INSIGHT AS INVENTION OF RELATIONAL REFERENCE SYSTEMS: EMERGING COGNITIVE MAPS IN SPATIAL AND NON-SPATIAL CONTEXTS

KÜBRA EREN

BOĞAZİÇİ UNIVERSITY

2018

INSIGHT AS INVENTION OF RELATIONAL REFERENCE SYSTEMS:

EMERGING COGNITIVE MAPS IN SPATIAL AND NON-SPATIAL CONTEXTS

Thesis submitted to the

Institute for Graduate Studies in Social Sciences

in partial fulfillment of the requirements for the degree of

Master of Arts

in

Cognitive Science

by

Kübra Eren

Boğaziçi University

2018

Insight as Invention of Relational Reference Systems:

Emerging Cognitive Maps in Spatial and Non-Spatial Contexts

The thesis of Kübra Eren

has been approved by:

Prof. Yağmur Denizhan
(Thesis Advisor)

Prof. Reşit Canbeyli
(Thesis Co-Advisor)

Assist. Prof. İnci Ayhan

Prof. Sevtap Cinan
(External Member)

Assist. Prof. Burcu Dilek
(External Member)

April 2018

DECLARATION OF ORIGINALITY

I, Kübra Eren, certify that

- I am the sole author of this thesis and that I have fully acknowledged and documented in my thesis all sources of ideas and words, including digital resources, which have been produced or published by another person or institution;
- this thesis contains no material that has been submitted or accepted for a degree or diploma in any other educational institution;
- this is a true copy of the thesis approved by my advisor and thesis committee at Boğaziçi University, including final revisions required by them.

Signature..

Date ....30.05.2018..........................

ABSTRACT

Insight as Invention of Relational Reference Systems:

Emerging Cognitive Maps in Spatial and Non-Spatial Context

Insight, specifically discovery of abstract regularities in experience can be thought as the invention of a relational framework which accommodate novel meaningful relationships within complex stimuli. Relatedly, for the flexibility in spatial navigation, since most of the necessary information is not directly or simultaneously perceived, relying on a relational reference system or a cognitive map seems to be required. In the present study, the ability to implicitly adapt to (implicit learning) and coherently formulate (discovery) an abstract regularity was assessed in a Number Reduction Task (NRT). To assess the ability for flexible navigation, a novel virtual environment was generated to simulate a set of way-finding and spatial judgement situations which necessitate reliance on a cognitive map. Those who can learn the regularity in the NRT were hypothesized to have higher performances in the navigation tasks since they can more easily generate relational reference systems to rely on during way-finding. This hypothesis was tested with 41 Boğaziçi University students. The results showed that discoverers in NRT performed significantly higher in the navigation tasks than non-discoverers (implicit learners and no relational learning group). Moreover, there observed a linear trend between relational learning levels (no relational learning, N; implicit learning, I; discovery, D) and navigation performances: D > I > N. The observed correlation of the performances in the two cognitive tasks was discussed in relation with the capacity to organize experiences as cognitive maps in spatial and non-spatial contexts.

ÖZET

İlişkisel Referans Sistemlerinin İcat Edilmesi Olarak İç Görü:

Uzamsal ve Uzamsal Olmayan Bağlamlarda Oluşan Bilişsel Haritalar

İç görü, daha spesifik olarak deneyimlenenin içindeki soyut bir düzenliliğin keşfedilmesi karmaşık uyaranlara dair yeni anlamlı ilişkileri tutan bir ilişkisel referans sisteminin icat edilmesi olarak düşünülebilir. Benzer şekilde, mekânda yön bulabilme esnekliğinin, gerekli verilerin tamamı doğrudan ya da aynı anda algılanmadığından, bir ilişkisel referans sistemine ya da bir bilişsel haritaya başvurmayı gerektirdiği düşünülmektedir. Bu çalışmada, gizli soyut bir düzenliliğe adapte olma (örtük öğrenme) ve onun tutarlı bir şekilde formüle etme (keşfetme) becerileri bir Sayı Eksiltme Görevi (SEG) içinde incelenmiştir. Esnek bir şekilde yön bulma becerilerini ölçmek için ise bilgisayar ortamında sanal bir mekân yaratılmış ve bilişsel bir haritaya başvurmayı gerektirecek bir dizi yön bulma ve uzamsal yargı durumlarının simülasyonu yapılmıştır. SEG deneyinde gizli soyut düzenliliği öğrenenlerin yön bulma görevleri sırasında başvurabilecekleri bir ilişkisel referans sistemini daha kolay oluşturacakları ve dolayısıyla bu görevlerde öğrenmeyenlere göre daha başarılı olacakları hipotezi 41 Boğaziçi Üniversitesi öğrencisiyle test edilmiştir. Sonuçlar, SEG deneyinde soyut bir düzenliliği keşfedenlerin keşfetmeyenlere (örtük öğrenme gösterenler ve hiç öğrenmeyenler) göre yön bulma görevlerinde daha başarılı olduğunu göstermiştir. Ayrıca, ilişkisel öğrenme seviyeleri (hiç öğrenmeme, H; örtük öğrenme, Ö; keşfetme, K) ve yön bulma performansları arasında doğrusal bir trend olduğu gözlemlenmiştir: K > Ö > H. İki bilişsel görevdeki performansların gözlemlenen korelasyonu uzamsal ve uzamsal olmayan bağlamlarda deneyimi bilişsel haritalar olarak organize etme kapasitesiyle ilişkili olarak tartışılmıştır.

ACKNOWLEDGEMENTS

First and foremost, I cannot thank enough to my advisor, Yağmur Denizhan, for her priceless support, guidance and inspiration in each phase of this thesis and my psychological states correlated with them. Her elegant, dignified and "playful" attitude towards life made each struggle meaningful and joyful. Besides the countless insights I gain by means of interaction with her always unfolding and cultivating ways of thinking, I believe I stored yet more seeds for the road. I would like to express my deep gratitude to my co-advisor, Reşit Canbeyli, for his support, guidance and insightful advices on the nature of doing science, of writing and of any kind of exploration as "the student of nature" which will guide me in all my academic and intellectual paths. I am very grateful for having the chance to study with these irreplaceable scholars I admire.

I would like to thank to my committee members, İnci Ayhan, Sevtap Cinan and Burcu Dilek for their valuable comments and suggestions, which make this study much neater and more comprehensible. To İnci Ayhan, again, for providing a space for my preliminary experiments. To Lucas Thorpe, for his always helpful and motivating attitude and the stimulating discussions

I have always felt lucky in respect of my friendships, all of which enrich my life in unique and irreplaceable manners. I want to thank to Dilan Saatoğlu who makes this world meaningful with a perfect blend of humor, inspiration and honesty. I wish she never "get bored of me". To Gizem Soğancıoğlu with whom I shared (in fact created, narrated, knotted and painted) a "home" in a new city which I will carry wherever I go. To Eren Düzenli, for the inspiration ensured by his very presence in this world. To my insight-mate, Anıl Karabulut, among all, for our unstoppable, always inspiring and cheering conversations and the vivid memories of shared insight, where my curiosity for the phenomenon have its sources. To Özlem Mutlu for her warm and heartfelt presence, support and inspiration whenever I need and when most needed, to Ezgi Kaya for being my "rumex", to Selin Kenet for her compassionate friendship which I always feel deeply despite distances and to Gülsün Demirezen, for her endless support and the joyful dorm adventures. To my Chaos etc. family: again, Yağmur Denizhan, Özge, Emre, Muhsin Bey, Mustafa and others for constituting such a special niche, which I will not try to describe. It makes me believe in an alternative world where I have more strength to fight against the "desertification" of life. To Ece, Elif, Doğa, Deniz, Can, Dila and my dearest Melisa, for their unique contributions to my CogSci adventure. To Serdar Tekin, for our genuine and inspiring conversations and for joining me in escapism. To my home mates, Duygu Yıldız & Zerrin Mor, without them and their life-affirming presence (and the balcony sessions and the mid-night cakes) I could not survive the last year of this thesis. To Melih Özmen, since it is hard to think of this thesis independent from him. He has stood by me and struggled with my ever-changing moods throughout this thesis with his characteristic methods. And to the memories of times when the violets had scent.

My warmest and deepest gratitude is obviously to my family: Hatice & Yılmaz Eren and Büşra Karahan, who made me grow up in a home full of love, walls of which always resound with laughter. Every day I understand more and over again the sacrifices they have made to make this happen and the strength I gain from their unconditional love and trust in me. To Kumsal Karahan, whose birth was like an elixir which brought me back to life; being her aunt is the title I am most proud of having. To my cousins, each of which is the only one of his/her kind, with whom I will never stop playing, imagining and creating. And to all other members of my larger family who made me grow up as a lively and happy child.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

The initial inspiration leading to the subject of this thesis was a self-reflective observation that at certain moments one's perception of a phenomenon or a situation qualitatively changes with a feeling of deeper and clearer understanding, as if a new dimension of thought has just emerged. Things once seemed irrelevant or unrelated become "meaningfully" associated with that moment of insight. Those transformative moments, that one says: "Now I see!", or more widely known as "aha! moments", have been used to describe diverse sets of experiences. To mention but a few, when a previously incomprehensible or ambiguous subject is suddenly grasped, when a puzzle is solved, when the underlying principle of a complex phenomenon is discovered or when a coherent narrative which meaningfully integrates a set of dispersed instances is formed, the person experiences an aha moment. As can be anticipated from instances extending to different domains of human cognition, the term insight is loaded with countless philosophical, scientific and colloquial connotations. Therefore, for the clarity of the following discussion, it seems necessary to specify the intended meaning of the term, after briefly introducing the most prevalent conceptualizations of the phenomenon in the scientific literature. (A more comprehensive review of the historical transformation of the conceptualization of the insight phenomenon can be found in Ash, Jee & Wiley's 2012 paper.)

Insight, when conceptualized as a learning process, as in Gestalt Psychology which introduced the term to Psychology literature, is characterized as the sudden discovery of a new relationship which restructures the prior knowledge of the learner (i.e. previous mental representations regarding a phenomenon or a situation), or in Tolman's terms, "conscious grasping of field relations or field rules" which were not previously at the "immediate command" of the organism (1951, p. 200). When conceptualized as a specific type of problem solving, which is prevalent in later accounts, insight is defined as a sudden discovery of a crystalized solution idea after getting stuck in a problem or a puzzling situation and mostly contrasted with other types of problem solving situations in which rigorous application of a known methodology can lead to the solution (Kounios & Beeman,2009; Luo & Niki, 2003). Although, at first glance, this definition seems to assign a different meaning to the term, it is worth-emphasizing that what is said to characterize insight in this context is not the solution to the problem but the restructuring of the previously incomplete or misleading representation of the problem which prevents one from "seeing" the correct solution path. That is, the solution path becomes apparent once the problem is reinterpreted in a newly emerged framework. Similarly, the term has been used in other contexts where what is being discovered is not a single novel relationship but a relational framework, which accommodates a complex set of relations and enables inferring further associations such as the discovery of a mathematical principle (Stephen, Boncoddo, Magnuson & Dixon,2009) or of an overarching narrative which restructures memory representations (Milivojevic, Vicente-Grabovetsky & Doeller, 2015). Thus, what characterizes insight seem to be the sudden discovery or, in fact, invention of a coherent relational framework which can accommodate novel relationships; either by restructuring or extending the previous framework or by generating a novel one. Considering this, insight can be defined as the invention of a relational framework which function as a reference system to derive novel meaningful relationships between elements that previously seemed uncorrelated. In this thesis, the term will be used in the sense implied by this definition.

In this broad sense, insight experiences are the manifestations of cognitive flexibility in forming and restructuring ways of understanding and creatively representing phenomena in different organizational levels. Such a flexibility in cognition allows making sense of the complex dynamics of experience and creating novel ways to "see" all kinds of phenomena. To investigate how the manifestations of this capacity in different domains of cognition relate to each other is the primary motivation leading to this thesis. However, a claim to investigate such a broad topic as a single construct in an experimental setup would inevitably pose the danger of oversimplifying the rich content of the phenomenon. For this reason, the research subject of this thesis was constrained to an instance of the phenomenon, namely the ability to discover abstract (i.e. not readily available in the perceived stimuli) relationships in what is being experienced (e.g.in a task material). A comprehensive account of other methods used to investigate insight phenomenon can be found in Dietrich and Kanso's review (2010).

The following section will be devoted to a discussion of the capacity to discover abstract regularities by referring to a specific line of research, namely implicit learning paradigm. In the next section, another domain, in which the same capacity is hypothesized to determine the nature of the experience, namely way-finding in spatial environments, will be discussed in relation with insight phenomenon. Consequently, the hypothesized relationship between these two domains of cognition will be investigated in an experimental setup.

1.1 Relational learning of abstract regularities in experience

Adapting to or acting in the complex dynamics of experience requires associating phenomena in ways independent from their instantaneous associations and making extrapolations based on abstracted regularities. In various experimental settings, it has been shown that people can attune their behavior to an embedded regularity in the task items (i.e. a hidden abstract rule, regularity or pattern embedded in the sequence of stimuli and/or responses) without being able to explicitly state what the "learned" regularity was, which has been prevalently called implicit learning of abstract regularities (A.S. Reber,1967). In contrast to the discovery of an abstract regularity which requires a coherent representation within a relational framework, implicit learning suggests the actions of the learner being gradually attuned to the regularity despite a lack of explicit formulation.

Whether what is "learned" in implicit learning of abstract regularities is as flexible and relational as the explicit relational knowledge is a matter of discussion. According to some accounts, since the implicit representations of the learned regularity are less accessible, they could not be entirely dis-embedded from their context-specific associations and thus they do not allow flexible transfer of the abstract rules to entirely novel cases (Dienes & Altmann,1997). In this respect, the applicability of the implicit representations pertains to situations which share some specific features with the situations out of which these representations were born, and thus implicit learning of relational material is necessarily less flexible in nature than the explicit forms of relational learning (Newell & Bright, 2002).

As might be expected, what is typical in an implicit learning task is that the completion of the task does not require the recognition and usage of the abstract rules.

Rather than that such tasks are intentionally designed to ensure that the regularities remain hidden throughout the experiment. Thus, in those studies, the data of the participants who can explicitly report the hidden regularity are generally excluded from the analysis to differentiate the cognitive processes specifically involved in implicit learning (Haider and Rose, 2007). Yet, it has been previously reported that 10-70% of participants of such experiments (depending on the experiment design) can explicitly formulate the learned regularity, which shows that they have gained insight on these abstract rules (Lang et al.,2006). There is an increasing number of studies particularly interested in those participants who discover the hidden rule in an implicit learning task (e.g. Verleger, Rose, Wagner, Yordanova, Kolev, 2013; Wagner, Gais, Haider, Verleger & Born,2004).

Implicit learning paradigm allows researchers to observe the incidental learning of relational material. In this respect, transition from the implicit learning to the discovery of abstract regularities is a form of relational learning. In literature, relational learning is mostly studied in situations where the learning is explicit, and mostly associated with hippocampal system (e.g. Preston, Shrager, Dudukovic and Gabrieli, 2004). Implicit learning paradigm has been used to dissociate the explicit and relational nature of the learning. Namely, in an fMRI study, Rose, Haider, Weiller & Büchel (2002) have contrasted the explicitly instructed procedure of an implicit learning task which requires fixed S-R mappings, and the implicit relational learning of abstract regularity. They have shown that the relational nature of the learned material (i.e. the abstract regularity embedded in the task material) suggests a differential Medial Temporal Lobe (MTL) activation including hippocampus, even when the learning is implicit. They interpreted this finding as MTL being associated with relational learning, regardless of whether the learning is implicit or explicit. Alternatively, P. J. Reber (2013) suggested that rather than searching for a single integrated system that is responsible for implicit learning of regularities, one should consider a general principle according to which neural circuits distributed in diverse brain regions adaptively reshape their functioning in accordance with experience. Thus, he states that implicit learning mechanisms are more robust in the face of brain damage and show less individual differences when compared to declarative forms of relational learning. Relatedly, Lang et al (2006) have shown that among implicit learners those who discover the abstract rule in later trials of an implicit learning task exhibit distinguishable EEG patterns (i.e. indicating more working memory capacity and more attention directed to the regularity-related aspects of the material) starting from the very beginning of the task. They interpreted this finding as an indicator of the fact that not all implicit learners are prospective discoverers and asserted that whether the implicit learning will be followed by discovery may depend on individual differences.

Among implicit learning tasks, the Number Reduction Task (NRT) has been proposed by Haider & Rose (2007) as a method of investigating insight, since it allows the “online” detection of changes in the response behavior that are associated with implicit learning and those that are associated with discovery of abstract regularities (i.e. insight) in a differentiated manner. The discovery can subsequently be verified through verbal reports of the participants. NRT consists of producing a sequence of digits (response string) in response to another sequence of digits (stimulus string) that is presented to the participants. Initially, an instruction is given to the participants with regards to the rules they must follow to derive the response string. However, the stimulus string can be designed in such a manner that the corresponding response string exhibits some structural regularity such as symmetry. The task is formulated in such a way that after repeated exposure to such regular stimulus strings those who implicitly learn the structural regularity, and those who discover and consciously use the regularity have distinct response time profiles. It has been claimed in the literature (Lang et al, 2006) that by using NRT it is possible to distinguish at least three main learning patterns during the task: (1) procedural learning of instructed rules without implicitly or explicitly learning the hidden regularity, (2) implicit learning of the hidden regularity without being able to explicitly state it, and (3) discovery of the hidden regularity with a detectable change in the response time profile. Besides, since the participants are not informed about the existence of abstract regularities and thus not provided with a generic description of them, how they formulate or describe the abstracted regularity can also be used as a cue to interpret the nature of the emergent relational framework.

Using NRT to investigate the discovery of abstract regularities allows contrasting implicit learners, discoverers, and those who show no relational learning pattern. Thus, it becomes possible to investigate the individual differences regarding different modes of relational learning during an incidental learning experience. In what other domains these individual differences can change the nature of experience is a relevant question. Relatedly, in the next section, way-finding in spatial environments will be discussed as another domain, in which the ability to form dependable relational frameworks determines the nature of the experience and the flexibility to adapt to novel situations.

1.2 Relational reference systems in spatial navigation

For one to flexibly find his/her way in a large-scale environment, forming spatial relational frameworks of the travelled place seems to be required, since most of the necessary information is not directly perceived or not perceived simultaneously so that it necessitates an extrapolation based on an internal reference system. In this respect, spatial representations used while navigating in a complex environment are commonly distinguished from the ones tested in table-top spatial memory tasks (Maguire, Burgess & O'Keefe,1999).

Existence of such spatial internal reference systems has been first proposed by Tolman (1948), during his studies on rats' learning of mazes, as the capacity for grasping field relationships which he called cognitive maps. What he suggested was that a rat's learning a maze, is not learning "a complicated chain of Stimulus-Response connections" but a cognitive map which accommodates the relationships between complex stimuli (S-S relations), which can be, an obscure sense of the layout of its environment that enables the rat to infer possible paths between different locations (as cited in Woody & Viney, 2017, p. 347). It is worthy of note that Tolman's (1951) previously mentioned definition of insight as the "conscious grasping of field relations or field rules" (p. 200) had references to his cognitive map concept. That is, he has conceptualized insight as the explicit behavioral manifestations of the capacity to form cognitive maps regarding not only spatial but also non-spatial environments.

Later, there have been different re-interpretations of cognitive maps, some of which highlighted the spatial connotations, and some did not. O'Keefe and Nadel (1978) have described cognitive maps as goal-independent memory of space. As Gillner and Mallot (1998) stated, a cognitive map "does not itself produce behavior but is 'loaded' into flexible mechanisms or referred to during planning" (p.445). What they suggested was that such reference frames can be acquired without the expectation of a reward. Gallistel's conceptualization (as cited in Gillner & Mallot, 1998) was more like the emergence of a relational framework in the sense mentioned in the previous sections, namely he defined cognitive map as a stage in spatial reasoning when not easily combined information sources are integrated and represented in a compatible way. Some recent accounts proposed cognitive maps as the common function or mechanism of hippocampus in different cognitive domains like spatial navigation and relational memory (Eichenbaum & Cohen, 2014; Schiller et al, 2015). Relatedly, Schiller et al (2015) have restated Tolman's original conceptualization of cognitive map as "a tool for systematically organizing information across multiple domains of life, supporting flexible expression of acquired knowledge in purposeful behavior" (p. 13905).

In the context of spatial navigation, two types of spatial reference systems have been repeatedly considered in literature. Namely, the egocentric (body-centered) representations which are based on sequence of the previously realized self-motion (i.e. using body-centered cues) and allocentric (world-centered) representations which require static position information in a reference frame formed using spatial relationships among landmarks (Burgess, 2006; Tversky, 1991). Different two-system models have been proposed for these two types of spatial representations. Previously, it has been suggested that allocentric system is functioning only in representing surface geometry of the environment while egocentric system is responsible for dynamic spatial updating (Wang & Spelke,2002). In a review, Burgess (2006) has suggested that these two systems are operating in parallel while the dominance of either type is determined by certain factors like "the amount of self-motion between presentation and retrieval, the size and intrinsic spatial structure of the environment; and the extent of prior experience within it" (p.556). Thus, the distinction has been put as "transient action-oriented egocentric self-object associations" and "more enduring representational allocentric object-object or environment-object associations” (p.555) and what enables a flexible way-finding is the constant translation between these two types of representations. Since the nature of the experience is necessarily egocentric during navigation, the allocentric representations need to be constantly mediated and updated by transient action-oriented egocentric self-object associations. Besides when the self-motion trajectory is a long and complicated one, egocentric representations need to be derived from more relational allocentric representations. In this line of thinking, as Burgess has offered as a future research direction, the allocentric representations and their interaction with action-oriented egocentric representations can be a good model for the relational memory and thus for the generation of relational representations in general (2006).

Investigating way-finding abilities in a natural setting (i.e.in actual places) raises some practical difficulties while controlling and manipulating the stimuli of experiments. Relatedly, with the expansion of relevant technologies, there has been increasing number of studies on human spatial navigation using computer-simulated virtual environments to capture the dynamism in the navigation experience. In such studies, different forms of navigation experiences have been created by controlling the stimuli and demands of the experiments and when matched with brain imaging techniques a great deal of neuroscientific data has been generated (e.g. Maguire, Burgess & O’Keefe, 1999; Maguire et al., 2000; Marchette, Bakker & Shelton, 2011). Yet, it is necessary to note that while navigating in a real space, one makes use of much more complex mechanisms involving multiple sensory modalities (e.g. visual, auditory, proprioceptive etc.) which cannot be fully mimicked in a virtual navigation experiment. Besides, the individual differences in the familiarity with the virtual environments should be considered while interpreting and generalizing the finding of these studies.

With that in mind, using virtual environments to investigate navigational skills have some practical advantages. Namely, they enable researchers to track participants' exact movement trajectories, separate the sensory input available through these trajectories and modify certain parameters during the navigation experience (Mallot, Gillner, von Veen & Bülthoff, 1998). Moreover, in such virtual navigation experiments, it is possible to generate spatial environments which are equally novel to all participants. Thus, they seem suitable for testing participants' ability to form novel relational frameworks while travelling in a spatial environment.

1.3 The aim of the study

The previous discussion aimed to demonstrate a theoretical correlation between incidental learning of abstract regularities in experience and representing them as coherent abstract rules and forming cognitive maps of travelled environments (See Figure 1). Namely, it is hypothesized that both the discovery of abstract regularities in experience and the generation of cognitive maps seem to depend on generating long-lasting coherent relational frameworks to accommodate novel meaningful relationships within complex stimuli. This hypothesis can be seen as an extension of the Tolman's (1948) or his successors' proposal on the cognitive maps in both spatial and non-spatial contexts (Schiller et al.,2015). If this conceptually derived correlation between two capacities is based on a shared mechanism functioning in both domains, it may be possible to observe a correlation between the competence in flexible way-finding and discovery of abstract regularities at the behavioral level. The primary aim of this study is to test whether those who could discover an abstract regularity in an implicit learning task is more competent in rapid formation of the cognitive map of a travelled environment and thus more flexible in adapting different way-finding situations. Therefore, an experiment was designed which includes NRT as the method of investigating implicit learning and discovery of abstract regularities, and a set of navigation tasks which depends on learning a novel virtual environment and forming relational representations of it. Since the aim of the navigation tasks is to investigate the formation of cognitive maps of the visited environments, they were designed to necessitate the flexibility provided by relational representations of the learned environment. Each navigation task is designed to simulate a way-finding or spatial judgement situation which has been previously reported as an indicator of cognitive map or depending on more relational representations of the visited environments. Namely, learning a path which requires a complex chain of self-motion (e.g. Burgess, 2006), deriving novel paths between previously encountered places, adapting to novel starting positions (e.g. Tolman, 1948), integrating multiple routes, deriving the map of the environment (e.g. Gillner & Mallot, 1998; Tversky,1991) and judging the positions of the encountered objects/places with respect to each other (as object-object relations in Burgess, 2006).

Moreover, as the discovery of abstract regularities will be investigated in an implicit learning paradigm, it allows observing the implicit learning of abstract regularities in the same experimental setup. Relatedly, the secondary aim of this study is to explore the role of action-based representations in spatial and non-spatial relational learning contexts. However, although the behavioral patterns indicating implicit learning and discovery can be observed in NRT, in a behavioral experiment, it is not possible to detect prospective discoverers among implicit learners who would have different EEG patterns as suggested by Lang et al. (2006) if the experiment was complemented by EEG recording. Thus, the hypothesis on the performances of the implicit learners in navigation tasks will be formulated as two alternatives regarding the status of implicit learners.

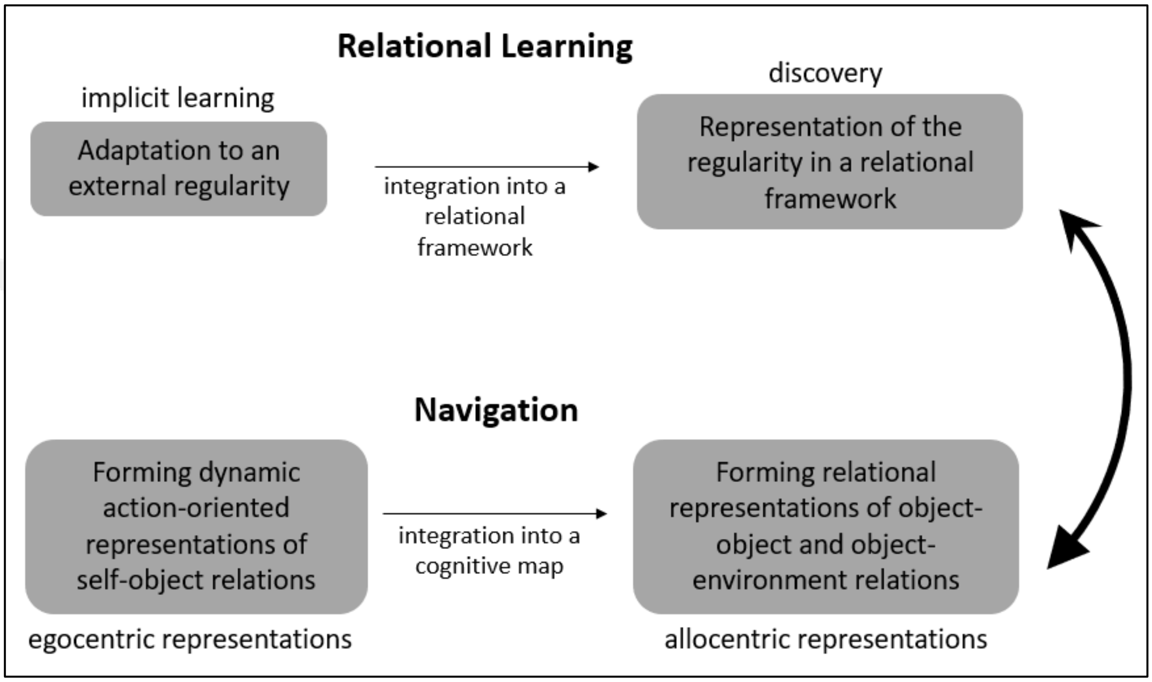


Figure 1. Diagram representing the hypothesized correlation between incidental learning of an abstract regularity and generation of cognitive maps during spatial navigation

1.4 General design and the specific hypotheses

To investigate the insight phenomenon, particularly in the context of discovering abstract regularities, previously mentioned Number Reduction Task (NRT) was used. A shorter version of the task was designed (i.e. 150 trials designed to follow a hidden regularity were distributed in 5 blocks followed by a 20-trial block including trials not conforming to the regularity) (compare to e.g. Haider& Rose,2007; Lang et al.,2006) for the study to be able to detect the individual differences in implicit learning and discovery even after short exposure to the relational material. For the design of Number

Reduction Task, see Figure 2. A detailed explanation of the task will be provided in the Section 2.2.1.

For the investigation of flexible way-finding skills, first, a series of previously-mentioned navigation experiences was simulated in a virtual environment:

1. Sign-Guided Path Following: following a complex path with the guidance of arrow signs located in the virtual environment
2. Self-Guided Path Following Task: following the recently learned complex path without external guidance
3. Blocked Path Task: deriving novel paths to reach previously encountered places when the familiar route is blocked
4. Different Starting Position Task: deriving a path from a novel start point to a previously encountered place
5. Optimum Path Task: generating the shortest possible path which integrates previously encountered places

These virtual navigation tasks were followed by other navigation tasks which examine the participants' knowledge of the configuration of the virtual environment and the relative positions of the objects encountered during the navigation experience, namely:

6. Map Recognition Task: recognizing the allocentric representation of the spatial configuration of the travelled virtual environment among alternatives (1) immediately after the navigation experience and (2) one week later (Post-Experiment Map Recognitions task).

7. Relative Positions Task/Virtual**:** estimating the relative positions of the virtual objects encountered during the navigation experience and to examine participants' existing spatial representations regarding actual familiar places:

8. Relative Positions Task/Actual: estimating the relative positions of actual familiar places.

The design of navigation tasks can be seen in Figure 2. The order of the navigation tasks was fixed for all participants and the order effects for individual navigation tasks were not controlled, for the following reasons: (1) All navigation tasks were designed in a logical sequence. To illustrate, before participants learn a specific path, testing their ability to derive novel paths when the learned path was blocked would be irrelevant, or similarly before they use separate paths to reach certain objects testing their ability to integrate those paths would not be useful. (2) The aim of the study was to investigate the construct of forming and relying on cognitive maps in the course of a series of navigation tasks, rather than the task specific performances. Thus, the hypothesis testing will be performed with a calculated composite score of all navigation tasks instead of individual performance measures. Individual analysis will be provided to illustrate how the performances change throughout the navigation section for each relational learning group.

Additionally, to evaluate how representative were participants' performances in these tasks, of their routine way-finding experiences and whether the virtual medium of the experience made any significant effect on the performances, a set of self-reflective measures were included in the experiment. Namely, Sense of Direction Scale was used to collect participants' self- reflective judgements about their spatial/navigational skills and habits. In an additional question, they were asked to rate their level of experience with computer games to evaluate their familiarity with the virtual environments. Among other questions, both a general medium-related difficulty and navigation-related difficulties of each navigation task were asked to be rated in the Post-Experiment Questionnaire Paper. (The full content of Post-Experiment Questionnaire Paper will be provided in Section 2.2.4)

To counterbalance the experimental order, participants were randomly distributed into two groups which differ in the order of Navigation and NRT sections. The general layout of the experiment for each experimental order group can be seen in Figure 2.

Based on the design of the study, the main hypothesis of the thesis can be more clearly formulated as the following: participants who gained insight on an abstract regularity in Number Reduction Task, which is, in this study, determined by the ability to coherently formulate that regularity, will have higher performances in a set of navigation tasks which were designed to require the generation of a cognitive map of the travelled environment. The hypothesis about the implicit learning can be formulated in two ways: The implicit learners who are prospective discoverers (in the sense implied in Lang et al., 2006), that is who may discover and coherently formulate the abstract rule when given enough time (a longer version of the task, in this case), would have performances in the navigation tasks similar to or approaching to those of discoverers. Besides, the implicit learners who are not prospective discoverers, or in other words, who do not integrate their action-based representations into a relational framework, would be expected to perform in the navigation tasks in lower levels than the discoverers since the tasks necessitate depending on more enduring relational reference systems. The results of the study will be discussed in relation with these two alternative hypotheses.

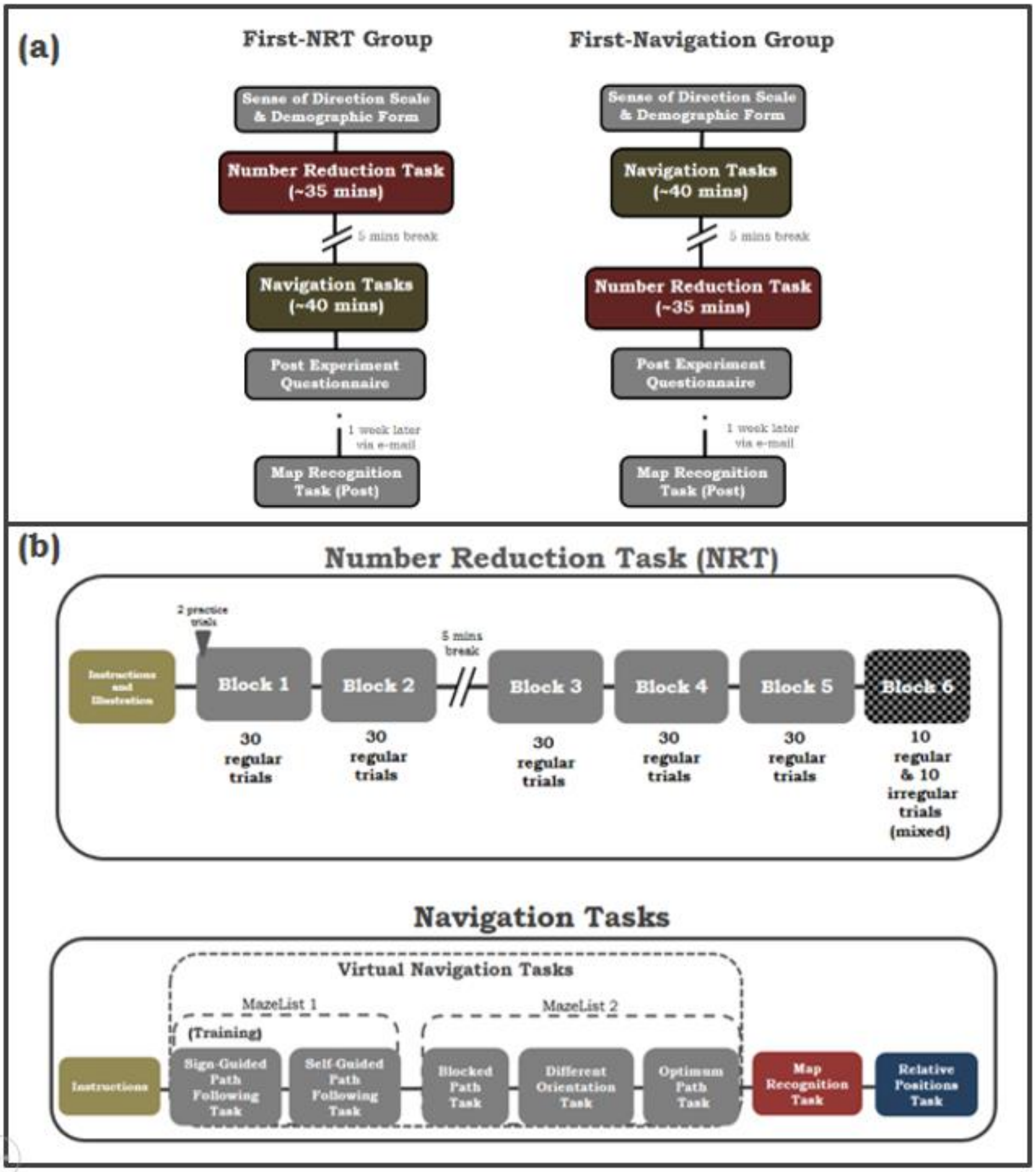


Figure 2. General Layout of the Experiment.

*Note***.** (a) flow chart of the experiment order given to two experimental order groups: first-Navigation and first-NRT, (b) detailed procedure of Number Reduction Task and Navigation Tasks.

CHAPTER 2

METHODOLOGY

2.1 Participants

Eighty-one Boğaziçi University students participated in the study in exchange for course credit. Data of 17 participants was excluded from the analysis for the following reasons. Eight participants reported feeling nauseous during virtual navigation tasks which might be a sign of "visually induced motion sickness" (Hettinger & Riccio,1992) and did not want to continue the experiment. Yet, two of them indicated that they were feeling sick before the experiment. Data of 4 students was not found reliable since they did not properly follow the experimental procedure. Three of them pressed random keys during the NRT experiment (as it was detected by the repeated errors and unusually low reaction times) and one of them did not follow the learned route in the virtual navigation experiment and exit the maze just after the trials begin). In one of the experiments, the program stopped working and the experiment could not be finished. One of the participants was fasting and sleepless and he indicated that his data might not be reliable. Two participants who rated the level of technical difficulty (the difficulty regarding the medium of experience) of the navigation task as 7 (out of 7), and their level of computer game experience as lower than 3 (out of 7) were also not included in the analysis. Lastly, the data of a participant who had an injury in his right index finger was excluded from the analysis, since it caused a remarkable disadvantage in the virtual navigation experiment.

The remaining 64 participants were aged between 18 and 26. There were 5 students of Faculty of Engineering (FENG), 23 students of the Faculty of Economics and Administrative Sciences (FEAS), 23 students of the Faculty of Arts and Sciences (FAS) and 13 students of the Faculty of Education (FEDU). Only 7 (10.8%) participants were left-handed. The duration of sleep that the participants had before the experiment changed between zero hours (0) and 10 hours with the average of 6.52 hours. The average rating regarding the level of experience with computer games in all 64 participants was 3.81 ($SD = 1.89$) which was rated on a scale of 7.

Participants were randomly assigned to two groups regarding the experiment order, namely first-Navigation ($N = 33$) and first-NRT group ($N = 31$). The mean age of the first-Navigation group was 20.79 ($SD = 1.73$) and that of the first-NRT group was 20.09 ($SD = 1.25$). The level of experience with computer games ($p = .283$) and the hours of sleep in the previous night ($p = .579$) did not differ significantly between the two experiment order conditions.

Besides, 23 participants did not completely follow the instructions of Optimum Path in at least one of the trials (i.e. while generating the optimum path they did not collect all 4 objects indicated in the instructions). Therefore, the performance measure for Optimum Path Task and thus the Composite Navigation Score were calculated only for 41 participants who followed the task instructions in both trials. The hypothesis was tested with these 41 participants (aged between 18-25; 5% left-handed; the distribution of their faculties being 10% FENG, 37% FEAS, 41% FAS, 12 % FEDU; had 1-10 hours of sleep before the experiment; the average familiarity with computer games being 3.71 out of 7) Among them 23 participants performed the Navigation Section first and 18 performed the NRT section first.

2.2 Materials

2.2.1 Number Reduction Task

The Number Reduction Task is a task used for investigating both the implicit learning and the sudden discovery of the abstract regularities. What makes the task suitable for such an investigation is that the task material can be designed to have a hidden regularity embedded in the sequence of the responses, without changing the explicitly instructed procedure of the task. When designed in this way, three types of behavior can be distinguished by examining the reaction time changes and verbal expressions of the participants: (1) discovery of the abstract regularity which is implied by the ability to explicitly formulate the regularity after the task, and sometimes accompanied by a change in strategy during the task, (2) implicitly using the abstract regularity (i.e. speeding the responses which can be predicted from the abstract regularity) without being able to explicitly formulate it, (3) applying the explicitly instructed procedure without implicitly using or explicitly formulating the abstract regularity.

In the explicit procedure of the Number Reduction Task which was provided in the instructions, 8-digit strings, which are composed only of “1”, “4” and “9” digits, are meant to be operated by using an algorithm that employs two distinct rules, namely the Identity Rule and the Difference Rule. A detailed explanation of the algorithm employed throughout a single trial can be found in Figure 3. Upon processing the digits pairwise from left to right by using this algorithm, a 7-digit response string is generated out of an 8-digit stimulus string. The highlighted goal of each trial is to find the correct answer of the last operation (i.e. the last digit of the response string) as quickly as possible.

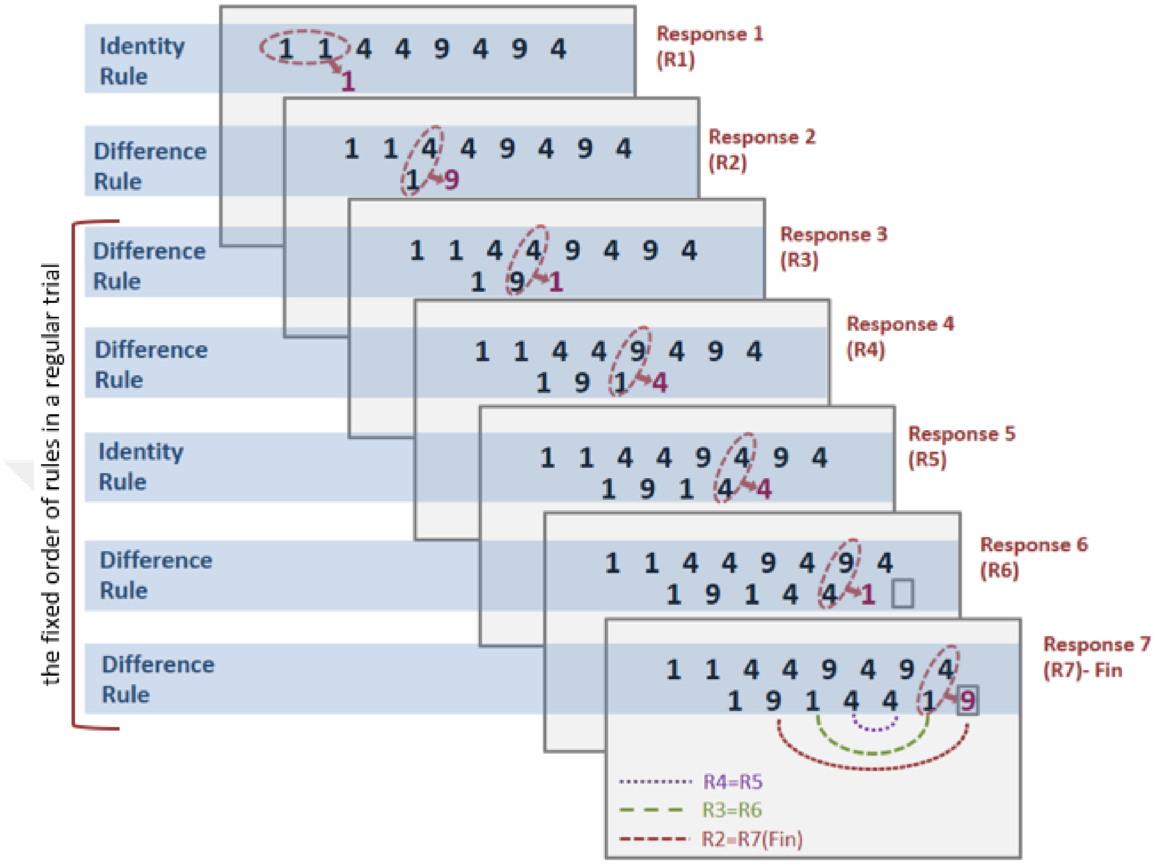


Figure 3. The illustration of a single (regular) trial of the Number Reduction Task and of the hidden response structure

Note. The digit string is processed pairwise from left to right by using an algorithm based on the Identity Rule and the Difference Rule. Identity Rule suggests that if the two digits to be compared are identical, that digit is the product of the operation, as illustrated in the 1st and 5th operations. Difference Rule suggests that if the digits in the pair are different, the product of the operation is the digit missing in the pair (from the 1-4-9 set), as illustrated in other operations. The first pair to be operated is the first two digits of the original string and the following pairs compose of the product of the previous pair and the next digit of the original string. The result of each pair is displayed successively under the original string as the participant proceed. The final response of the trial (Fin) is emphasized with a blank black frame displayed next to the 6th response. In trials with the regular digit strings, the last 3 responses (R5-7) and the previous three responses (R2-4) displayed a mirror symmetry (as illustrated by the arrow pairs). In regular trials, last 5 operations are always in the order of Difference-Difference-Identity-Difference-Difference.

As mentioned above the stimulus strings used in this task can be designed in a specific way (i.e. last 5 operations are always in the order of Difference-Difference-Identity-Difference-Difference) so that the digits of the resulting response string display a regularity, namely they exhibit a mirror symmetry, if the first response is disregarded (i.e. X A B C C B A). Thereafter, the stimulus strings which exhibit and do not exhibit this regularity will be called “regular strings” and “irregular strings”, respectively. Similarly, trials involving the regular strings will be called “regular trials” and that involving irregular strings “irregular trials”. Regular and irregular trials are illustrated in Figure 4.

In a regular trial, as an implication of the symmetrical structure in the response string, the last three responses can be predicted from the previous three responses, which will be called “predictable” and “unpredictable” responses, respectively (See Figure 4). Thanks to this feature, after an exposure to the regular trials, participants can learn to predict the last three operations (i.e. can speed up in the second half of each trial) implicitly. Thus, a noticeable speeding in specifically predictable responses of the trials which exhibit the abstract regularity is generally regarded as implicit learning if the learner is not aware of the abstract rule (e.g. Verleger et al., 2013). Moreover, when formulated as an abstract rule, this structural regularity can be used to infer the final response without exhaustively applying the explicitly instructed algorithm. Thus, a sudden sharp decrease in the reaction times of all responses without compromising the accuracy is commonly regarded as the moment of discovery if the participant can explicitly formulate the rule after the task (e.g. Verleger et al., 2013).

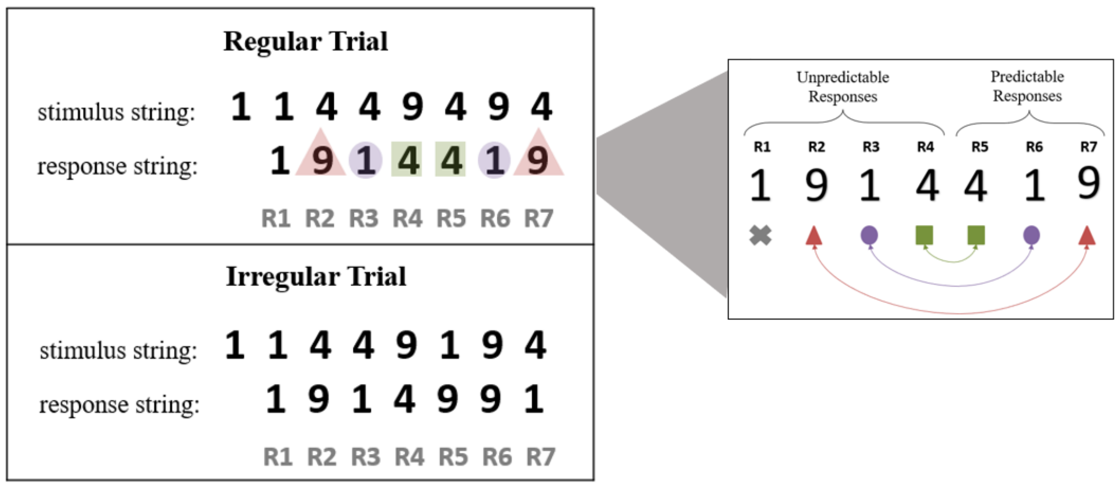


Figure 4. Sample stimulus and response strings of the regular and irregular trials of Number Reduction Task, and the illustration of the predictable and unpredictable responses in a regular trial

Based on the same structural regularity, it is possible to formulate different abstract rules (See Figure 5). The prevalently reported abstract rule, which will be called Response Symmetry Relation in this study, suggests that the final response can be reached by processing only the first three or last three digits of the stimulus string. In other words, the second response is always equal to the final response in a regular trial. Besides, there is another implication of the same structural regularity, namely Diagonal Relation, which has not been reported in the literature before. According to this rule, the final response can be predicted from the stimulus string, as well. Namely, if the last two digits of the stimulus string are identical, the final response is equal to the 6th digit of the stimulus string; and if they are different, the final response is equal to the 7th digit of the stimulus string (i.e. at the left diagonal of the final response). The underlying reason of this alternative implication will be discussed later, in relation with the specific design of the regular trials. Since the irregular strings do not exhibit the regularity in the response string, the irregular trials cannot be processed by using neither of the hidden rules. For the illustration of the formulated abstract rules, see Figure 5.

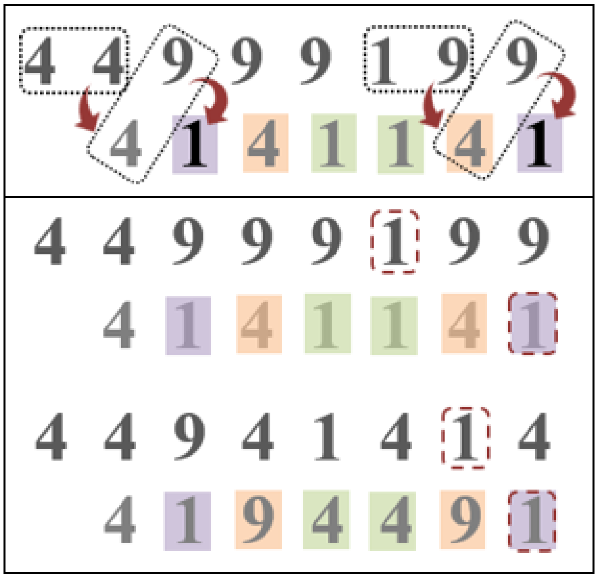


Figure 5. The formulated abstract rules in the Number Reduction Task

Note. The figure above illustrates the Response Symmetry Relation: Symmetrical nature of the response string enables reaching the final solution by processing only the first three or the last three digits of the stimulus string since the responses are reset in the middle. The figure below illustrates the Diagonal Relation: The final response is equal to the 7th digit of the stimulus string (the one in the diagonal position) unless the last two digits of the stimulus string are identical, in that case, the final response is equal to the 6th digit of the stimulus string.

For the present study, the Number Reduction Task, was designed and performed in the E-Prime 2.0 Software (Schneider, Eschman & Zuccolotto, 2002). All trials started with the display of an 8-digit string in black on a white-colored background. All digits of the string were displayed simultaneously rather than successively, as in other studies in literature which use 8-digit strings instead of 6-digit strings (e.g. Wagner et al.,2004; Rose et al.,2002). Within each block “1”, “4” and “9” keys were set as only available options in E-Prime program to prevent mistaken hits to the other keys. Upon pressing one of these digits, the entered digit was displayed as the first response just under the first pair of the original string (See Figure 3). When the response to the next pair was entered, it was displayed on the right of the previous response. This operation was repeated until a blank black frame, signaling the expected final response, appear on the right side of the 6^{th} response. When the final response was entered, a feedback screen was displayed for 1500 msec. On this screen, if the entered response was correct, it was displayed in green; if not incorrect, displayed in red. The reaction times (RTs) of 7 responses and the accuracy of the final response of each trial were recorded by the E-prime program during the task.

The digit strings used in the present study were selected from the list uploaded to the website of Science in School (Börsch-Haubold,2006) and checked for the applicability of the Response Symmetry Relation. In total, 160 regular trials and 10 irregular trials were created using this list. Some of the regular strings were used more than once during the task but not consecutively in the same block. The total 170 trials were distributed into six blocks: five including 30 trials and one including 20 trials. All trials of the first five blocks were regular trials and their order was fixed for all participants. The last and shorter block included 10 regular and 10 irregular trials which were randomly ordered in the block for each participant to detect the behavioral changes associated with the change in the abstract structure, since the only difference between regular and irregular trials are the abstract regularity embedded in the regular trials.

Instead of using a separate practice block, the rules of the task were demonstrated with examples until the participants confirmed that they understood the task and correctly completed two trials by themselves. In between the blocks, a text is displayed indicating that the previous block has been completed and the next block can be started by pressing the ENTER key. In the preliminary studies, it was observed that when all 6 blocks were completed in one sitting, it could be exhaustive for the subjects and their attention could seriously decrease at the last blocks. Therefore, the task was divided into two sessions which were separated by a 5-minutes break. The first session included two regular 30-trial blocks (approx. 10 minutes) and the second session included three regular 30-trial blocks and one mixed 20-trial block (approx. 20 minutes).

As mentioned above, the time point when the participant gains insight on one of the hidden rules and changes his/her strategy, was detected by the sudden acceleration of the responses and thus the sharp drop in the reaction times. For detecting the strategy change more explicitly, most NRT studies in the literature have used a shortcut key in addition to the procedure explained above. In this setting, participants are instructed that whenever they think the last digit they have entered is the final response, they can press "ENTER" key and finalize the trial. In this way, the change in strategy becomes apparent with a sudden reduction of the number of the responses. In the present study, the shortcut key was not used for the following reasons: (1) in the preliminary studies, some of the participants stated that they found all the final responses by processing the digits in their minds, so they were not exposed to the regularity in the response strings; that means, availability of a shortcut key might lead participants to skip some of the responses before recognizing the regularity, which makes the recognition of the hidden rules very unlikely; (2) introducing a shortcut key might give the participants a clue about the existence of a hidden rule. In this study, even if no shortcut key was used, the strategy change was still detectable by the sudden drop in reaction times. Since the participants were informed that the responses before the final response is not recorded by the system, those who gain insight on the covert rule could quickly press random keys until the final response, which can also be observed as a sudden drop in reaction times.

In the present study, specifically the ability to provide a coherent formulation of the hidden regularity just after the task was regarded as the indicator of discovery, since not all discoverers change their strategy to reach the final response. However, among those who can explicitly formulate the regularity, those who made a strategy change during the task was detected from a sharp decrease in reaction times.

Implicitly learning the abstract regularity would suggest speeding up especially in predictable responses during the first 5 regular blocks and slowing down in irregular trials of the last block. For the detection of implicit learning pattern, initially, the average reaction times of predictable and unpredictable responses were calculated for (1) the first half of the regular trials (the first 75 trials), (2) the second half of the regular trials (trials from 76 to 150), and (3) the last mixed block (the last 20 trials). Then, based on these variables, basically three criteria were used: (1) monotonous decrease in reaction times of predictable responses during the sequence of regular trials (i.e. the first half of the regular trials having longer average reaction times than the second half), (2) decrease in reaction times of predictable responses faster than the decrease in reaction times of unpredictable responses during the sequence of regular trials (i.e. the difference between two halves of regular trials being larger for predictable responses than for unpredictable responses), (3) increase in reaction times of predictable responses in irregular trials (the last mixed block having longer reaction times than the second half of the regular trials). Note that, since the 5th response is derived by using the Identity Rule in all regular trials, it is more easily and more quickly derived with respect to other responses (Verleger et al.,2013). Therefore, the comparison between predictable and unpredictable responses were made by using the 3rd and the 4th responses as unpredictable responses and the 6th and the 7th responses as predictable responses, since all of them are derived by using Difference Rule. Participants who exhibit the above-mentioned reaction time profile during NRT without being able to explicitly formulate any of the abstract regularities are regarded as implicit learners. A more detailed procedure will be provided in Chapter 4.

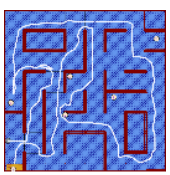
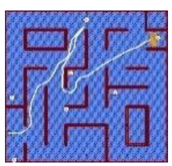
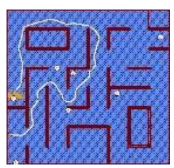
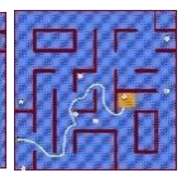
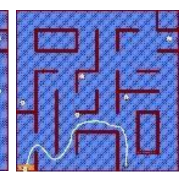
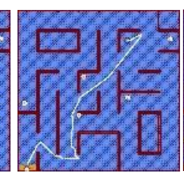
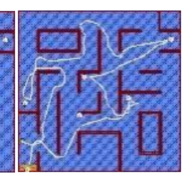
2.2.2 Navigation tasks

2.2.2.1 Virtual navigation tasks

Virtual navigation part of the experiment consisted of 5 different virtual navigation tasks, namely Sign-Guided Path Following Task (training), Self-Guided Path Following Task, Blocked Path Task, Different Starting Position Task and Optimum Path Task (See Table 1).

The Sign-guided Path Following Task was designed to guide the participants through a specific route in the virtual environment and was based on following the arrow signs placed on the walls and the floor of the environment in a numerical order (For the design of the arrow signs, see Table 2). These guided tours were repeated for 8 trials. The training path was designed in a way that ensures passing through all main parts of the virtual environment and encountering four different everyday objects on the way in this sequence: a chair, a table, a television set and a coach. For the trajectory of the training path on the map of the virtual environment, see Table 1.

Table 1. The Five Virtual Navigation Tasks

Tasks	Sign-Guided Path Following (Training)	Self-Guided Path Following Task	Blocked Path Task				Different Orientation Task		Optimum Path Task
Goal	Following the arrow signs throughout the maze and exit from the door	Following the training path throughout the maze without guidance and exit from the door	Finding the chair object when the familiar route is blocked	Finding the table object when the familiar route is blocked	Finding the television set object when the familiar route is blocked	Finding the coach object when the familiar route is blocked	Finding the door starting from Position A	Finding the door starting from Position B	Finding the shortest possible path to collect four objects and to exit from the door
Number of Identical Trials	8	2	1						2
Maze Version	Maze A in Table 2	Maze B in Table 2	Maze C in Table 2	Maze D in Table 2	Maze E in Table 2	Maze F in Table 2	Maze G in Table 2	Maze H in Table 2	Maze B in Table 2
Sample Route Pattern									

In the Self-Guided Path Following Task, to test the ability to learn a complex path in the travelled environment, the arrow signs were removed, and participants were asked to traverse the same path without external guidance in two consecutive trials. Thus, during the Sign- and Self-Guided Path Following tasks, the participants have visited all main regions of the virtual environment by using the same path.

To test the ability to flexibly adapt to a change in this training path, Blocked Path Task was designed in such a way that the participants had to derive a novel path to reach a target object, since the training path was blocked by a grey wall (For the design of the blockages, see Table 2. This task was performed for four different target objects (i.e. the ones encountered during the Path Following tasks) with the path blocked in four different positions (For the position of each blockage on the map of the virtual environment see Table 2).

Different Starting Position Task was designed to necessitate way-finding from novel starting positions. In this task, the starting position of the participants were different from the previous trials and the goal was to reach the exit (i.e. the door) as quickly as possible. This task was performed for twice with different starting positions (For the starting position of all tasks on the map of the virtual environment, see Table 2).

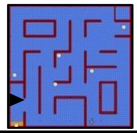
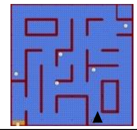
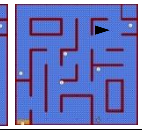
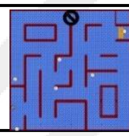
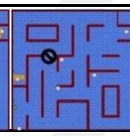
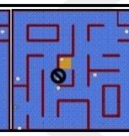
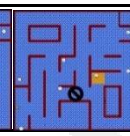
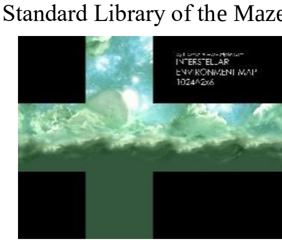
Lastly, to test the ability to integrate distinct paths previously traversed for different objectives, the Optimum Path Task was designed, the goal of which was to derive the shortest possible path which passes by all four encountered objects and terminates at the door. This task was performed for twice with the same objective.

All virtual navigation tasks were designed and performed in the MazeSuite program, which allows generating and editing virtual mazes via MazeMaker application, virtually navigating in them via MazeWalker application and analyzing the navigation performance via MazeAnalyzer application (Ayaz, Allen, Platek & Onaral, 2008). Using the MazeMaker application 8 different versions of a computer-based virtual maze[1] with the scale of 8 x 8 cells were generated. In all versions of the generated maze, the general spatial configuration of the virtual environment and the position of virtual objects were kept constant. Only minor changes (e.g. adding a blockage, altering the start and end positions, removing the arrow signs etc.) were made according to the task objective. The version of the maze used in each trial can be seen in Table 1 and the structural details of the maze versions can be seen in Table 2.

After each maze was generated as a different maze file (i.e. the computer files used to run each navigation trial) in the program, in order not to interrupt the performances between trials, two MazeLists were created in which a sequence of trials can be run one after another, and instructions can be inserted in between them. The content and organization of both MazeLists can be seen in Appendix A. Sign-Guided Path Following Tasks and Self-Guided Path Following Tasks (respectively) were run in the first maze list and Blocked Path Task, Different Starting Position Task and Optimum Path Task (respectively) were run in the second maze list. At the beginning of each trial, an instruction text informing about the goal of the following trial was displayed as a text message in white on a black background. In between every two trials, a message was presented in which the participants were advised to rest their eyes for 4-5 seconds then click a button to continue with the next trial.

[1] Note that the word "maze" is not used to refer to a labyrinth which has one possible path between the entrance and exit, but to the virtual environments created in the program.

Table 2. Structural Details of Eight Different Versions of the Virtual Maze

Version	Maze A	Maze B	Maze C	Maze D	Maze E	Maze F	Maze G	Maze H
Start Position	Next to the door 						Position A 	Position B 
End Action	Walking through the door		Walking through the **chair** object	Walking through the **table** object	Walking through the **television set** object	Walking through the **coach** object	Walking through the door	
Arrow Signs	 Embedded on the wall or ground textures*	None						
Blocked Path**	None						None	None
Wall texture	"wall_stones" texture from the Standard Library of the MazeSuite program 							
Floor Texture	"ground_grass" texture from the Standard Library of the MazeSuite program 							
Skybox Texture	"skybox1" texture from the Standard Library of the MazeSuite program 							
Ambient Light Intensity	0.4f***							
Move Speed& View Speed	0.006 maze unit/ s & 0.06 degree/s							

Note. *For the placement of the arrow signs, the original wall and ground textures were manipulated to have arrow signs on them and included in the texture collection, then, placed on certain walls and ground pieces to specify a path. ** For blocking the specified positions, "Elevator" object from the Standard Library of the program was used. From the traveler's perspective, the object was viewed as a grey wall which completely blocks the passage. *** "f" is the unit which is used in the MazeSuite program.

The participants navigated in the maze with a first-person view (i.e. route perspective) on the ground-level. The move speed (0.006 maze unit/s) and view speed (0.06 degree/s) values were heuristically determined after preliminary studies with the help of the feedbacks of participants. The main criterion was to simulate the most natural sense of movement while minimizing the possibility of motion sickness.

During each navigation trial, the length of the followed path (in maze units), the total time passed until the end action (in seconds) and the average velocity (total length/ total time) were recorded by the program. Apart from these variables, the route patterns and view vectors of each trial was displayed on the 2D map of the maze. For sample route patterns of each virtual navigation task, see Table 1.

2.2.2.2 Map Recognition Task

Map Recognition Task was designed to test participants' ability to recognize the spatial configuration of the travelled environment represented as a. bird's eye view map. Both during the main experiment (i.e. immediately after participants declared that they completed the second maze list) and one week later (via e-mail), participants were asked to identify the correct map of the virtual environment among alternatives.

The maps of generated mazes could be displayed in the MazeSuite program. The correct map of the virtual environment was created by removing all details of the maze other than the walls in this representation. For the task performed during the main experiment, 12 alternative maps were generated by manipulating the correct map of the virtual environment in various degrees and by randomly orienting them. Then, a PowerPoint presentation with all 13 maps was created, in which the correct map was on the 7th slide (Figure 6). Participants declared their choice by indicating the number of the slide which includes the chosen map and rated their level of certainty regarding their decision on a scale of 10: 1 (*not sure at all*) and 10 (*completely sure*). There was no time limit for choosing the map, but the durations of the decision making were recorded by the experimenter with the chronometer application of a mobile phone.

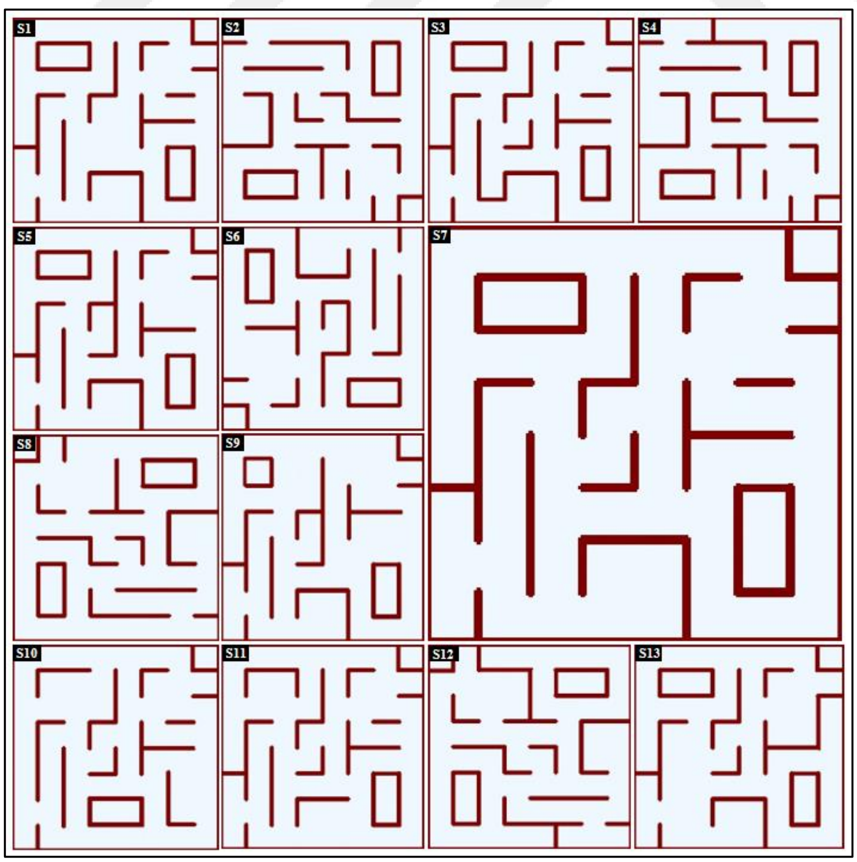


Figure 6. Map Recognition Task map alternatives

Note. Slide number of each alternative in the PowerPoint presentation is presented in the upper left part of the figures (S1-13). The correct map of the virtual environment is shown in S7.

Another PowerPoint presentation was created with the same 13 maps for post-experiment Map Recognition Task. In this new set, the orientations of the maps were changed, and the order of the slides was shuffled. The correct map was on the 5th slide of this presentation (See Appendix B). This presentation was sent to the participants via e-mail after one week. In this e-mail, participants were, again, requested to choose the correct map among alternatives, and in a reply e-mail, to indicate the number of the slide which includes the chosen map, the level of certainty regarding their choice (on a scale of 10) and the time spent during the decision-making.

2.2.2.3 Relative Positions Task

For evaluating participants' knowledge of the relative positions of objects encountered during virtual navigation and of places in the real world, a paper-based Relative Positions Task was prepared. In each question, three objects/places were matched with "X", "Y" and "Z" letters, which depict the place to be located (X), the place to be directed towards (Y) and the place whose relative angular position is supposed to be estimated (Z). In other words, the goal of the task was, while imagining oneself at the position of X and directed towards the position of Y to estimate and mark the relative angular position of Z on the presented circle (Figure 7).

There were four questions regarding the encountered objects during virtual navigation (Relative Positions Task /Virtual) and three questions regarding actual places (Relative Positions Task /Actual). For the Virtual part, different ternary combinations of the objects (i.e. chair, table, television and coach) and the door were generated. For the first questions of the Actual part, places from Boğaziçi University which are commonly used by all students of the university such as university library building, main entrance of the South Campus and the North Campus cafeteria were chosen. The second question of the Actual part included three well-known neighborhoods of Istanbul, namely Taksim, Beşiktaş and Hisarüstü (i.e. the neighborhood where Boğaziçi University is located). The last question of the actual part was formed in a different way. In this question, participants were asked to imagine themselves entering the library building and to locate the relative angular position of their real location in the library (i.e. where the experiment took place). For the actual positioning of the objects and the door in the virtual environment and of the actual places in the real maps see Figure 7.

For the Virtual part, the correct points depicting the relative angular positions of the asked objects were marked on the circles to generate an answer key. For the Actual part, instead of a single point, a range of 10^o was determined as the correct range, since the neighborhoods and buildings occupy larger areas which could not be reduced to a single point. Based on this, the angular distance of each marking from the correct angular position or range was measured with a protractor. To illustrate, if the marked position on the circle is 10^o away from the correct marking (point or range), the score was coded as 10. Hereafter, these scores will be called "angular errors". For the sample paper of the task, see Appendix C.

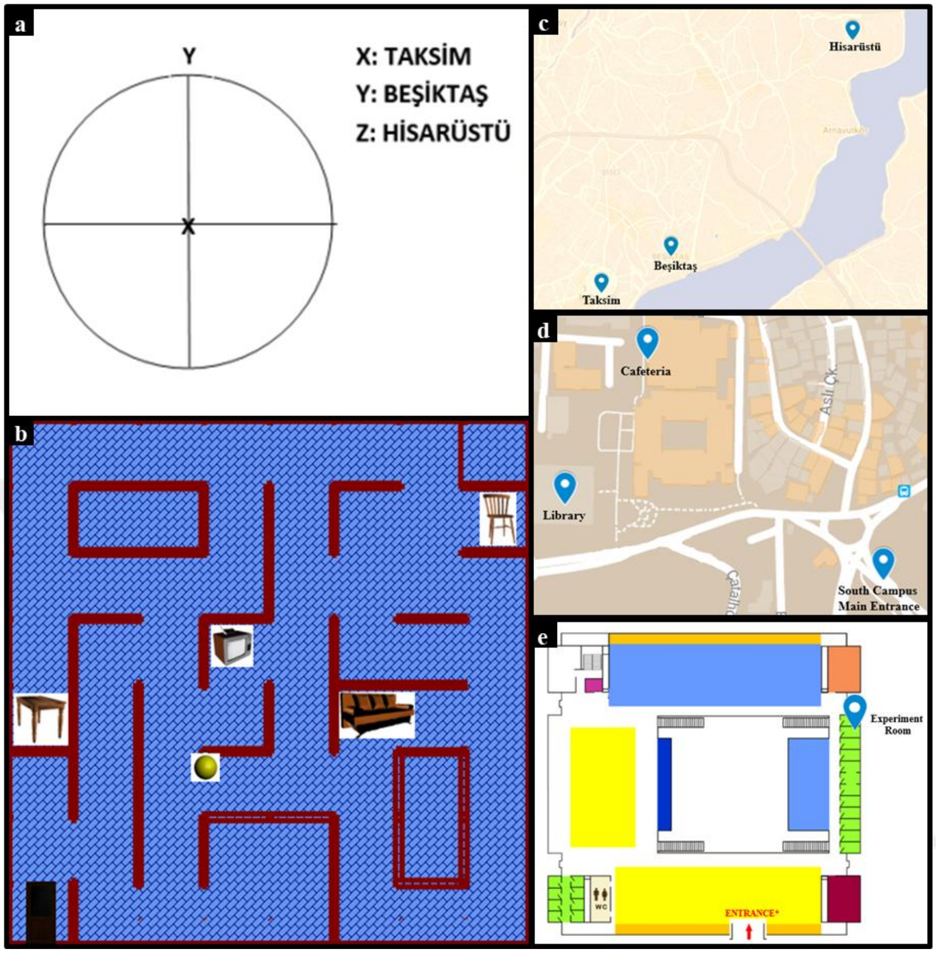


Figure 7. Illustration of Relative Positions Task and the maps representing the actual positioning of the objects/locations

Note. (a) Sample question from the task, (b) the positioning of the objects and the door in the virtual environment, (c) the positioning of Taksim, Beşiktaş and Hisarüstü Neighborhoods on the map of Istanbul, (d) the positioning of the Cafeteria, Library and South Campus Main Entrance on the map of the area where Boğaziçi University is located, (e) the positioning of the experiment room and the entrance of the library (i.e. the projection of its actual location in the ground floor) on the map of University Library.

2.2.3 Santa Barbara Sense of Direction Scale and General Information Paper

Santa Barbara Sense of Direction Scale was translated to Turkish and printed with additional Age, Handedness, Department of Education and Experience with Computer Games questions (Hegarty, Richardson, Montello, Lovelace & Subbiah, 2002). The scale included 15 sentences related with different spatial/navigational skills such as reading maps, giving and understanding address descriptions and judging distances etc. (See Appendix D for full list of sentences). The sentences were rated on a 7-point Likert scale: 1 (*strongly disagree*) and 7 (strongly agree). Eight of the sentences were negatively formed (e.g. I DO NOT have a good “cognitive map” of my environment). In order to derive a general score (SoDNet) out of this scale, the scores of negatively formed sentences were reversed. To illustrate, strong agreement (i.e. score of 7) to a negative sentence was coded as a strong disagreement (score of 1) to its positive version. Then, all 15 scores were summed and divided by 15.

Since the navigation task was taking place in a virtual environment in which the movements were coordinated with arrow keys as in the certain types of computer games. The level of experience with computer games was also rated as if it is the last question of the scale. The scale of the rating ranged between 1 (*I have never played.*) and 7 (*I play consistently.*).

2.2.4 Post-Experiment Questionnaire Paper

The questionnaire was composed of four parts. In the first part, the subjective difficulty of (1) performing a computer-based virtual navigation experiment, (2) the Self-Guided Path Following Task, (3) Blocked Path tasks, (4) Different Starting Position tasks, (5) Optimum Path tasks, (6) Map Recognition Task and (7) Relative Positions tasks was rated on a scale of 7: 1(*very easy*) and 7 (*very difficult*).

In the second part, participants were asked to provide a scalar answer to the question: "How do you think would your navigation performance have changed if the task was held in an actual place?". The question was rated on a scale of 7: 1 (*It would be much worse.),* 4 (*It would be similar.),* 7 (*It would be much better*.).

In order to control the effect of familiarity of the places used in the Relative Positions Task/ Actual, in the third part of the questionnaire, the time spent specifically in Boğaziçi University and generally in Istanbul was asked. In the last part, participants were asked to indicate how long they slept in the previous night. (See, Appendix E)

2.3 Experimental procedure

All experiments were performed in one of the private carrels of Boğaziçi University Library, which was reserved for this research. The room has two layers of windows for sound and heat insulation and the windows were covered with black curtains during the experiments. In the room, there was also a chair for the experimenter facing back the participants and separated from them with a coat hanger. This chair was used by the experimenter only during the Navigation Tasks in which multiple tasks were needed to be started immediately after another. In Number Reduction Task, the experimenter left the room after starting the experiment. Computer-based tasks of the experiment was performed on a personal notebook computer. Paper-based tasks were printed on A4 papers and handed just before the corresponding task.

The experiment consists of two main sections, namely the Navigation and the Number Reduction Task (NRT) sections. Participants were randomly assigned to First-

Navigation and First-NRT groups to counterbalance the experiment order. Each participant was taken to the experiment room individually and asked to read and sign the Consent Form which was approved by the Boğaziçi University Social Sciences Ethic Committee before starting the experiments (See Appendix F). For both groups, a paper including the Santa Barbara Sense of Direction Scale and demographic questions was distributed before the instructions. Depending on the experiment order, the instructions of the first section was given by the experimenter. In between Navigation and Number Reduction Task sections, there was a 5-minutes break.

For the Number Reduction Task (NRT), participants were first informed that in each trial they would see an 8-digit string which consisted of 1,4 and 9 digits and that they were supposed to operate the digits pairwise from left to right by using two simple rules, namely the Identity Rule and the Difference Rule to generate the final (7^{th}) response of that trial. The explicit rules (i.e. Identity and Difference Rules) were explained and illustrated in an example on a paper by the experimenter. It was indicated that the responses before the final response would not be processed by the system, so even if they made mistakes in the first 6 responses, if the 7^{th} (final) response was correct, their answer for that trial would be counted as correct. It was also mentioned that a blank black box would appear near the 6^{th} response to indicate that the next response would be the final one. The goal of the task was stated as giving the correct final response for each trial as quickly as possible. As soon as the participants confirmed that they understood the rules and the procedure of the experiment, the experiment was opened in the E-Prime program and participants were asked to place their fingers on the 1,4 and 9 keys located on the upper part of the keyboard to get ready for the experiment. It was implied that the experiment consists of multiple blocks all of which include trials with the same procedure and that they could rest their fingers in between the blocks, if needed. The experimenter left the room after participant's two consecutive successful trials.

When the first session with two blocks was completed (in approximately 10 minutes), the experimenter entered the room and opened the second session which includes four blocks. Experimenter left the room after informing the participants of that they could start the experiment by pressing ENTER key whenever they felt ready without exceeding 5 minutes. The full version of the instructions in NRT section in Turkish can be found in Appendix G.

After the second session was completed (in approximately 20 minutes), participants were asked whether they recognized anything which they would like to share. If they did not state the regularity or one of the hidden rules, they were asked whether they recognized any difference in the last block. The existence of a hidden regularity was not mentioned until the participants explained what they had recognized or, stated that they did not recognized anything. Then, the regularity was illustrated in an example for all participants. Verbal expressions of each participant were recorded in writing.

At the beginning of the Navigation section, the participants were told that they would be navigating in a virtual place by using the arrow keys on the keyboard, as if in a computer game. They were informed that in the training stage, they were supposed to follow the numbered arrow signs placed on the walls and the floor of the virtual place for 8 trials to learn a specific path in the environment. Upon following the arrows in the numerical order, they would return to the starting position, near of which a door was located, and they were supposed to exit the maze by walking through the door, then the next trial would start from the same position. After eight guided tours, the arrow signs would disappear, and they will be asked to traverse the same path without guidance in two consecutive trials. After the instructions, the MazeList1 which includes eight Sign-Guided Path Following trials and two Self-Guided Path Following trials (Appendix A) was opened in the MazeWalker application and the participants were informed that the experimenter will watch the first guided trial to clarify the instructions and then will read a book in the other side of the room. Before starting the second trial, the procedure and instruction related questions were answered by the experimenter (e.g. The question “Can I exit from the door without following all arrow signs?” was answered as “No, you need to follow the guided path.”) but the questions which exceeds the content of instructions were not answered. The related instructions were reminded by a displayed text before each trial.

After the MazeList1 was completed (in approximately 10 minutes), the MazeList2 (See Appendix A), which includes four Blocked Path tasks, two Different Starting Position tasks and two Optimum Path tasks, was opened in the MazeWalker application. This time, the participants were only informed that they would be in the same virtual environment to accomplish different tasks. The related instructions were displayed on the screen just before each trial. The goal of the Blocked Path tasks was stated as finding the target object (i.e. one of the four encountered objects in each task: the chair, the table, the TV and the coach, respectively) as quickly as possible. Participants was not informed that the familiarized path was blocked, or about which part of the path was blocked before starting the trials. In each of the two Different Starting Position tasks, the participants started navigating from different positions in the maze and the goal of the tasks was stated as finding the door from where they started as quickly as possible. The goal of the Optimum Path task was stated as collecting all four objects and exiting from the door by using the shortest possible path and it was also indicated that when they passed next to an object, the object would be counted as collected. This task was performed twice with the same objective.

Upon completion of the second maze list (in approximately 10 minutes), for the Map Recognition Task, a PowerPoint presentation with 13 slides, each of which presented a map, was opened. The participants were asked to choose the map of the virtual environment in which they navigated during the previous tasks and to indicate their level of certainty for their choice in a scale of 10. There was no time limit for choosing the map. The duration of decision making recorded by the experimenter (1-13 minutes). Participants did not receive feedback regarding their map choice.

Immediately after Map Recognition Task, as the last stage of the Navigation Tasks, the participants were handed the paper-based Relative Positions Task. They were, first, asked to read the instructions written on the paper. Then the experimenter repeated the instructions. In this task, they were asked to imagine themselves in the position of a certain object/place directed towards another object/place, and to estimate the relative position of a third object/place. The task started after the participants confirmed that the procedure was understood, it took 5-10 minutes.

Immediately after both experimental sections (i.e. Navigation and NRT sections) were completed, all participants were handed the Post-Experiment Questionnaire paper (which was filled in 2-3 minutes). Before the participants left the experiment room, they were informed that, after a week, they will be asked a single question via e-mail as the last stage of the experiment. One week later, all the participants were sent the second PowerPoint presentation via e-mail, which included the Post-Experiment Map Recognition Task. For the general layout of experiment, see Figure 2.

CHAPTER 3

RESULTS

3.1 Descriptive statistics of the Number Reduction Task

For the Number Reduction Task, the main criteria used to determine the participants who gain insight on the regularity was their verbal reports recorded after the task. In these reports, the symmetrical nature of the response string was expressed by the participants in various ways. The most prevalent expression was that the numbers were reset in the middle, so the final response can be reached by processing only the first or the last three digits of the original string. Some participants stated that they recognized a rhythmic pattern while reading the responses silently before recognizing the symmetric nature of the strings.

As mentioned in the previous chapter, apart from the Response Symmetry Relation which was intentionally embedded on the response strings, another hidden regularity, namely, Diagonal Relation, was repeatedly expressed by the participants throughout the experiments. This alternative rule was confirmed to be applicable in all regular trials and not applicable in irregular trials therefore it was regarded as another implication of the specific design of the used stimuli. Since this rule consisted of a conditional statement (i.e. the final response is the digit in the left diagonal position, unless the last two digits of the stimulus string is identical; in that case, the final response is the digit preceding the identical pair), it could be regarded as a coherently formulated abstract rule only when both conditions of it was recognized. Relatedly, the participants who had partial knowledge of it (i.e. those who recognized only one of the conditions), expressed it as an incomprehensible eccentricity they have observed during the task rather than a coherent abstract regularity. Therefore, only full recognition of it was regarded as gaining insight on a (coherent) abstract regularity. Hereafter, recognizing both conditions of Diagonal Relation and formulating it in a coherent relational framework will be called discovery of Diagonal Relation, while recognizing only one of the conditions will not be regarded as discovery since it is not sufficient to coherently represent the regularity as an abstract rule applicable to all regular trials. While some participants used the hidden rule which they discovered (either Response Symmetry or Diagonal Relation) as a shortcut to the final response, some others expressed it only as an observation. Lastly, there was another group of participants who suspected that there is a hidden rule or an abstract pattern but could not clearly state it.

Table 3 was generated to present all the above-mentioned varieties in verbal expressions and the number of participants using those expressions. Among those expressions, especially the ones which imply the discovery of one of the abstract relations are relevant for the present study. Namely, 7 participants discovered only Response Symmetry Relation, 9 participants discovered only Diagonal Relation and 1 participant was able to formulate both relations thus in total 17 (26.5%) participants discovered a coherent abstract regularity during the Number Reduction Task. In the analysis, participants who discovered at least one of the abstract regularity was coded as "discoverers". Those who discover specifically Response Symmetry Relation or Diagonal Relation were coded separately, as well, to investigate possible differences between two relations.

Table 3. General Themes in Participants’ Verbal Expressions Regarding the Regularities in Number Reduction Task

	Recognizing or suspecting a hidden regularity in NRT						Not recognizing or suspecting any hidden regularity to exist in NRT
	Recognizing any hidden regularity in NRT					Suspecting a hidden regularity but not being able to state it	
	Discovery of an abstract rule				Recognizing a statistical regularity without a coherent formulation		
	Response Symmetry Relation		Diagonal Relation				
	Using the relation as a shortcut	Not using the relation as a shortcut	Using the relation as a shortcut	Not using the relation as a shortcut			
Sample Expression in Verbal Reports	«Responses reset in the middle» **or** «There was a symmetry in responses» **so** « I processed only the first 3 (or the last 3) digits of the SS to reach the Fin»	«Responses reset in the middle» **or** «There was a symmetry in responses»	As the used strategy: «Fin was the digit in the diagonal position unless the last 2 digits of SS were identical, in that case, Fin was the digit preceding the identical pair »	As an observation: «Fin was the digit in the diagonal position unless the last 2 digits of SS were identical, in that case, Fin was the digit preceding the identical pair »	«Fin was mostly the digit in the diagonal position but not always»	«There seemed to be a covert rule, but I cannot put into words» OR «There seemed to be a rhythm/ melody in the responses»	«I did not recognize anything except the stated rules»
Number of participants using the expression	4 *a, b	4 *c	6	3 *c	8 *a, b	8	34

Note. *Three participants’ expressions could be included in more than one category. Those participants are represented in both categories in the table. The letters a, b or c indicate those 3 participants. Fin= final response of each trials, SS =stimulus string.

For those who discovered and used the abstract regularity as a shortcut for the final response (i.e. changed their strategy to obtain the final response), the approximate point where the strategy change occurs could be detected from the dramatic decreases in average reaction times (RT) (i.e. average of 7 responses of each trial). That is, for those participants, the average of average RTs of each 15 trials were calculated for the regular blocks and compared with that of the previous 15 trials. The point where the most dramatic decrease (i.e. by approx. 2-3 times) occurs was determined as the point where the participant's strategy has changed. Among 10 participants who change their strategy to reach the final response, one had a dramatic RT decrease in the middle of 2nd block, two at the beginning of and two in the middle of the 3rd block, two at the beginning of the 4th block and three at the beginning of the 5th block. In Figure 8, the graph representing the average reaction time changes throughout the task of the participant who changed his/her strategy at the end of the 3rd block (or at the very beginning of the 4th block) can be seen.

The participants were coded as implicit learners if they did not discover any of the abstract regularities and their reaction time changes during the task exhibited an implicit learning pattern. As mentioned in the previous chapter, three criteria were used to detect implicit learning pattern: (1) monotonous decrease in reaction times of predictable responses during the sequence of regular trials, (2) decrease in reaction times of predictable responses faster than the decrease in reaction times of unpredictable responses during the sequence of regular trials, (3) increase in reaction times of predictable responses in irregular trials. The first two trials of each session (i.e. trials 1,2,61 and 62) were eliminated from the analysis, considering that the first two trials of the first session were used as practice trials and that at the beginning of the second session, some participants did not wait for the experimenter to leave the room to start the session. From the valid trials, the average of the reaction times in 3rd and 4th responses were calculated for each trial and coded as RTs of unpredictable responses, and that in 6th and 7th responses were calculated and coded as RTs of predictable responses. Later the valid trials of the first 5 (regular) blocks (i.e. 146 trials) were divided into two halves (regular half 1 and regular half 2) and the half averages of RTs were calculated for predictable and unpredictable responses separately. Similarly, the average RTs in 20 trials of the last mixed block were calculated for predictable and unpredictable responses separately. The combination of a decrease in the RTs of predictable responses in the second half compared to the first half of the regular trials (criterion 1), which is more than that of unpredictable responses (criterion 2) and an increase in the RTs of predictable responses in the last block (criterion 3) was coded as implicit learning pattern. For a sample RT change graph of an implicit learner, see Figure 9. By using these three criteria, 9 (14%) participants were determined as implicit learners.

During the data preparation, it was realized that the correct answer for the 21st trial of the 5th block was incorrectly entered to the program; thus, all participants received an inaccurate feedback in that trial (i.e. regardless of the accuracy of their responses all participant received feedback for an incorrect response), which might have distracted the participants for the subsequent few trials.

Based on both verbal expressions and implicit learning patterns in the reaction time profiles, three relational learning groups were generated: discoverers (n=17), implicit learners (n=9) and no relational learning group (n=38).

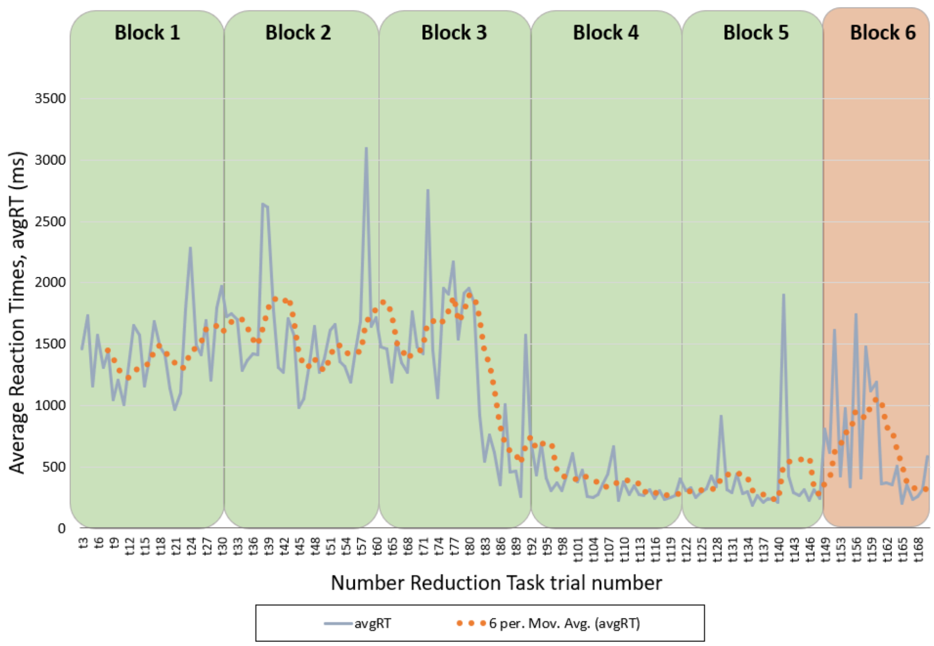


Figure 8. Sample graph representing the change in average reaction times of 7 responses throughout the six blocks of NRT

Note. A trendline with 6-period moving averages was created to illustrate the patterns.

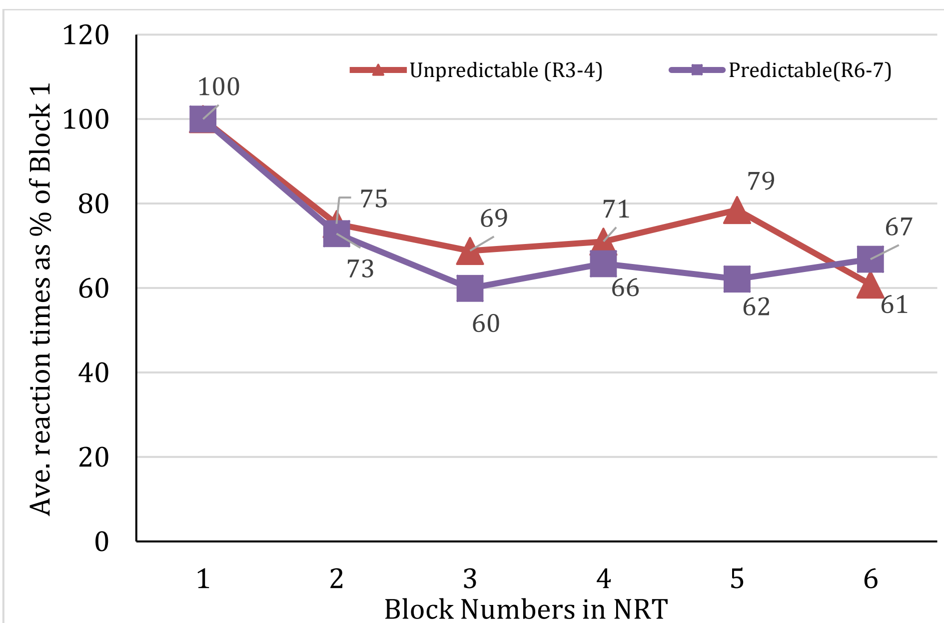


Figure 9. Sample reaction time change graph of an implicit learner throughout the 6 blocks of Number Reduction Task

Note. To illustrate and compare the decrease in RTs of predictable and unpredictable responses, block averages of both predictable and unpredictable responses are presented as relative percentages based on the first block averages.

Whether the participants performed NRT or Navigation section first was not significantly related with the relational learning behavior in the NRT, as tested by a chi-square test of independence (p = .315).

3.2 Descriptive statistics of navigation tasks

3.2.1 Virtual navigation tasks

For the analysis of Self-Guided Path Following Task, the route patterns of each participant in both trials were displayed in the MazeAnalyzer application and compared with the correct route pattern. Only the trials in which the correct route was completely followed was accepted as correct. 25 (39.1%) participants could follow the fixed path correctly in both trials and 10 (15.6%) participants in only one trial. Remaining 29 (45.3%) deviated from the route in both trials. For the analysis of the performances in Self-Guided Path Following Task, a variable which is based on the number of successful trials (i.e. 2, 1 or no trials) was generated. In some analyses, those who have at least one unsuccessful trial were collapsed and those who could successfully follow the training path in both attempts are compared with others using a categorical variable.

For the Blocked Path Task and Different Starting Position Task, the performance measures were the number of wrong turns during the tasks. For counting the wrong turns, the shortest path between the current position of the participant and the target place was dynamically updated as the participants move in the maze, and each deviation from the current shortest path was counted until the participant reached the target place.

The number of wrong turns which exceed 8 was equalized to 8 because, as can be observed in Figure 10, more than or equal to 8 wrong turns corresponded to a behavior of getting lost in the maze, instead of using short versus long paths to reach the target place. Moreover, finding the target object after getting lost was mostly accomplished by coincidental encounter with the target places since the participants had already traversed different parts of the maze more than once. The sample movement patterns for the illustration of counting procedure is presented in Figure 10. In this way, total number of wrong turns in 4 trials of Blocked Path Task (*M* =14.48, *SD* = 8.46) and that in 2 trials of Different Starting Position task (*M* = 6.11, *SD* = 4.05) were calculated as performance measures. Smaller number of wrong turns in total were interpreted as higher performances in the corresponding task.

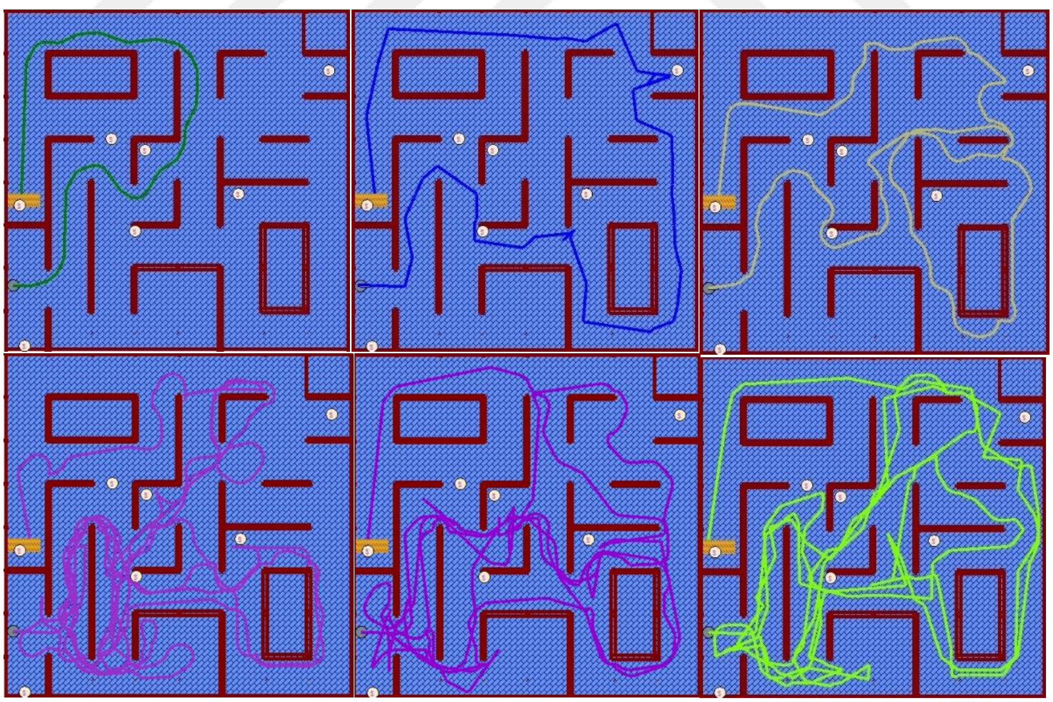


Figure 10. Sample movement patterns in Blocked Path Task trial 2

Note. The movement patterns at the top row corresponds to no wrong turn (left), 3 wrong turns (middle) and 5 wrong turns (right) respectively. The ones at the bottom row represents three examples of 8 and more wrong turns. Although these three participants' count of wrong turns vary (all being equal to or more than 8), they all find the target place after traversing all main regions of the maze at least once.

For the Optimum Path task, although the participants were instructed to follow the shortest possible path while passing through all four objects, a group of participants finished the trials by skipping at least one of the objects. Therefore, the scores which include the Optimum Path task, including the composite navigation score which will be used to test the main hypothesis, were calculated for the 41 participants who collected all four objects in both trials. The performance measure for the Optimum Path task was the pathlength values (in maze units) recorded by the MazeSuite program during the task ($M = 531.59$, $SD = 237.09$). Shorter pathlengths were interpreted as higher performances in Optimum Path task, since the aim was to derive the shortest possible path while passing by certain places in the maze.

3.2.2 Map Recognition Task

When the accuracy of the chosen map in the Map Recognition Task (performed during the experiment) was analyzed, it was observed that 24 (37.5%) participants chose the correct map of the virtual environment among 13 alternatives. The durations of decision-making ranged between 1 and 13 minutes ($M = 4.37$, $SD = 2.74$) and the level of certainty reported by the participants ranged between 0 and 10 (out of 10) ($M = 5.36$, $SD = 2.5$). Later, the participants were divided into two groups regarding the recorded duration of their map selection based on the median value 4. According to this grouping, 11 (17.2%) participants could recognize the map in a short time (less than 4 minutes), while for the remaining 13 it took a longer time to choose the correct map (up to 13 minutes). For the analysis of the performances in Map Recognition Task, a variable based on both the accuracy and the immediacy of the accuracy, was created. In this variable, those who recognized the correct map in a short time have given the score of 2, those who chose it in a long time was given 1 and those who chose an incorrect map was given no (0) scores.

Additionally, when participants were categorized into four groups considering both the accuracy and the level of certainty in Map Recognition Task, 9 participants chose the correct map with high confidence, 5 with low confidence, and 13 participants chose an incorrect map with high confidence and 27 with low confidence.

The analysis of the Post-Experiment Map Recognition Task could not be performed, since not all participants replied the e-mail and among those who replied, the time interval between the experiments and the replies to the e-mails highly varied. Among 57 participants who replied the e-mail, 15 chose the correct map. 15 participants did not declare the duration of their decision-making and 1 participant did not declare his certainty level (decision-making durations: M = 2.92, SD = 2.37; certainty levels (out of 10): M = 5.18, SD = 2.73).

3.2.3 Relative Positions Task

The average angular distance error in the Relative Positions Task/Virtual ranged between 21.25 and 148.75 degrees (M = 85.06; SD = 31.19) and that in the Actual part ranged between 0 and 75 degrees (M = 27.40; SD = 19.48). It was tested whether the performances in estimating the relative positions of buildings of Boğaziçi University and neighborhoods of Istanbul are correlated with the time spent in these places, and no significant correlation was found between the angular distance errors in Relative

Positions Task/Actual and the number of years spent in Istanbul, r =.14 p = .366 and Boğaziçi University, r = -.11, p =.383.

3.2.4 Sense of Direction Scale scores and difficulty ratings

The general score in the Sense of Direction Scale ranged between 1.67 and 4.80 (M = 4.30, SD = 1.15) on a scale of 7. The mean subjective difficulty rating (on a scale of 7) for Self-Guided Path Following Task was 3.31 (SD = 1.79), for Blocked Path Task, 4.22 (SD = 1.79); for Different Starting Position Task, 3.83 (SD = 1.49); for Optimum Path Task, 4.53 (SD = 1.64); for Map Recognition Task, 6.06 (SD = 1.17); for Relative Positions Task, 5.33 (SD = 1.55), and mean rating of the medium-related difficulty of all virtual navigation tasks was 2.42 (SD =1.41).

3.2.5 Composite navigation score

The hypotheses of the study were tested with a global navigation measure instead of individual performance measures of each task. To provide a global navigation score out of 7 navigation tasks (i.e. Self-Guided Path Following Task, Blocked Path Task, Different Starting Position Task, Optimum Path Task, Relative Positions Task/virtual, Relative Positions Task/actual and Map Recognition Task), composites navigation scores were calculated by averaging the unit-weighted z scores of 7 navigation tasks. Namely, the scale of the performance measures of each task were standardized by calculating the z-scores[2] and for the tasks whose performance measure have negatively correlated with higher performances (i.e. number of wrong turns, pathlengths, and

---

[2] Z-score= (Mean - Raw Score)/Standard Deviation

angular errors), the z-scores were reversed (i.e. aligned). In this way, the standardized and aligned scores for each task was obtained. Cronbach's α (for standardized items) for 7 standardized and aligned scores was .797, which indicates a high reliability. For the correlation analysis between the standard scores of 7 navigation tasks, which constitutes the composite navigation score, see Appendix H. Then, the average of the standardized and aligned scores of 7 tasks was calculated (for 41 participants who have valid Optimum Path Task performance), which will be called "the composite navigation score", hereafter. Shapiro-Wilk Test of Normality showed normal distribution for the composite navigation scores (p = .217), which has skewness of -.644 (SE = .369) and kurtosis of .179 (SE =.724). The frequency distribution of composite navigation scores for all participants and for relational learning groups can be seen in the histograms in Appendix I. The composite navigation scores of those who first performed NRT or Navigation section did not differ significantly (p = .998).

In order to test whether the performances in the navigation tasks were representative of the participants' general navigational skills, the correlation between the participants' self-reflective judgements about their spatial/navigational skills (based on Sense of Direction Scale) and the composite navigation scores was investigated, and a large significant positive correlation was observed, r = .568, N = 41, p < .001. Note that, since the Sense of Direction Scale was distributed before all navigation tasks, the participants' ratings were not biased by their performances in the navigation tasks.

The composite navigation scores were observed to be positively correlated with the computer game experience levels, r = .502, p = .001, as it might be expected due to the virtual nature of the navigation experiments. However, computer game experience levels were not significantly different between the relational learning groups F(2,61) =

.134, p = .875 or between discoverers and non-discoverers, t = .000, p = 1.00 (means being exactly equal).

3.3 Testing the hypothesis

The composite navigation scores were compared between relational learning groups with one-way ANOVA. However, since the group sizes were unequal (Table 4) and the Levene's Test showed unequal variances (p = .031), Welch's Robust Test of Equality of Means were used (df adjusted from 38 to 16.991). There was a significant effect of relational learning on the composite navigation scores, $F(2,17) = 9.950$, p = .001, ω^2 = .30 (Figure 11).

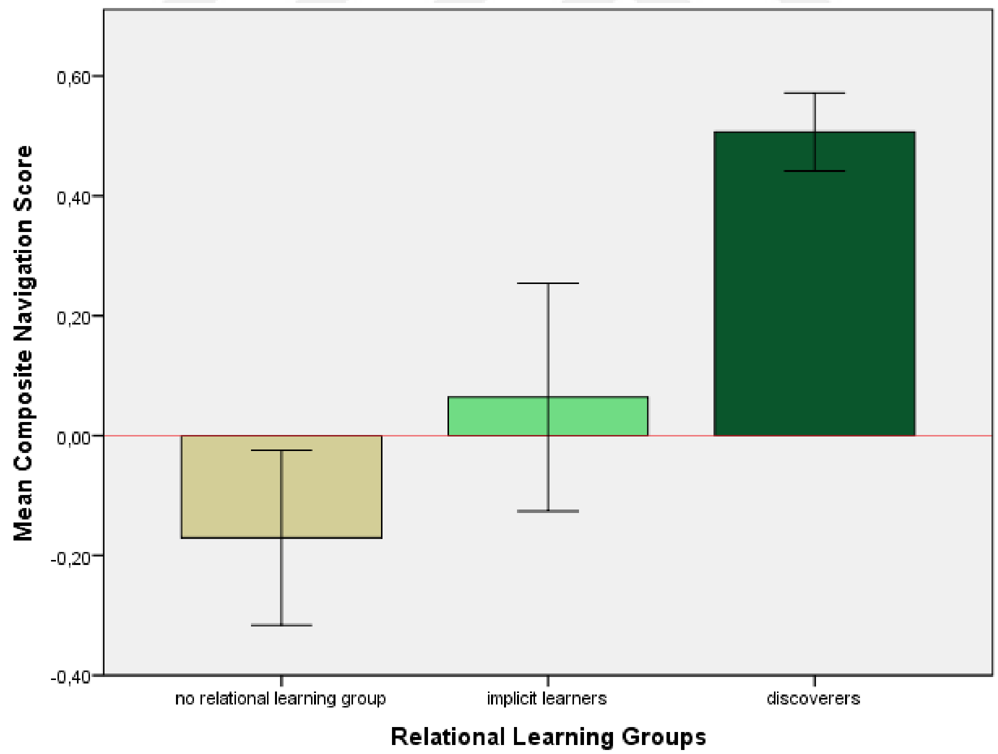


Figure 11. Bar charts representing the mean composite navigation scores in relational learning groups.

Note. Error bars indicate the standard error of the mean. There observed a significant difference between the scores of discoverers compared to non-discoverers (none and implicit learning groups combined), $p < .001$. Implicit learners and none group's scores did not significantly differ, $p = .377$.

Instead of Post Hoc tests, planned comparisons were performed. A significant linear trend, $F(1, 38) = 5.990$, $p = .019$, $\omega^2 = .11$ was observed, which indicates that the composite navigation scores increases from none group to implicit learners and then to discoverers, as can be observed in Figure 11. Two planned comparisons were made between discoverers and non-discoverers (i.e. implicit learning and none groups combined) and then between implicit learners and none group. The first comparison showed that the discoverers ($M = .507$, $SD = .173$) have significantly higher composite navigation scores than non-discoverers ($M = -.115$, $SD = .701$), $t(21.891) = -4.101$, $p < .001$, with a large effect size, $r = 0.60$. The second comparison did not show a significant difference between the composite navigation scores of implicit learners and none group, $p = .377$, r = 0.14. The descriptive statistics of the composite navigation scores in relational learning and discovery groups are presented in Table 4.

When the hypothesis was tested in two experiment order groups (first-NRT and first-Navigation) separately to control for any priming effect. The difference between relational learning groups' scores was observed to be statistically significant in first-NRT group $F(2,7) = 8.381$, $p = .015$. In the first-Navigation group although the difference is not statistically significant $F(2,8) = 3.398$, $p = .084$, the trend is also in the hypothesized direction. Such a split in data caused the sample sizes of each groups to be dramatically reduced (Table 5) thus the results should be interpreted by taking this into consideration. The group sizes of the relational learning groups and the means and the standard deviations of their composite navigation scores in both experiment order groups can be seen in Table 5.

Table 4. Descriptive Statistics of The Composite Navigation Scores of Relational Learning and Discovery Groups

Relational Learning Groups	Composite Navigation Scores			Discovery Groups	Composite Navigation Scores		
	N	*M*	*SD*		*N*	*M*	*SD*
Discoverers	7	.507	.173	Discoverers	7	.507	.173
Implicit Learners	8	.064	.538	Non-discoverers	34	.115	.701
None	26	.171	.744				

Table 5. Descriptive Statistics of The Composite Navigation Scores of Relational Learning Groups in Both Experiment Order Groups

		Experiment Order					
		first-Navigation			first-NRT		
		Composite Navigation Score			Composite Navigation Score		
		N	*M*	*SD*	*N*	*M*	*SD*
Relational Learning Groups	Discoverers	3	.42	.04	4	.57	.02
	Implicit learners	4	-.04	.14	4	.16	.51
	None	16	-.08	.67	10	-.31	.38

The line graph representing the changes of the relational learning groups' standardized and aligned scores throughout the navigation tasks can be seen in Figure 12. The graph seems to show that discoverers' scores are fluctuating between positive values (higher than *M* = 0) whereas the scores of no relational learning group are changing between negative values (less than *M* = 0) and that of implicit learners fluctuates between negative and positive scores throughout the 7 navigation tasks. The descriptive statistics of the raw performance measures in each navigation tasks among relational learning groups can be seen in Appendix J. Relatedly, the line graphs representing the mean subjective difficulty ratings for navigation tasks can be compared between relational learning groups in Appendix K.

Participants' self-reflective judgements on their navigational skills which were assessed by Santa Barbara Sense of Direction Scale were not significantly different in relational learning (p = .811) or discovery groups (p = .660) (see Table 6).

Table 6. Descriptive Statistics of the Net Score of Sense of Direction Scale of Relational Learning and Discovery Groups

Relational Learning Groups	The net score in Sense of Direction Scale			Discovery Groups	The net score in Sense of Direction Scale		
	N	*M*	*SD*		*N*	*M*	*SD*
Discoverers	16	4.41	1.16	Discoverers	16	4.41	1.16
Implicit Learners	9	4.44	1.23	Non-discoverers	48	4.26	1.15
None	39	4.22	1.15				

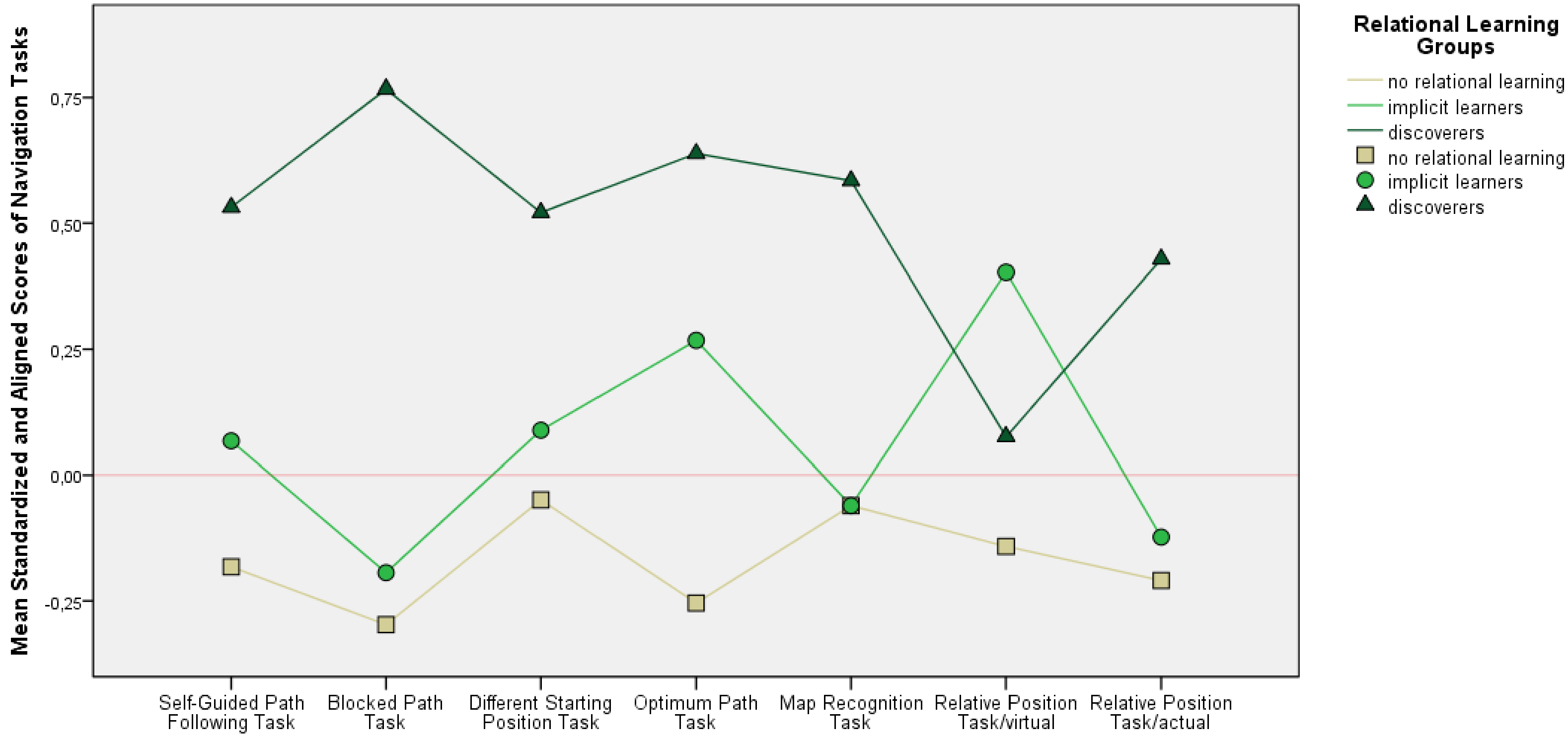


Figure 12. The mean standardized and aligned scores of relational learning groups in the sequence of seven navigation tasks.

Note. The trendline represents zero standardized and aligned score of navigation which indicates the mean raw score of each task.

CHAPTER 4

DISCUSSION

In this study, it was hypothesized that the ability to discover abstract regularities in experience can be correlated with more easily generating and relying on a relational reference system (i.e. a cognitive map) and thus with more flexibility during way-finding in novel spatial environments. To test this hypothesized correlation, a behavioral experiment was designed, in which these two capacities were examined in two separate sections (the order of these sections being counterbalanced). In one of the sections, participants were asked to accomplish a Number Reduction Task involving a hidden abstract regularity, in which their ability for implicitly adapting to this regularity (i.e. implicit learning) and providing a coherent formulation of it (i.e. discovery) was tested. In the other section (i.e. Navigation Section), participants were asked to perform a series of way finding and spatial judgement tasks with different goals, which are mostly based on learning a computer-based virtual environment. The goals of the tasks in the Navigation Section was (1) to learn a path which requires a complex chain of self-motion, (2) to derive novel paths between previously encountered places, (3) to adapt to novel starting positions, (4) to integrate multiple routes, (5) to recognize the map of the environment and to judge the positions of the encountered virtual objects (6) and real-life places (7) with respect to each other. The success in each of them has been previously reported as the indicator of forming cognitive maps of the visited environments (Burgess, 2006; Gillner & Mallot, 1998; Tolman, 1948; Tversky,1991). To obtain a global measure out of the performances in the Navigation Section, for each participant, a composite navigation score was calculated by averaging the standardized success scores in 7 navigation tasks.

After the experiment, based on the reaction time profiles and verbal expressions in the Number Reduction Task section, participants were grouped into three relational learning groups: discoverers, implicit learners and no relational learning group. There were 17 (~27%) participants who discovered an abstract regularity (i.e. could express a coherent formulation of it which is applicable to all regular trials). The rate of the discoverers is relatively higher than the stable base rate of 20% participants in Verleger et al.'s series of studies (2013). In their studies the discoverers of only Response Symmetry Relation were included, whereas, in the present study, those who came up with an alternative formulation (i.e. Diagonal Relation) of the same abstract regularity were included in this count. Moreover, among 17 discoverers only 10 used the regularity as a shortcut to final response. Thus, the time point of the strategy change (as an indicator of discovery) could be detected for these 10 participants only. However, since the NRT used in this study was relatively shorter than that in other studies in literature, all discoverers were actually "fast discoverers" compared to participants in the other studies. Majority of the participants (53%) neither showed an implicit learning pattern nor discovered any abstract rule. Because of the brief nature of the task, it is possible that participants were not exposed to the regular structure in task material long enough for an implicit learning to occur. Still, 9 (14%) participants could adapt to the regularity even after a short exposure, which might imply individual differences in implicit learning of abstract regularities, as well.

In order to test whether the performances in the navigation tasks correlate with incidental learning of abstract regularities in NRT, as hypothesized, the composite navigation scores of three relational learning groups were compared by using a one-way between-subjects ANOVA. Since 23 participants did not completely followed the instructions of one of the navigation tasks (i.e. integration of multiple paths), the composite navigation scores could be calculated only for 41 participants who followed the instructions in all navigation tasks. Thus, the analysis was performed with 7 discoverers, 8 implicit learners and 26 no relational learning group members.

The results of ANOVA showed that navigation performances significantly change at the $p < .05$ level across three relational learning groups: discoverers, implicit learners and no relational learning group. When the composite navigation scores of discoverers are contrasted with those of non-discoverers (combination of implicit learners and no relational learning group), discoverers' scores were observed to be significantly higher (with a large effect size) than those of non-discoverers, as hypothesized. That is, the participants who discovered one of the abstract regularities in Number Reduction Task had significantly higher overall performances in navigation tasks when compared to those who could not coherently formulate an abstract regularity even if they have learned to adapt to the regularity. The scores of implicit learners were not significantly different from those of no relational learning group. However, a significant linear trend was observed between the relational learning levels and the composite navigation scores: discoverers had the largest navigation scores, followed by implicit learners and, the no relational learning group had the lowest scores (i.e. discoverers> implicit learners > no relational learning), which may further support a correlation between the incidental learning of abstract regularities and the flexible navigation in novel environments.

The present study demonstrates a behavioral correlation between the ability to discover abstract regularities in experience and the ability of flexible way-finding in novel spatial environments. Based on the observed correlation, it is possible to speculate on an underlying mechanism shared by both cognitive capacities. The role of medial temporal lobe (MTL) in declarative memory, relational learning and spatial navigation tasks, specifically the role of hippocampus has been previously studied (Maguire, Burgess & O'Keefe, 1999; Maguire et al., 2000; Eichenbaum & Cohen, 2014; Rose et al.,2002). Recent studies propose that the role of hippocampus in these different cognitive domains can be conceptualized as the instances of a more general function, namely the organization of experiences within contextually relevant maps in spatial, temporal and associational contexts (Schiller et al., 2015). Such maps are proposed to support "the expectancies of events and planning of routes to obtain those expectancies" (p.1309). Those events can be in spatial, temporal, mnemonic or situational "spaces". In this line of thinking, a coherent description or formulation of the abstract regularity can also function as a cognitive map which represents the expectancies of the events in trials of NRT exhibiting the abstract regularity. Furthermore, it enables one to infer novel strategies by referring to this relational representation, just as the cognitive map of an environment used to infer possible paths to reach a target location in that environment. Thus, the observed correlation between the ability to discover abstract regularities and the ability of flexible way-finding in a novel environment may be grounded in the common function of hippocampus in encoding and organizing a wide range of information regarding the spatial, temporal and associational contexts.

Moreover, generation of cognitive maps in spatial environments can be a good model to understand the transition from implicit learning to the discovery of abstract regularities. As previously stated, formation of cognitive maps of the visited environments is based on the interaction and transfer between transient action-based representations and more enduring relational (i.e. allocentric) representations (Burgess, 2006). It was previously shown that damage to the projections of MTL along dorsal stream of vision impairs the coordination of egocentric and allocentric reference systems (Kravitz, Saleem, Baker, Ungerleider & Mishkin, 2013). Being one of the regions where dorsal and ventral streams of vision (the so-called vision-for-action and vision-for-perception streams, respectively) interact is another property of MTL which makes it particularly relevant for the interpretation of the present findings. In a review, Kravitz et al. (2013) have stated the general function of the dorsal stream as "capturing arbitrary and dynamic spatiotemporal relationships between multiple items", while the ventral stream is involved in "forming specific representations or associations involving stable aspects of visual information" (p.30). Both incidental learning of abstract regularities and flexible navigation in spatial environments necessitate the transition from dynamic adaptation of actions to arbitrary relationships of experience to the generation of relational representations which accommodate invariant aspects of the experience. Namely, during spatial navigation, one forms dynamic action-based representations which are based on arbitrary (i.e. changing with the current position of the person) self-object relationships. When those representations are integrated into a cognitive map which accommodates stable aspects of the experience (or in other words, a representation independent of the person's current point of view or position in this environment), one can infer novel paths by relying on this cognitive map. Similarly, in the NRT, implicitly adapting to a regularity suggests forming dynamic action-based representations which coordinate one's actions in accordance with the expectancies of events suggested by the abstract regularity. Besides, the discovery suggests that those representations are integrated into a relational framework which represents the regular aspects of the experience and can function as a reference frame to plan novel strategies. Thus, the transition from implicitly adapting to an abstract regularity to its discovery can be further investigated in relation with the interaction between the two streams via MTL. Clearly, making direct inferences on the neural mechanisms from the findings of a behavioral experiment would be only speculative. However, these inferences can be further investigated (such as with neuroimaging techniques and with larger sample sizes) to clarify the picture this study has intended to draw.

It seems necessary to discuss some of the constraints of the present study. In this study, the relational learning groups to be compared in terms of their navigation performances were formed based on participants' incidental learning of abstract regularities in NRT section. Therefore, it was not possible to control and balance the group sizes prior to experiments. Although robust tests were used for the comparison between groups with unequal group sizes and variances, performing the experiment with a larger sample size would be a better strategy. Moreover, the observed effect of relational learning on the navigation performances turn out to be statistically significant in participants who performed the NRT section first but not in those who performed the Navigation section first (in fact, near significant, p = .084). However, as another consequence of the small group sizes, when the data were split for separate analysis of experimental order groups, the already-small sample sizes were dramatically reduced. It is possible that the sample sizes and thus the power of the statistical analysis were too small to detect a significant effect in both experiment order conditions.

One topic of discussion regarding the generalizability of the findings of this study can be the virtual nature of the navigation section. In this study, a virtual environment was used as the medium of navigation experience, and navigation performances were observed to be correlated with the familiarity with virtual environments implied by the computer game experience levels. Thus, the generalizability of this findings to natural navigation experiences in real places can be questioned. However, the performances in the virtual-environment based navigation tasks and the participants' self-reflective judgements about their spatial/navigational skills (as measured by Sense of Direction Scale) exhibit significantly positive correlation, which might imply that the navigation tasks designed for this study are representative of the participants' past navigation experiences in real places. Since the participants' self-evaluations were assessed prior to the navigation experiments, it can be assumed that they were not biased by their performances in navigation tasks while scoring their navigational skills. Still, in further studies the participants' familiarity with virtual environments can be controlled during sampling to dissociate the effect of medium-related (i.e. virtual versus real) constraints in such virtual navigation tasks.

In the present study, even though the participants who can adapt to the abstract regularity (implicit learners) and who can explicitly formulate the regularity (discoverers) could be distinguished based on the reaction time profiles and verbal expressions, it was not possible to detect those who are in the middle of a transition from implicit learning to discovery. Previously it has been shown that implicit learners who gain insight on the abstract regularity in the later trials of NRT handle the relational material differently as compared to the ones who do not eventually gain insight, that is they exhibit a differentiated EEG pattern from the very beginning of the task, which was considered as the "precursors of insight" (Lang et al.,2006). The question of whether the implicit learners who had low and high navigation performances could have been differentiated in terms of their way of handling the relational material in NRT could not be answered from the present findings, but it can be investigated in future studies complemented with brain imaging techniques which may detect distinct patterns of brain activity preparatory to or correlated with discovery (e.g. EEG, fMRI).

The last point of discussion is related to a second implication of the specific design of the regular trials of Number Reduction Task, namely the Diagonal Relation, which was introduced in the present study. This alternative relation was observed to be applicable to all regular trials and none of the irregular trials. Thus, it was regarded as another coherent formulation of the same abstract regularity since it explains the relationship between the stimulus string and responses and enable participants to infer the final response of all regular trials. Although none of the participants who formulated the Diagonal Relation have stated its relationship with the design of the stimuli, it may be useful to discuss this relationship for a clear understanding of the task. In fact, discovery of this relationship was also an insight experience for the author of this thesis and can be used to further illustrate and discuss the nature of the insight phenomenon. The design of the regular strings of NRT necessitates the employment of Identity(I) and Difference(D) rules in a specific order for a mirror symmetry to emerge in the response string, namely X-X-D-D-I-D-D. For the last two operations to be the Difference Rule, the last three digits of the stimulus string always have the nature of ABB or ABA but never of ABC or AAB (since these orderings necessitates using at least one Identity Rule). When two consecutive Difference Rules are applied in these triads, the final response is always equal to the digit which is not repeated in the triad, namely *A* in the

ABB and *B* in the *ABA*. Thus, as stated by the participants, if the last two digits are identical (ABB) the result is the 6th digit of the stimulus string (i.e. the first digit of the triad) and if they are nonidentical (ABA), the result is the 7th digit of the stimulus string (i.e. the second digit of the triad). Participants abstracted the same regularity from all regular trials of the task, but they expressed it by referring to two distinct conditions of it. However, it was also possible to make one more level of abstraction to express these two conditions as a single rule, that is, the final response is always equal to the digit which is not repeated in the last three digits of the stimulus string. Obviously, it would be very unlikely for the participants to make such an abstraction during the task when the time constraint is considered. However, the variation in the ways of coherently describing the same abstract regularity which was exemplified in this case seem to illustrate an important point. That is, just as the cognitive map of a traversed environment cannot be thought as a generic "objective" map, so there is not a single generic way to coherently represent an abstract regularity. Both formation of cognitive maps and discovery of abstract regularities implies a creative act of "inventing" relational frameworks to make sense of the complex dynamics of experience.

APPENDIX A

THE ORGANIZATION OF THE MAZELISTS

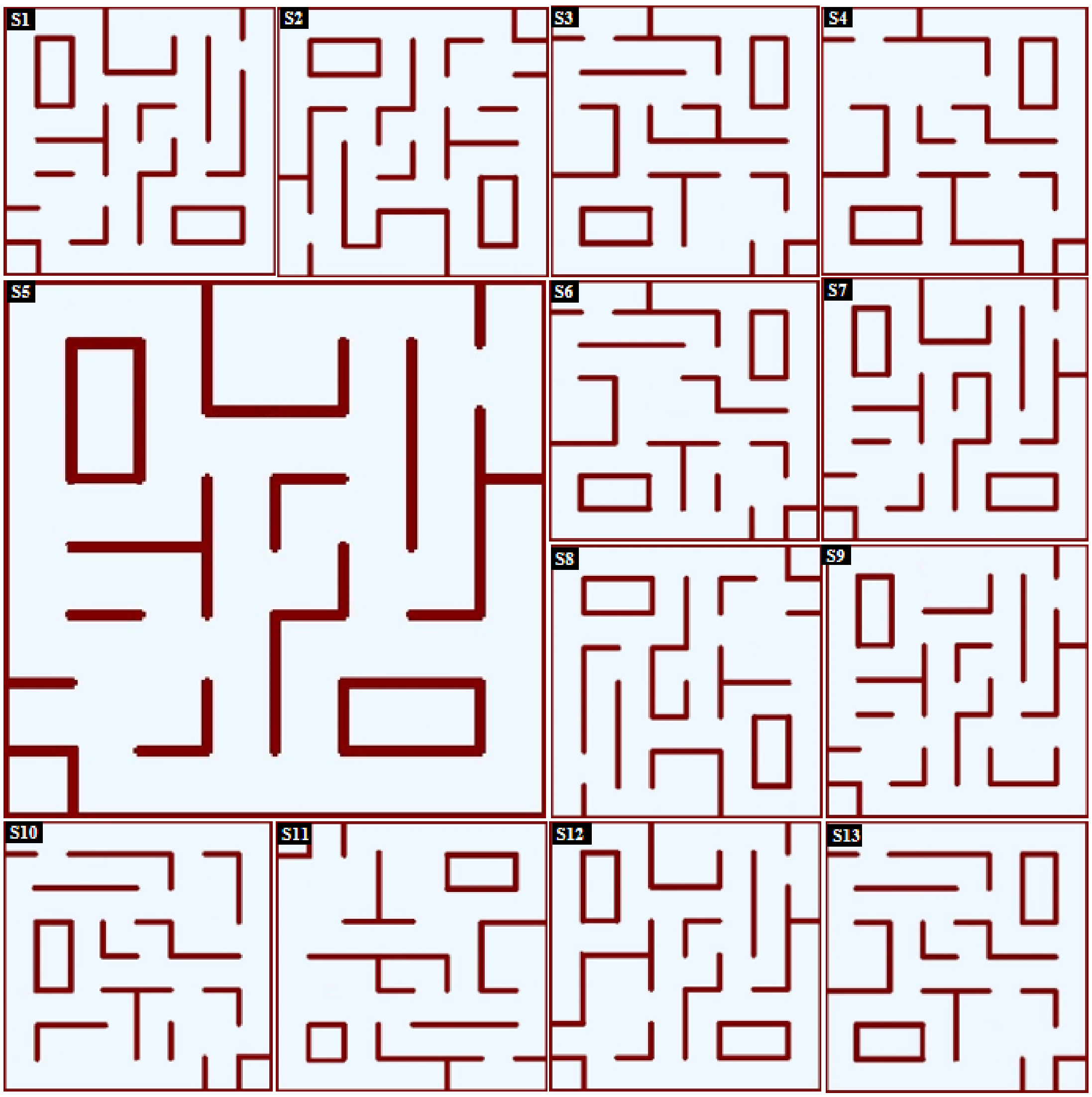
Maze List 1	
1	[Text] - «Deneye hosgeldiniz! Lutfen hicbir tusa basMAyiniz, deney kendiliginden ilerleyecektir.» *(Welcome to the experiment! Please do NOT press any button. The experiment will proceed automatically.)*
2	[Text] - «Hareketinizi klavyedeki ok tuslarıyla kontrol edebilirsiniz.» (*You can control your movement by using the arrow keys on the keyboard.*)
3	[Text] - «Lutfen sirasiyla oklari takip ederek turu tamamlayip kapidan cikiniz.» (*Please, follow the arrow signs in order and exit from the door.*)
4	[Maze] – MazeA.maz *Sign-Guided Path Following Task- Trial 1*
5	[Multiple Choice] – «Hedefe ulastiniz! \aDevam etmek icin tiklayiniz.» (*You reached the goal! Click here to continue.*)
6	[Text] - «Lutfen tekrar oklari takip ederek turu tamamlayip kapidan cikiniz.» (*Please, follow the arrow signs in order and exit from the door, again.)*
7	[Maze] – MazeA.maz *Sign-Guided Path Following Task- Trial 2*
8	[Multiple Choice] – «Hedefe ulastiniz! Lutfen gözlerinizi 4-5 saniye dinlendirin. \aDevam etmek icin tiklayiniz» (*You reached the goal! Please rest your eyes for 4-5 seconds, then click here to continue.*)
9	[Text] - «Lutfen tekrar oklari takip ederek turu tamamlayip kapidan cikiniz.» (*Please, follow the arrow signs in order and exit from the door, again.)*
10	[Maze] – MazeA.maz *Sign-Guided Path Following Task- Trial 3*
11	[Multiple Choice] – «Hedefe ulastiniz! \aDevam etmek icin tiklayiniz» (*You reached the goal! Click here to continue.*)
12	[Text] - «Lutfen tekrar oklari takip ederek turu tamamlayip kapidan cikiniz.» (*Please, follow the arrow signs in order and exit from the door, again.)*
13	[Maze] – MazeA.maz *Sign-Guided Path Following Task- Trial 4*
14	[Multiple Choice] – «Hedefe ulastiniz! Lutfen gözlerinizi 4-5 saniye dinlendirin. \aDevam etmek icin tiklayiniz» (*You reached the goal! Please rest your eyes for 4-5 seconds, then click here to continue.*)
15	[Text] - «Lutfen tekrar oklari takip ederek turu tamamlayip kapidan cikiniz.» (*Please, follow the arrow signs in order and exit from the door, again.)*
16	[Maze] – MazeA.maz *Sign-Guided Path Following Task- Trial 5*
17	[Multiple Choice] – «Hedefe ulastiniz! \aDevam etmek icin tiklayiniz» (*You reached the goal! Click here to continue.*)
18	[Text] - «Lutfen tekrar oklari takip ederek turu tamamlayip kapidan cikiniz.» (*Please, follow the arrow signs in order and exit from the door, again.)*
19	[Maze] – MazeA.maz *Sign-Guided Path Following Task- Trial 6*
20	[Multiple Choice] – «Hedefe ulastiniz! Lutfen gözlerinizi 4-5 saniye dinlendirin. \aDevam etmek icin tiklayiniz.» (*You reached the goal! Please rest your eyes for 4-5 seconds, then click here to continue.*)
21	[Text] - «Lutfen tekrar oklari takip ederek turu tamamlayip kapidan cikiniz.» (*Please, follow the arrow signs in order and exit from the door, again.)*
22	[Maze] – MazeA.maz *Sign-Guided Path Following Task- Trial 7*
23	[Multiple Choice] – «Hedefe ulastiniz! \aDevam etmek icin tiklayiniz» (*You reached the goal! Click here to continue.*)
24	[Text] - «Lutfen tekrar oklari takip ederek turu tamamlayip kapidan cikiniz.» (*Please, follow the arrow signs in order and exit from the door, again.)*
25	[Maze] – MazeA.maz *Sign-Guided Path Following Task- Trial 8*
26	[Multiple Choice] – «Hedefe ulastiniz! Lutfen gözlerinizi 4-5 saniye dinlendirin. \aDevam etmek icin tiklayiniz» (*You reached the goal! Please rest your eyes for 4-5 seconds, then click here to continue.*)
27	[Text] - «Lutfen ogrendiginiz rotayi bu kez göstergeler olmadan takip edin.» (*Please, traverse the route you have learned without the guidance of signs.*)
28	[Maze] – MazeB.maz *Self-Guided Path Following Task- Trial 1*

29	[Multiple Choice] – «Hedefe ulastiniz! \aDevam etmek icin tiklayiniz» (*You reached the goal! Click here to continue.*)
30	[Text] - «Lutfen ogrendiginiz rotayi bu kez göstergeler olmadan takip edin.» (*Please, traverse the route you have learned without the guidance of signs.*)
31	[Maze] – MazeB.maz *Self-Guided Path Following Task- Trial 2*
32	«Hedefe ulastiniz! Sonraki bolume gecmek icin deney sorumlusuna haber veriniz.» (*You reached the goal! Please, inform the experimenter to proceed to the next section.)*
	Maze List 2
1	[Multiple Choice] – Baslamak icin tiklayiniz.(*Click here to start.*)
2	[Text] - «Lutfen en kisa surede "SANDALYE"yi bulunuz.» (*Please, find the CHAIR object within the shortest time.*)
3	[Maze] – MazeC.maz *Blocked Path Task- Trial 1*
4	[Multiple Choice] – «Hedefe ulastiniz! \aDevam etmek icin tiklayiniz» (*You reached the goal! Click here to continue.*)
5	[Text] - «Lutfen en kisa surede "MASA"yi bulunuz.» (*Please, find the TABLE object within the shortest time.*)
6	[Maze] – MazeD.maz *Blocked Path Task- Trial 2*
7	[Multiple Choice] – «Hedefe ulastiniz! Lutfen gözlerinizi 4-5 saniye dinlendirin. \aDevam etmek icin tiklayiniz» (*You reached the goal! Please rest your eyes for 4-5 seconds, then click here to continue.*)
8	[Text] - «Lutfen en kisa surede "TELEVIZYON"u bulunuz.» (*Please find the TV SET object within the shortest time.*)
9	[Maze] – MazeE.maz *Blocked Path Task- Trial 3*
10	[Multiple Choice] – «Hedefe ulastiniz! \aDevam etmek icin tiklayiniz» (*You reached the goal! Click here to continue.*)
11	[Text] - «Lutfen en kisa surede "KOLTUK"u bulunuz.» (*Please, find the COACH object within the shortest time.*)
12	[Maze] – MazeF.maz *Blocked Path Task- Trial 4*
13	[Multiple Choice] – «Hedefe ulastiniz! Lutfen gözlerinizi 4-5 saniye dinlendirin. \aDevam etmek icin tiklayiniz» (*You reached the goal! Please rest your eyes for 4-5 seconds, then click here to continue*.)
14	[Text] - «Lutfen basladiginiz noktadan en kisa surede kapiyi bulunuz.» (*Please, find the door from where you start within the shortest time.*)
15	[Maze] – MazeG.maz *Different Starting Position Task- Trial 1*
16	[Multiple Choice] – «Hedefe ulastiniz! \aDevam etmek icin tiklayiniz» (*You reached the goal! Click here to continue.*)
17	[Text] - «Lutfen basladiginiz noktadan en kisa surede kapiyi bulunuz.» (*Please, find the door from where you start within the shortest time.*)
18	[Maze] – MazeH.maz *Different Starting Position Task- Trial 2*
19	[Multiple Choice] – «Hedefe ulastiniz! Lutfen gözlerinizi 4-5 saniye dinlendirin. \aDevam etmek icin tiklayiniz» (*You reached the goal! Please rest your eyes for 4-5 seconds, then click here to continue.*)
20	[Text] - «En kisa yolu kullanarak masa, tv, sandalye ve koltugu toplayip kapidan cikiniz.» (*By using the shortest possible path, collect table, tv set, chair and coach objects and exit from the door.*)
21	[Text] - «Not: Nesnelere dokundugunuzda topladiginiz varsayilacaktir.» (*Note: The objects you touch will be counted as being collected.*)
22	[Maze] – MazeB.maz *Optimum Path Task- Trial 1*
23	[Multiple Choice] – «Hedefe ulastiniz! \aDevam etmek icin tiklayiniz» (*You reached the goal! Click here to continue.*)
24	[Text] - «En kisa yolu kullanarak masa, tv, sandalye ve koltugu toplayip kapidan cikiniz.» (*By using the shortest possible path, collect table, tv set, chair and coach objects and exit from the door.*)
25	[Text] - «Not: Nesnelere dokundugunuzda topladiginiz varsayilacaktir.» (*Note: The objects you touch will be counted as being collected.*)
26	[Maze] – MazeB.maz *Optimum Path Task- Trial 2*
27	[Text] - « Hedefe ulastınız! Diger asamaya gecmek icin deney sorumlusuna haber veriniz.» *(You reached the goal! Please, inform the experimenter to proceed to the next stage.)*

APPENDIX B

THE THIRTEEN MAP ALTERNATIVES

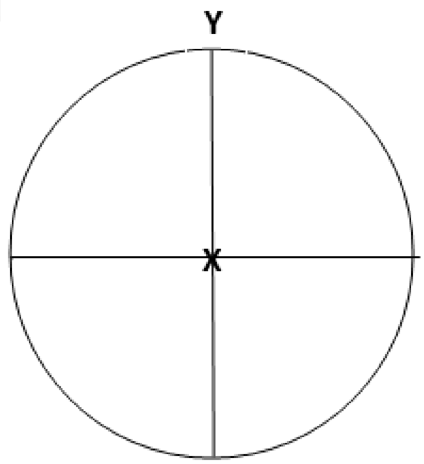
IN THE POST-EXPERIMENT MAP RECOGNITION TASK



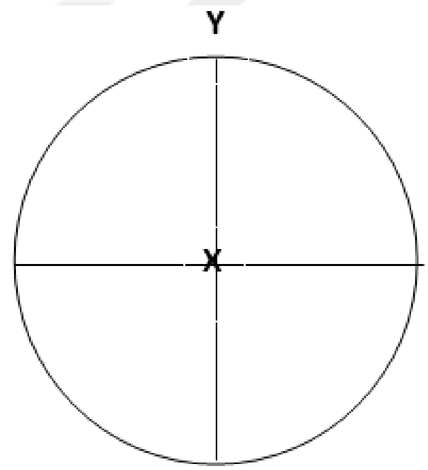
APPENDIX C

RELATIVE POSITIONS TASK QUESTIONS

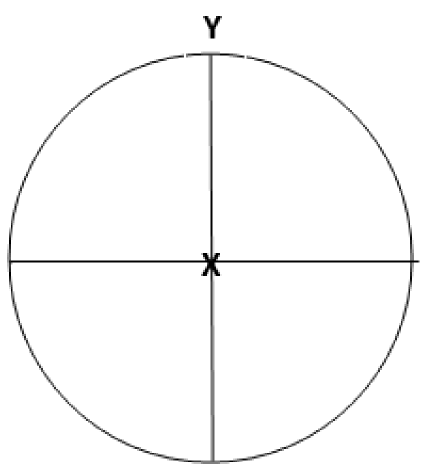
Dolaştığınız labirentin içinde olduğunuzu düşünün. (*Imagine that you are in the maze in which you navigated.)* X nesnesinin durduğu yerde durup Y nesnesine doğru dönerseniz Z nesnesi ne tarafınızda kalır? *(If you are in the position of X object directed towards the Y object, where would be the relative position of Z object?)* Çemberin üzerinde gösteriniz. *(Please, mark on the circle*.*)* Küçük açı farklılıkları önemli değildir, lütfen yaklaşık olarak bir noktayı işaretleyin. *(Minor angular differences are not important, please mark an approximate point.*)



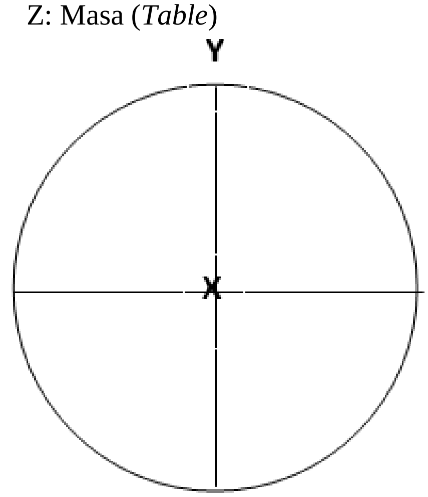
X: Masa (*Table*)
Y: Sandalye (*Chair*)
Z: Koltuk (*Coach*)



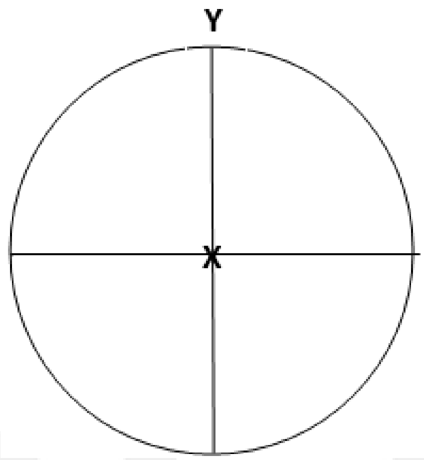
X: TV (*TV set*)
Y: Koltuk (*Coach*)
Z: Masa (*Table*)

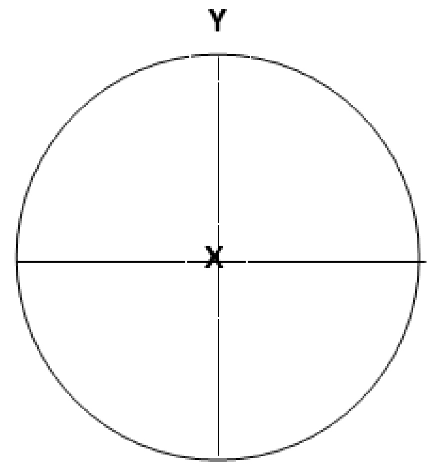


X: TV (*TV set*)
Y: Sandalye (*Chair*)
Z: Kapı (*Door*)



X: Koltuk (*Coach*)
Y: TV (*TV set*)
Z: Sandalye (*Chair*)

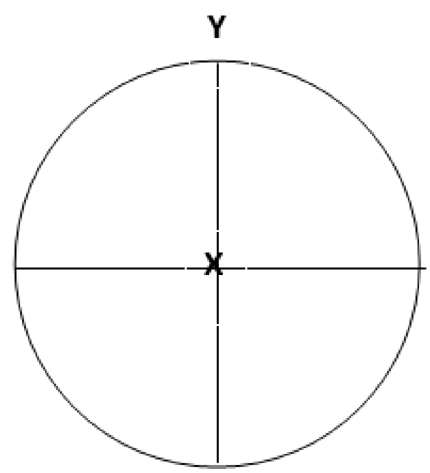




X: Taksim
Y: Beşiktaş
Z: Hisarüstü
(*the names of the neighborhoods in Istanbul)*

X: Güney Kampüs Ana Giriş
(*South Campus Main Entrance*)
Y: Kuzey Yemekhane
(*North Campus Cafeteria*)
Z: Kütüphane
(*Library*)

Bu son soru için: Kütüphaneye dönük bir şekilde kütüphane kapısının önünde olduğunuzu düşünün (X bulunduğunuz yer, Y baktığınız yön). (*For the last question: Imagine that you are in front of the entrance of the library directed towards the building* (*X being your location and Y being your direction*). Şu anda bulunduğunuz yeri (Z) daire üzerinde işaretleyin.
Mark your actual position in the building (Z) on the circle)



APPENDIX D

SANTA BARBARA SENSE OF DIRECTION SCALE

AND DEMOGRAPHICS FORM

Okuduğunuz Bölüm *(Department of Study)*:
Yaşınız *(Age)*:
Baskın kullandığınız eliniz (Sağ/Sol) *(Handedness (Right/Left))*:

Aşağıda mekânsal ve dolaşımsal (navigational) yetenekleriniz, tercihleriniz ve deneyimlerinizle ilgili bir takım ifadeler bulunmaktadır. (*Below, there is a set of statements regarding your spatial/navigational skills, preferences and experiences.*) Lütfen her ifadenin size uygunluk derecesini ölçek üzerinde işaretleyin.(*Please rate your level of agreement with each of the statements.*) Eğer ifade sizin için hiç uygun değilse 1'i, çok uygunsa 7'yi, emin değilseniz 4'ü veya ifadenin uygunluk derecesi bu uçların arasındaysa ölçekte uygun gelen diğer sayıları işaretleyin. (*If you strongly disagree mark 1, if strongly agree mark 7, if you are not sure mark 4 and if your level of agreement is in between mark the corresponding number on the scale.*)

1. Yol tarif etme konusunda iyiyimdir. *(I'm good at giving directions.)*
kesinlikle katılmıyorum 1 2 3 4 5 6 7 kesinlikle katılıyorum
(strongly disagree) *(strongly agree)*
2. Eşyaları bıraktığım yerleri hatırlama konusunda kötü bir hafızam var. *(I have a poor memory for where I left things.)*
kesinlikle katılmıyorum 1 2 3 4 5 6 7 kesinlikle katılıyorum
(strongly disagree) *(strongly agree)*
3. Mesafeleri tahmin etme konusunda iyiyimdir. *(I am very good at judging distances.)*
kesinlikle katılmıyorum 1 2 3 4 5 6 7 kesinlikle katılıyorum
(strongly disagree) *(strongly agree)*
4. Yön duygum iyidir. *(My sense of direction is very good.)*
kesinlikle katılmıyorum 1 2 3 4 5 6 7 kesinlikle katılıyorum
(strongly disagree) *(strongly agree)*
5. Çevremi kardinal yönlerle (Kuzey,Güney,Doğu,Batı) düşünme eğilimindeyimdir. *(I tend to think of my environment in terms of cardinal directions (N, S, E, W).)*
kesinlikle katılmıyorum 1 2 3 4 5 6 7 kesinlikle katılıyorum
(strongly disagree) *(strongly agree)*
6. Yeni bir şehirde çok kolay kaybolurum. *(I very easily get lost in a new city.)*
kesinlikle katılmıyorum 1 2 3 4 5 6 7 kesinlikle katılıyorum
(strongly disagree) *(strongly agree)*

7. Harita okumayı /haritayla yön bulmayı severim. *(I enjoy reading maps.)*
kesinlikle katılmıyorum 1 2 3 4 5 6 7 kesinlikle katılıyorum
(strongly disagree) *(strongly agree)*

8. Yol tariflerini anlamakta zorluk yaşarım. *(I have trouble understanding directions.)*
kesinlikle katılmıyorum 1 2 3 4 5 6 7 kesinlikle katılıyorum
(strongly disagree) *(strongly agree)*

9. Harita okuma konusunda iyiyimdir. *(I am very good at reading maps.)*
kesinlikle katılmıyorum 1 2 3 4 5 6 7 kesinlikle katılıyorum
(strongly disagree) *(strongly agree)*

10. Arabada yolcu olarak seyahat ettiğim zaman geçtiğim rotaları pek hatırlayamam. *(I don't remember routes very well while riding as a passenger in a car.)*
kesinlikle katılmıyorum 1 2 3 4 5 6 7 kesinlikle katılıyorum
(strongly disagree) *(strongly agree)*

11. Yol tarif etmekten pek hoşlanmam. *(I don't enjoy giving directions.)*
kesinlikle katılmıyorum 1 2 3 4 5 6 7 kesinlikle katılıyorum
(strongly disagree) *(strongly agree)*

12. Nerede olduğumu bilmek benim için önemli değildir. *(It's not important to me to know where I am.)*
kesinlikle katılmıyorum 1 2 3 4 5 6 7 kesinlikle katılıyorum
(strongly disagree) *(strongly agree)*

13. Uzun geziler için dolaşma/yön bulma planını başkalarının yapmasına izin veririm. *(I usually let someone else do the navigational planning for long trips.)*
kesinlikle katılmıyorum 1 2 3 4 5 6 7 kesinlikle katılıyorum
(strongly disagree) *(strongly agree)*

14. Sadece bir kez gezdiğim yeni bir rotayı genelde hatırlayabilirim. *(I can usually remember a new route after I have traveled it only once.)*
kesinlikle katılmıyorum 1 2 3 4 5 6 7 kesinlikle katılıyorum
(strongly disagree) *(strongly agree)*

15. Çevreme dair iyi bir "zihinsel haritam" yoktur. *(I don't have a very good "mental map" of my environment.)*
kesinlikle katılmıyorum 1 2 3 4 5 6 7 kesinlikle katılıyorum
(strongly disagree) *(strongly agree)*

APPENDIX E

POST-EXPERIMENT QUESTIONNAIRE PAPER

Labirentin içinde yön bulurken hareketinizi klavyedeki tuşlarla yönlendirmekte ne kadar zorlandınız? (*While way-finding in the maze, how much difficulty you had in controlling your movements with the arrow keys on the keyboard?*):

(none) hiç 1 2 3 4 5 6 7 çok fazla *(too much)*

Deneyin içindeki yön bulma görevlerinin zorluğunu 1-7 arasında numaralandırın. *(Rate the difficulty of the navigation tasks in the experiment on a scale of 1-7.)*

(too easy) çok kolay 1 2 3 4 5 6 7 çok zor *(too difficult)*

a. Rotayı oklar olmadan takip etmek *(traversing the route without arrow signs)*:
b. Öğrendiğim yollar kapandığında hedefi bulmak *(finding the target when the familiar paths are blocked)*:
c. Farklı bir noktadan başlayıp kapıyı bulmak *(finding the door starting from an unusual position)*:
d. En kısa rotayı oluşturmak *(generating the shortest path)*:
e. Haritayı seçmek *(choosing the map)*:

Sizce bu deney bilgisayardaki bir mekanda değil de gerçek bir mekanda gerçekleşseydi yön bulma performansınız şimdikine göre nasıl değişirdi? *(How do you think would your navigation performance have changed if the task was held in an actual place instead of a computer-based environment?)*

1	2	3	4	5	6	7
Çok daha kötü olurdu. *(It would be much worse.)*			Benzer olurdu. *(It would be similar.)*			Çok daha iyi olurdu. *(It would be much better.)*

Ne kadar süredir… *(For how long you have been…)*
İstanbul'dasınız? *(in Istanbul?)*:
Boğaziçi Üniversitesi'ndesiniz? *(in Boğaziçi University?)*:

Deneye gelmeden önceki gece kaç saat uyudunuz? *(How many hours did you sleep in the previous night?)*:
Hangi saatler arasında? *(Between which hours?)*:

APPENDIX F

CONSENT FORM

KATILIMCI BİLGİ ve ONAM FORMU

Boğaziçi Üniversitesi
İçgörü ve Navigasyon ilişkisi: İçeride ve Dışarıda Yön Bulma
Prof. Dr. Reşit Canbeyli (canbeyli@boun.edu.tr),
Adres: Boğaziçi Üniversitesi
Psikoloji Bölümü
34342, Bebek, İstanbul
Telefon: 0 212 359 71 29

Bu deney yön bulma ile farklı kavrayış türleri arasındaki bağlantıyı incelemektedir. Deney, yön bulma simülasyonu ve çeşitli problemlerin çözümünü içeren iki ana bölümden oluşmaktadır. Deney süreci ve sıralaması hakkında detaylı bilgi deneyi yürüten kişi tarafından deney başlamadan önce verilecektir. Deney, yaklaşık 1 saat sürecektir. Deneye katılmanız karşılığında size aldığınız PSY 101 ya da PSY 241 dersi için 1 kredi verilecektir.

Çalışmada isminiz ve bilgileriniz gizli tutulacaktır. Katılımınız tamamen isteğe bağlıdır. İstediğiniz zaman deneyi durdurabilir ve çalışmaya katılmaktan vazgeçebilirsiniz. **Lütfen sormak istediğiniz soruları deneyi yürüten kişiye çekinmeden sorunuz.**

Bana anlatılanları ve yukarıda yazılanları anladım**, anlamadığım kısımlar hakkında araştırmacıdan gerekli bilgileri aldım**. Bu formun bir kopyasını aldım. Çalışmaya katılmayı kabul ediyorum.

Katılımcı Adı-Soyadı: …………………………………..
İmzası:………………………………………………
Tarih (gün/ay/yıl): ..../.........../..............

Deney Sorumlusu Adı-Soyadı: …………………………………..
İmzası:………………………………………………
Tarih (gün/ay/yıl): ..../.........../..............

APPENDIX G

INSTRUCTIONS FOR NUMBER REDUCTION TASK

In each trial of the experiment, an 8-digit number string which is composed of the digits of 1, 4 and 9 will be presented on the screen. (Experimenter notes the digits of 1,4 and 9 and writes a sample string on a paper.) You are expected to process the digits in these strings by using two simple rules based on pair-wise comparisons. As you enter your responses, the responses will be presented as a second string below. The first comparison is supposed to be made between the first two digits of the given string and the subsequent comparisons between your response and the next digit in the original string.

The rules you will be using during the comparisons are Identity and Difference rules. According to the Identity Rule, if the two digits to be compared are identical, that digit is the product of the operation. According to the Difference Rule, if the digits in the pair are different, the product of the operation is the digit missing in the pair among the 1, 4 and 9 triad. (Experimenter completes the trial on the paper.) Only the final digit of the resultant response string will be recorded as your answer for that particular trial by the system and its accuracy will be checked. That is, even if you enter the previous digits of the response string incorrectly, as long as you fixed it until the final response and enter the final response accurately, the trial will be accepted as successful. In all trials throughout the experiment, your goal is to enter the correct response as quickly as possible.

Now, let's make a sample trial on the computer. Please put your fingers over the 1,4 and 9 buttons on the keyboard, you will be using only these buttons throughout the trials. (A real trial is opened in the E-prime program and the participant completes a trial.) As you see, just before the final operation a blank response box appears for you to enter your final response. Once you enter your response, if the response is correct it is presented in green; if incorrect, presented in red on the subsequent screen.

Now, let's make one more trial. (The participant completes the second trial.) The experiment consists of 6 blocks in total, in which you are expected to perform the same operation. After the first two blocks are completed, there will be a short break and I will come and open the second session which consists of 4 blocks. You can start the experiment when you are ready. (The experimenter leaves the experiment room.)

Deneyin her bir denemesinde ekranda 1,4 ve 9 rakamlarından oluşan 8 rakamlı bir sayı dizisi gösterilecek. (Deney sorumlusu bir kâğıda 1,4 ve 9 rakamlarını not alır ve örnek biz dizi yazar.) Bu dizilerdeki rakamları iki basit kuralı kullanarak ikişer ikişer karşılaştırmalarla işlemeniz bekleniyor. Siz cevabınızı bastıkça cevaplar aşağıda ikinci bir dizi olarak belirecek. İlk karşılaştırmayı verilen dizinin ilk iki rakamı arasında, sonraki karşılaştırmaları ise kendi cevabınızla orijinal dizinin bir sonraki rakamı arasında yapmalısınız.

Karşılaştırmaları yaparken kullanacağınız kurallar Aynılık ve Farklılık kuralıdır. Aynılık kuralına göre eğer karşılaştırılan rakamlar birbirinin aynısıysa cevap o rakama eşit olur. Farklılık kuralına göre eğer karşılaştırılan rakamlar farklıysa cevap 1, 4 ve 9 üçlüsünden çiftin içinde olmayan rakama eşit olur. (Deney sorumlusu kâğıt üzerinde örnek bir denemeyi tamamlar.) Oluşan bu cevap dizisinin yalnızca son rakamı sizin bu denemeye verdiğiniz cevap olarak sistem tarafından işlenecek ve doğruluğu kontrol edilecektir. Yani cevap dizisinin ilk rakamlarını yanlış basmış olsanız bile son cevaba gelene kadar düzelttiğiniz ve son cevabı doğru bastığınız sürece o deneme başarılı kabul edilecektir. Her denemede sizden beklenen doğru cevabı en kısa sürede basmanızdır.

Şimdi bilgisayarda örnek bir deneme yapalım. Lütfen parmaklarınızı klavyenin 1,4 ve 9 tuşlarına yerleştirin, denemeler boyunca sadece bu tuşları kullanacaksınız. (E-prime programında gerçek bir deneme açılır ve katılımcı bir denemeyi tamamlar.) Gördüğünüz gibi son karşılaştırmanın hemen öncesinde son cevabınızı girmeniz için boş bir cevap kutusu beliriyor. Cevabı tuşladığınızda eğer cevabınız doğruysa bir sonraki ekranda yeşil ile, yanlışsa kırmızı ile gösteriliyor.

Başka bir deneme daha yapalım. (Katılımcı ikinci denemeyi tamamlar.) Deney aynı işlemi uygulamanız beklenen toplam 6 bloktan oluşuyor. İlk iki blok tamamlandıktan sonra bir ara vereceğiz, ben gelip 4 bloktan oluşan ikinci kısmı açacağım. Hazır olduğunuzda deneye başlayabilirsiniz. (Deney sorumlusu odadan çıkar.)

APPENDIX H

CORRELATIONS BETWEEN THE SUCCESS SCORES IN 7 NAVIGATION TASKS

Correlations

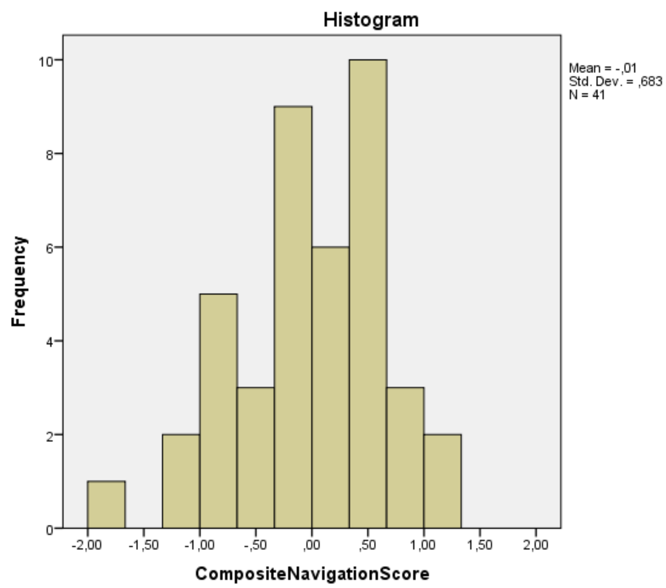
		Success Score in Self-Guided Path Following Task	Success Score in Blocked Path Task	Success Score in Different Starting Position Task	Success Score in Optimum Path Task	Success Score in Relative Position Task/virtual	Success Score in Relative Position Task/actual	Success Score in Map Recognition Task
Success Score in Self-Guided Path Following Task	Pearson Correlation	1	,260*	,215	,286	,257*	,102	,159
	Sig. (2-tailed)		,038	,089	,070	,041	,423	,209
	N	64	64	64	41	64	64	64
Success Score in Blocked Path Task	Pearson Correlation	,260*	1	,459**	,588**	,249*	,359**	,331**
	Sig. (2-tailed)	,038		,000	,000	,047	,004	,007
	N	64	64	64	41	64	64	64
Success Score in Different Starting Position Task	Pearson Correlation	,215	,459**	1	,563**	,122	,377**	,146
	Sig. (2-tailed)	,089	,000		,000	,339	,002	,250
	N	64	64	64	41	64	64	64
Success Score in Optimum Path Task	Pearson Correlation	,286	,588**	,563**	1	,319*	,407**	,360*
	Sig. (2-tailed)	,070	,000	,000		,042	,008	,021
	N	41	41	41	41	41	41	41
Success Score in Relative Position Task/virtual	Pearson Correlation	,257*	,249*	,122	,319*	1	,036	,115
	Sig. (2-tailed)	,041	,047	,339	,042		,780	,367
	N	64	64	64	41	64	64	64
Success Score in Relative Position Task/actual	Pearson Correlation	,102	,359**	,377**	,407**	,036	1	,055
	Sig. (2-tailed)	,423	,004	,002	,008	,780		,667
	N	64	64	64	41	64	64	64
Success Score in Map Recognition Task	Pearson Correlation	,159	,331**	,146	,360*	,115	,055	1
	Sig. (2-tailed)	,209	,007	,250	,021	,367	,667	
	N	64	64	64	41	64	64	64

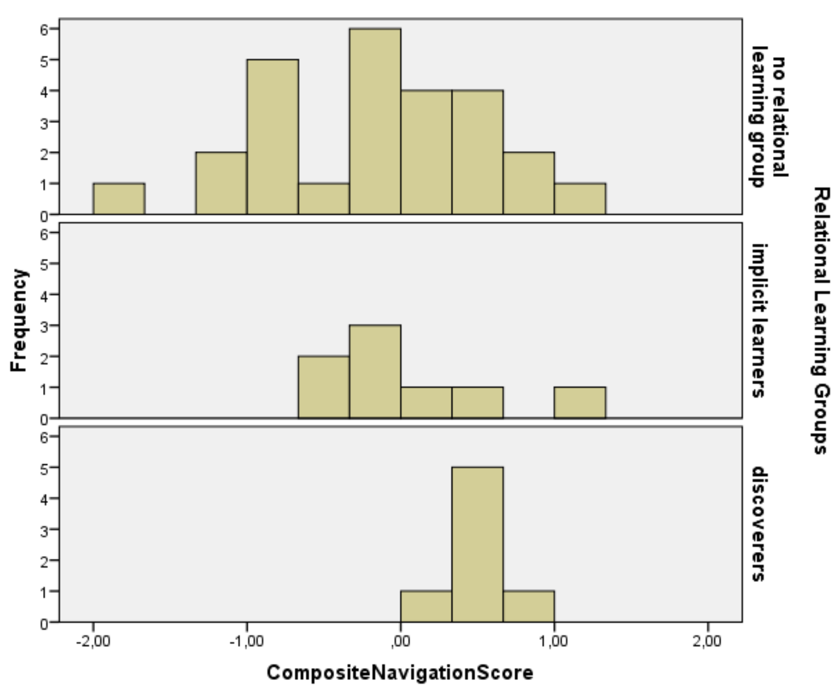
*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

APPENDIX I

THE HISTOGRAMS OF COMPOSITE NAVIGATION SCORES OF ALL PARTICIPANTS AND OF RELATIONAL LEARNING GROUPS





APPENDIX J

DESCRIPTIVE STATISTICS FOR PERFORMANCE MEASURES OF RELATIONAL LEARNING GROUPS IN INDIVIDUAL NAVIGATION TASKS

Table F1. Performance measures of relational learning groups in Blocked Path, Different Starting Position, Optimum Path and Relative Positions tasks

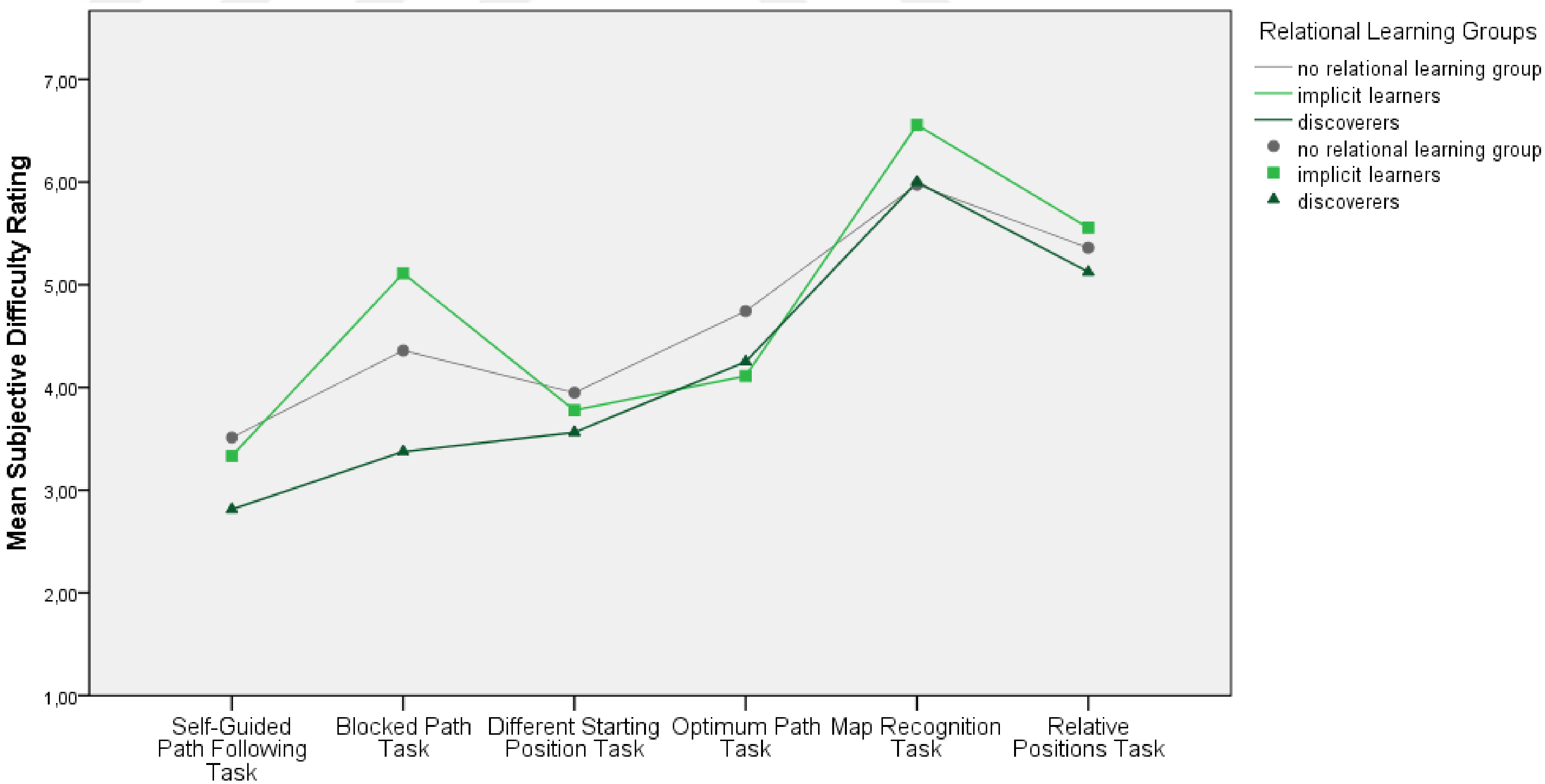
	Total num. of wrong turns (count)				Total Pathlengths (maze units)		Angular errors (degrees)			
	Blocked Path Task		Different Starting Position Task		Optimum Path Task		Relative Positions Task			
							Virtual		Actual	
	M	SD	M	SD	M	SD	M	SD	M	SD
Discoverers	8	5.26	4	2.77	380.18	58.86	82.68	23.75	19.05	8.38
Implicit Learners	16.13	8.46	5.75	3.45	468.16	153.86	72.50	27.36	29.79	19.71
None	17	9.19	6.31	4.27	591.88	266.45	89.47	35.86	31.47	22.00

Table F2. Performance measures of relational learning groups in Self-Guided Path Following and Map Recognition tasks

	Self-Guided Path Following Task			Map Recognition Task		
	successful in both attempts	successful in one attempt	not successful in any attempt	accurate in a short time	accurate in a long time	inaccurate
Discoverers	9	2	5	6	3	7
Implicit Learners	3	3	3	1	2	6
None	13	5	21	4	8	27

APPENDIX K

SUBJECTIVE DIFFICULTY RATINGS OF RELATIONAL LEARNING GROUPS FOR DIFFERENT NAVIGATION TASKS



Note. Subjective difficulty ratings are based on a 7-point scale: 1(*too easy*), 7 (*too difficult*).

REFERENCES

Ash, I. K., Jee, B. D., & Wiley, J. (2012). Investigating insight as sudden learning. *The Journal of Problem Solving*, *4*(2): 1-27.

Ayaz, H., Allen, S. L., Platek, S. M., & Onaral, B. (2008) Maze Suite 1.0: A complete set of tools to prepare, present, and analyze navigational and spatial cognitive neuroscience experiments. *Behavior Research Methods 40*(1): 353-359.

Börsch-Haubold, A. (2006). Sleep and learning. *Science in School*, *3*(5), 63-66. Retrieved from http://www.scienceinschool.org/2006/issue3/sleep/exercises

Burgess, N. (2006). Spatial memory: How egocentric and allocentric combine. *Trends in Cognitive Sciences*, *10*(12), 551-557.

Dienes, Z., & Altmann, G. (1997). Transfer of implicit knowledge across domains: How implicit and how abstract? In D. Berry (Ed.), *How implicit is implicit learning* (pp. 107-123). New York, NY: Oxford University Press.

Dietrich, A., & Kanso, R. (2010). A review of EEG, ERP, and neuroimaging studies of creativity and insight. *Psychological Bulletin*, *136*(5), 822-848.

Eichenbaum, H., & Cohen, N. J. (2014). Can we reconcile the declarative memory and spatial navigation views on hippocampal function? *Neuron*, *83*(4), 764-770.

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

Haider, H., & Rose, M. (2007). How to investigate insight: A proposal. *Methods*, *42*(1), 49-57.

Hegarty, M., Richardson, A. E., Montello, D. R., Lovelace, K., & Subbiah, I. (2002). Development of a self-report measure of environmental spatial ability. *Intelligence*, *30*(5), 425-447.

Hettinger, L. J., & Riccio, G. E. (1992). Visually induced motion sickness in virtual environments. *Presence: Teleoperators & Virtual Environments*, *1*(3), 306-310.

Kounios, John, and Mark Beeman. (2009). The Aha! Moment the cognitive neuroscience of insight. *Current Directions in Psychological Science*, *18*(4), 210-216.

Kravitz, D. J., Saleem, K. S., Baker, C. I., Ungerleider, L. G., & Mishkin, M. (2013). The ventral visual pathway: an expanded neural framework for the processing of object quality. *Trends in Cognitive Sciences*, *17*(1), 26-49.

Lang, S., Kanngieser, N., Jaśkowski, P., Haider, H., Rose, M., & Verleger, R. (2006). Precursors of insight in event-related brain potentials. *Journal of Cognitive Neuroscience*,*18*(12), 2152-2166.

Luo, J., and Niki, K. (2003). Function of hippocampus in "insight" of problem solving. *Hippocampus, 13*(3), 316-323.

Maguire, E. A., Burgess, N., & O'Keefe, J. (1999). Human spatial navigation: cognitive maps, sexual dimorphism, and neural substrates. *Current Opinion in Neurobiology*, *9*(2), 171-177.

Maguire, E. A., Gadian, D. G., Johnsrude, I. S., Good, C. D., Ashburner, J., Frackowiak, R. S., & Frith, C. D. (2000). Navigation-related structural change in the hippocampi of taxi drivers. *Proceedings of the National Academy of Sciences*, *97*(8), 4398-4403.

Mallot H.A., Gillner S., van Veen H.A.H.C., Bülthoff H.H. (1998) Behavioral experiments in spatial cognition using virtual reality. In: Freksa C., Habel C., Wender K.F. (Eds) *Spatial cognition: Lecture notes in computer science*, (pp. 447-467), Berlin, Germany: Springer.

Marchette, S. A., Bakker, A., & Shelton, A. L. (2011). Cognitive mappers to creatures of habit: differential engagement of place and response learning mechanisms predicts human navigational behavior. *The Journal of Neuroscience*, *31*(43), 15264-15268.

Milivojevic, B., Vicente-Grabovetsky, A., & Doeller, C. F. (2015). Insight reconfigures hippocampal-prefrontal memories. *Current Biology*, *25*(7), 821-830.

Newell, B. R., & Bright, J. E. (2002). Evidence against hyperspecificity in implicit invariant learning. *The Quarterly Journal of Experimental Psychology: Section A*, *55*(4), 1109-1126.

O'Keefe, J.& Nadel, L. (1978) *The hippocampus as a cognitive map*, Oxford, England: Clarendon Press.

Preston, A. R., Shrager, Y., Dudukovic, N. M., & Gabrieli, J. D. (2004). Hippocampal contribution to the novel use of relational information in declarative memory. *Hippocampus*, *14*(2), 148-152.

Reber, A. S. (1967). Implicit learning of artificial grammars. *Journal of Verbal Learning and Verbal Behavior*, *6*(6), 855-863.

Reber, P. J. (2013). The neural basis of implicit learning and memory: a review of neuropsychological and neuroimaging research. *Neuropsychologia*, *51*(10), 2026-2042.

Rose, M., Haider, H., Weiller, C., & Büchel, C. (2002). The role of medial temporal lobe structures in implicit learning: an event-related FMRI study. *Neuron*, *36*(6), 1221-1231.

Schiller, D., Eichenbaum, H., Buffalo, E. A., Davachi, L., Foster, D. J., Leutgeb, S., & Ranganath, C. (2015). Memory and space: Towards an understanding of the cognitive map. *Journal of Neuroscience*, *35*(41), 13904-13911.

Schneider, W., Eschman, A., & Zuccolotto, A. (2002) *E-Prime user's guide*. Pittsburgh: Psychology Software Tools Inc.

Stephen, D. G., Boncoddo, R. A., Magnuson, J. S., & Dixon, J. A. (2009). The dynamics of insight: Mathematical discovery as a phase transition. *Memory & Cognition*, *37*(8), 1132-1149.

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

Tolman, E. C. (1951). *Purposive behavior in animals and men*. Berkeley, CA: University of California Press.

Tversky, B. (1991). Spatial mental models. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 27, pp. 109-145). San Diego, CA: Academic Press.

Verleger, R., Rose, M., Wagner, U., Yordanova, J., & Kolev, V. (2013). Insights into sleep's role for insight: Studies with the number reduction task. *Advances in Cognitive Psychology*, *9*(4), 160.

Wagner, U., Gais, S., Haider, H., Verleger, R., & Born, J. (2004). Sleep inspires insight. *Nature*, *427*(6972), 352-355.

Wang, R.F. and Spelke, E.S. (2002) Human spatial representation: insights from animals. *Trends in Cognitive Science*, *6*(9), 376–382.

Woody, W. D., & Viney, W. (2017). *A history of psychology: The emergence of science and applications*. New York, NY: Taylor & Francis.