationalisme. In M. H. Jacobsen, K. Lippert-Rasmussen, & P.

Nedergaard (Eds.), *Videnskabsteori i statskundskab.* (1st ed., pp. 88–117). Copenhagen: Hans Rietzels Forlag.

Vidal, M., Amorim, M. A., & Berthoz, A. (2004). Navigating in a virtual three-dimensional maze: How do egocentric and allocentric reference frames interact? *Cognitive Brain Research*, *19*(3), 244–258. https://doi.org/10.1016/j.cogbrainres.2003.12.006

Walz, N., Mühlberger, A., & Pauli, P. (2016). A Human Open Field test Reveal Thigmotaxis Related tto Agoraphobic Fear. *Biological Psychiatry*, *80*(5), 390–397.

Wang, R. F. (2016). Building a cognitive map by assembling multiple path integration systems. *Psychonomic Bulletin and Review*, *23*(3), 692–702. https://doi.org/10.3758/s13423-015-0952-y

Wang, R. F., & Spelke, E. S. (2000). Updating egocentric representations in human navigation. *Cognition*, *77*(3), 215–250. https://doi.org/10.1016/S0010-0277(00)00105-0

Wiener, J. M., Berthoz, A., & Wolbers, T. (2011). Dissociable cognitive mechanisms underlying human path integration. *Experimental Brain Research*, *208*(1), 61–71. https://doi.org/10.1007/s00221-010-2460-7

Wolbers, T. (2015). *Spatial Navigation*. *International Encyclopedia of the Social & Behavioral Sciences* (Second Edi, Vol. 23). Elsevier. https://doi.org/10.1016/B978-0-08-097086-8.51058-7

Yoder, R. M., Clark, B. J., & Taube, J. S. (2011). Origins of landmark encoding in the brain. *Trends in Neurosciences*, *34*(11), 561–571. https://doi.org/10.1016/j.tins.2011.08.004

Zhao, M., & Warren, W. H. (2015). Environmental stability modulates the role of path integration in human navigation. *Cognition*, *142*, 96–109. https://doi.org/10.1016/j.cognition.2015.05.008

10 Appendix

As part of the thesis, an appendix is available with the bitmaps of date, the categorized bitmaps, as well as the categorization code and a document with an overview of the appendix content. A zip folder can be downloaded at the following link:

https://drive.google.com/drive/folders/1ACy6ZK2ddXfx5m3_1MgFLaj5vaFS-A4k?usp=sharing