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Bachelor Thesis Cognitive Science

# A module dependent effect in the Corsi block tapping task

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# Abstract

This study investigates the effects of variations in the Corsi block tapping task. For this four experiments were conducted. Participants viewed the sequence of fields either on a computer screen or on the floor in a live environment. For reproduction of the sequence they either clicked with a mouse on a computer or walked on the floor. It was found that, walking speed decreases with increasing difficulty. The worst performance was found in the condition in which participants watched the sequence on the screen and reproduced it by walking on the floor. The best performance was found when watching the sequence on the screen and also reproducing it on the screen. Walking seems to reduce performance a lot. Especially when participants rotated a lot performance was impaired. Participants on the other hand believed that they were more influenced in their performance by a translation than by walking. They were also better remembering the beginning of a sequence than the end. Especially during the walking conditions. Generally this study supports the view that walking takes up more cognitive resources than traditionally thought.

# Acknowledgements

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# Contents

# List of Figures

# List of Tables

# List of Abbreviations

| | |
|---|---|
| **CBT** | Corsi block tapping task |
| **PTA** | Perspective-Taking Ability |
| **SS** | screen/screen condition |
| **SF** | screen/floor condition |
| **FS** | floor/screen condition |
| **FF** | floor/floor condition |
| **PRW** | Performance Right Wrong, completely right vs wrong routes |
| **PAF** | Performance Amount of Fields, the amount of right fields is measured |
| **PLS** | Performance Longest Sequence, length of the longest sequence |

# Chapter 1

# Introduction

Is there a difference in the reproduction and memorisation of paths and patterns? If so, what exactly is it? Do different cognitive mechanisms and cortical areas play a role? Does the difference lie in the perception, the memorisation or the reproduction? In order to at least narrow some of these questions down a study was conducted in which pattern as well as route memorisation and reconstruction were evaluated. The Corsi block tapping task was used in four modified ways, one for route memorisation and reproduction, one for pattern memorisation and reproduction. Memorisation speed and reproduction speed was held constant. Furthermore the cross-modal versions: pattern memorisation and route reproduction and route memorisation and pattern reconstruction were evaluated.

In this chapter we will first take a look at the Corsi block tapping task, then at possible important mechanisms like working memory, spatial updating and walking. At the end of this chapter we will link this to the current study.

## 1.1 The Corsi block tapping task

The Corsi block tapping task (CBT) is a classical alternative to measure the working memory span. It was first introduced by Corsi (1972). Nine wooden cubes are positioned in front of the subject. The examiner taps a certain sequence of blocks at a rate of one block per second. This sequence has to be memorised and reproduced by the subject. Every couple of trials the sequence grows longer. The amount of correctly reproduced blocks is known as the memory or Corsi span of the subject. It is usually about 5 blocks long (Kessels et al. 2000). Especially its nonverbal character makes it a useful alternative in memory studies. It was quickly adopted by a large number of researchers as a measurement for visuospatial memory.

In a review paper by Berch et al. (1998) the high variability of the CBT was considered a result from many little variations in the setting of the task. Those variations included differences in block color, number, size, placement in the display area, pointing procedure, the block-tapping rate, the starting point, the number of trials per level, characteristics of the sequences and the order of the recall.

Later studies were especially interested in the last two points, which seem to be the most influential, when it comes to performance. For example Busch et al. (2005) took a look at the sequence complexity and ended up verifying the usefulness of the CBT as a memory measure. Here researchers tested 94 young adults with the CBT and found a great consistency within a level, the same length of a sequence. The only other determiner seemed to be the number of path crossings. This number also indicates the relative complexity of the path. It is quite intuitive that at a level seven or eight a path that has no crossings is basically one that goes in a circle where as one that has many crossings has no such geometric form.

Another study by Kessles (2008) explored the relationship of the verbal and the spatial working memory factor. For this a comparison between the CBT and the classical digit span task was made. The results showed that while performance in the digit span task decreases when replicating the sequence backwards, the performance in the CBT remains the same. This suggests a dissociation between the verbal and the non-verbal components of the working memory. It also makes the CBT a quite interesting method for measuring a different kind of memory.

The CBT is also interesting because it enable researchers to investigate a couple of mechanisms. It is not only a memory task, but also a motor task, for the subject needs to tap the blocks with his finger. The CBT can also be modified rather easily. It is now commonly used on a computer screen, not representing blocks in a 3D-version, but as quadrates in 2D as seeing the blocks from above. This also simplifies analysis and makes it easier to increase difficulty for the subjects.

An alternative method is to let the subject actually walk the sequence of blocks using a greater scale (Piccardi et al. 2008). They can either view the sequence directly on the live environment or on a computer screen. When walking live, mechanisms like spatial updating and mental rotation play an important role. When first watching the sequence on the Computer screen subjects need to translate the pattern on the screen into the pattern on the floor, which also depends on additional cognitive resources. What now seems likely is that performance should decrease due to more cognitive resources needed. But what exactly are those mechanisms filling up the resources?

We now take a closer look at the working memory, spatial updating and walking.

## 1.2 Working Memory

Working Memory is one of the most fascinating and most discussed paradigms in psychology and other sciences. It can be defined as the system that is responsible for the temporary maintenance and manipulation of information. Baddeley (1986) suggested a model in which the maintenance of information through memorizing is the factor determining whether or not the information will be translated into the long-term memory. Important for the size of the memory span is, according to Baddeley, the speed in which we can memorize the given material in. Baddeley's model consisted of three components: the central executive, the articulatory or phonological loop and the visuospatial sketchpad. In 2000 Baddeley added another subsystem the so-called episodic buffer. Baddeley's model is shown in figure 1.1.

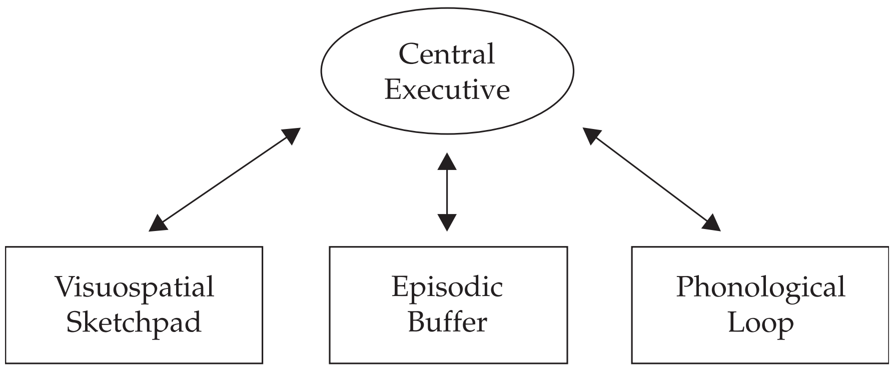


**Figure 1.1:** Model of working memory by Baddeley. This figure shows the basic model of the working memory as proposed by Baddeley 1986 and revised by Baddeley in 2002. The Central Executive is the module that is responsible for attention focusing, dividing and switching. The Visuospatial Sketchpad evaluated visual and spatial information. The Phonological Loop revises auditory information. The Episodic Buffer is a capacity for integrated information that can be retrieved consciously. (Figure from Baddeley 2002)

The central executive works as an attentional controller. It is supported by the articulatory loop, which is concerned with verbal and acoustic material and the visuospatial sketchpad, which is concerned with visual information. The episodic buffer functions as a storage system using multimodal coding.

For a long time the central executive was viewed as a homunculus, organizing tasks and controlling the subsystems. Since the introduction of the episodic buffer it is considered to be a mere attentional system. It is said to focus attention, divide attention and switch attention (Baddeley 2000). It is therefore the basis for evaluating the importance of information and the need to remember it.

The episodic buffer is considered to be a buffer in the sense that it is a limited capacity interface between systems which use different codes. The episodic part means that it stores integrated scenes. Overall it functions as a memory aid, because information can be retrieved from it through conscious means. With it more than one source of information can be considered at a time and so a model of the environment can be developed which can be used to solve problems and plan future behavior.

In 1975 Baddeley et al. found that the immediate memory span for a word memorisation task is not constant. Instead it depends on the length of the words that the subject is asked to recall. They also suggested that however many words a subject could read in two seconds, this was the number of words the subject was able to recall. Baddeley et al. also asked subjects to make a sound during memorization and found that the word length effect disappeared when the words where presented visually but not when presented auditory.

The auditory loop has two components: a phonological store and an articulatory rehearsal system. In the phonological store the information is held but grows less distinct over time. The rehearsal system refreshes the information. It limits the capacity of the articulatory loop, for only a certain amount of information can be refreshed in a certain amount of time. When there is too much information it is degenerated before the rehearsal system has a chance to restore it.

Most interesting to our topic is the so-called visuospatial sketchpad in which visuospatial information is temporarily held. This means that the sketchpad plays an important role in spatial orientation and in solving visuospatial problems. Baddeley suggests that it forms an interface between visual and spatial information and either the long-term memory or the senses can access the visuospatial sketchpad.

In a study by Bruyer and Scailquin (1997) the authors tried to investigate the functioning and the organization of the visuospatial sketchpad further by designing three inference experiments one with an articulatory suppression task, one with a spatial suppression task and one with a random generation task.

In the articulatory suppression task they found that the visuospatial sketchpad is needed for mental imagery, that it is mostly independent of the articulatory loop and that image generation may require more attentional resources than so far expected. For the spatial suppression task the most interesting finding was that there may be a dissociating within the visuospatial sketchpad between a passive store of information and an active transformation of information. Their findings pointed in that direction but failed to be significant. From the random generation task they suggest that mental rotation requires additional attentional resources.

Therefore, the authors conclude that the by Logie (1995) suggested subparts of the visuospatial sketchpad "visual cache" and "inner scribe" may be similar to the organization of the articulatory loop with the storage and the rehearsal part. This also means a dissociation of spatial and visual information within this visuospatial sketchpad.

Overall, the working memory seems to be a multiple component system with many subsystems.

## 1.3 Spatial Updating

When we go for a walk outside, not really caring for what direction we are walking, in most situations we are still able to determine in which direction we would have to walk in order to get back to our starting position. This is due to an involuntary process known as spatial updating. When walking, some internal representation of our position in space is updated, so that we have a measure of how far and in what direction we have moved from a starting position or in comparison to a reference point. This fascinating process seems to be not only involuntarily but also unwillingly, because we usually do not seem to be able to prohibit this process. But there are also inter-individual differences that are quite strong. Some people never lose orientation, others are easily confused by a couple of turns. But what gives us the ability to keep our representation up to date?

Rieser (1989) investigated the role of the object-to-object relation and the observer-to-object relation and their possible part in rotations and translations. In three experiments he found that translation seems to be based on an environment-centered representation whereas rotation also needs the person-centered representation.

In the first Experiment Rieser made participants learn a certain set-up of objects in a room and then ask them, with closed eyes to point at the objects in order to make sure they had learned the set-up. After that, participants performed in one of two conditions. In the first condition subjects had to imagine a translation, in the second a rotation. Consistent over each subject Rieser found that a rotation was considered more difficult than a translation.

In the second and third experiment he investigated these differences further. For the imagined rotation trials he found an effect of the magnitude of rotation, the greater the degree of rotation the worse the performance and the longer the reaction time. This seems to be in line with the results of the classical experiment by Shepard and Metzler (1971) about Mental Rotation.

What seems to be the most interesting finding is that performance in the baseline condition and in the translation trials did not differ, whereas performance in the baseline condition and in the rotation trials did significantly differ. This seems to be evidence for different processes needed for translation and rotation or for additional processing needed for rotation in comparison to translation. Rieser concluded that this could be due to accessing different knowledge: Translation uses the object-to-object relations, whereas rotation also uses the person-to-object relations.

Another point is that Rieser found that after actual locomotion performance increased significantly. When actually moving to the new station point, subjects were able to be more accurate about pointing at the target and also after rotation they were more precise.

Klatzky et al. 1998 investigated whether there was a difference between real, imagined and simulated locomotion and the resulting updating processes. For this, they used a simple two legged setup. This means there was a three meter walking leg, followed by a 90 degree turn to the right and again a three meter walking leg. Subjects either walked this setup in reality, they imagined walking it or they watched somebody else walk it. Then they had to turn until they faced their original position. Klatzky et al. found that performance was best when subjects walked themselves, than when they watched somebody else walk, which was still better then when they imagined walking. Without the physical turn subjects failed to update their position correctly.

This leads to the common opinion that spatial updating is a mechanism that does not rely merely on vision but also on information from proprioception like vestibular sensing or kinesthetic feedback from muscles, tendons and joints (Frissen et al. 2011). There is also evidence that optical flow (Srinivasan et al. 1996) and magnetic fields (Frier et al. 1996) may play a role in spatial updating. However the last two points have only been analyzed in insects such as ants and honeybees. It is therefore possible that humans do not rely on those sources of information.

Frissen et al. (2011) investigated the role of vestibular and proprioceptive information for spatial updating. They created a uni-modal task in order to take a look at these processes separately. What they found when manipulating the information sources was that even though both inputs were in conflict, they were still integrated and a compromise between them was found. When only one information source was given, the vestibular information led to better results than the proprioceptive information. However this might be, according to the authors, a problem of the task itself and not of the general less informative quality of proprioceptive information.

All these experiments along with many others show the importance of modality integration for accurate spatial updating.

Wang and Simons (1999) were interested in the updating mechanisms when a viewer changes his position or when the world around him changes. For this they positioned a table with an arrangement of objects on it in front of a subject. The table could be occluded from view with curtains. Connected to the table was a handlebar which the subjects could see at all times. With this handlebar the table could be turned. In the curtains were two windows.

Subjects were now asked to perform one of four different tasks: 1. walk from one window to the other, 2. turn the table with the handlebar, 3. move to the other window passively or 4. the table was turned for them. On the table they had to recognize any changes after the viewpoint changing. It turned out that the best performance was reached, when the subjects moved actively, than when they were moved passively. The third best performance was achieved when subjects moved the table themselves and they performed worst when the table was moved for them.

Therefore, changes in the scenery seem to be hard to detect when a viewpoint change occurs that is not due to self-motion. This may underline the difference in updating when one is moving in comparison to when something else is moving. Subjects where fully aware of the movement of the table because they either turned it themselves or they saw the handlebar moving. Hence they had all the information needed to make an update of the table's orientation.

In this sense spatial updating occurs during self-motion. The other mechanism needed when something else is turned is called mental rotation.

## 1.4 Walking

Walking has long been thought of as a ballistic, automatic motor task. Burke et al. (2001) talk about a central pattern generator that produces a rhythmic moter command. Therefore walking has been classically viewed as a task that does not depend greatly on cognitive functions. However in the last couple of years evidence that points into the opposite direction increased. First stability of gait and balanced was researched (Sheridan et al. 2003) and it was found that during a dual task these factors would decrease. Yogev-Seligmann et al. (2008) reviewed many studies and concluded that in young healthy adults walking speed decreases with increasing difficulty in a dual task. Walking therefore might be a task that involves more cognitive resources than so far thought of.

## 1.5 Concerning the study

In the CBT, subjects need to use visuospatial processes. They use their working memory, especially the visuospatial sketchpad in order to remember the sequence. Moreover, certain transformations need to be fulfilled, so that motor commands can be given. For these transformations spatial updating may play an important role. It is certainly of big importance when the CBT becomes a walking task, in which subjects have to move through space in order to reproduce the sequence. Here motor commands are produced on the go, but only after a mental presentation of what everything should look like is made.

Röser et al. (ongoing work) did a study in which two different experiments concerning the CBT were constructed. One was a figural condition in which participants saw the sequences on a computer screen. If a square was part of the sequence a circle would appear within it. After the last circle was shown, participants had to reproduce the sequence by clicking on the squares on the screen. In the other experiment participants again watched the sequence on the screen but then had to walk in a 5m x 5m area in which the same pattern of squares was presented. They found that the performance in the figural condition was significantly better than the one in the walking condition.

My bachelor thesis is based on the study of Röser et al. (ongoing work). For it a study was created with four different experiments using the CBT. In one experiment subject had to memorise the corsi-sequence watching it displayed on a computer screen and reproduce it with clicking on the screen (experiment SS). In the next experiment subjects saw the sequence again on a computer screen but had to reproduce it by walking the pattern on the floor (experiment SF). Another experiment displayed the sequence on the floor and had participants reproduce it on the screen (experiment FS) and the last experiment showed the sequence on the floor and subjects reproduced it on the floor as well (experiment FF). Walking speed, performance and rotation were evaluated. There are three main hypothesis:

1. Walking speed will decrease with the increasing of difficulty.

2. Performance will differ between the experiments.

3. Routes in which participants have to rotate a lot will be harder and therefore have a worse performance score.

# Chapter 2

# Method

## 2.1 Participants

15 subjects took part in this study. One subject had to be excluded due to measuring difficulties. All were university students or still in school. There were six male participants, mean age = 21.83 years, SD = 2.228 and eight female, mean age = 21.12 years, SD = 0.991. They all had normal or corrected to normal vision. Five subjects were participating without any payment, four received 2.5 subject hours and six received 8 euros per hour which gives them a total payment of 20 Euros.

## 2.2 Material and set-up

### 2.2.1 Location

The experiments took place in a large room with no windows (see figure 2.1 a.). On one side of the room three experimental computers were positioned. One (System: Microsoft Windows XP, Professional, Version 2002, Intel(R), Pentium(R), 4CPU 3.00 GHz, 2.99 GHz, 1,50 GB RAM) of them controlled 15 flashlights (LED TL 3W HP: LED - Taschenlampe 3W LED, Zoom, 130lm) installed on the ceiling. Another computer (System: Microsoft Windows XP, Professional, Version 2002, Intel (R), Pentium(R) 4CPU 3.00GHz, 2.99 GHz, 0,99 GB RAM) was used to control the motion tracker. The next computer(System: Microsoft Windows XP, Professional, Version 2002, Intel(R) Core(TM), i3-2100CPU @ 3.10 GHz, 3.09 GHz, 3,16 GB RAM, Monitor of this PC (SyncMaster 931BF, Samsung, 1280x1024, 32 Bit, 60Hz)) was used by the participants only when doing the Perspective Taking Ability (PTA) task and experiment one. Participants also used a Laptop (System: Microsoft Windows XP, Professional, Version 2002, Dell PRECISION M70, Intel(R) Pen-

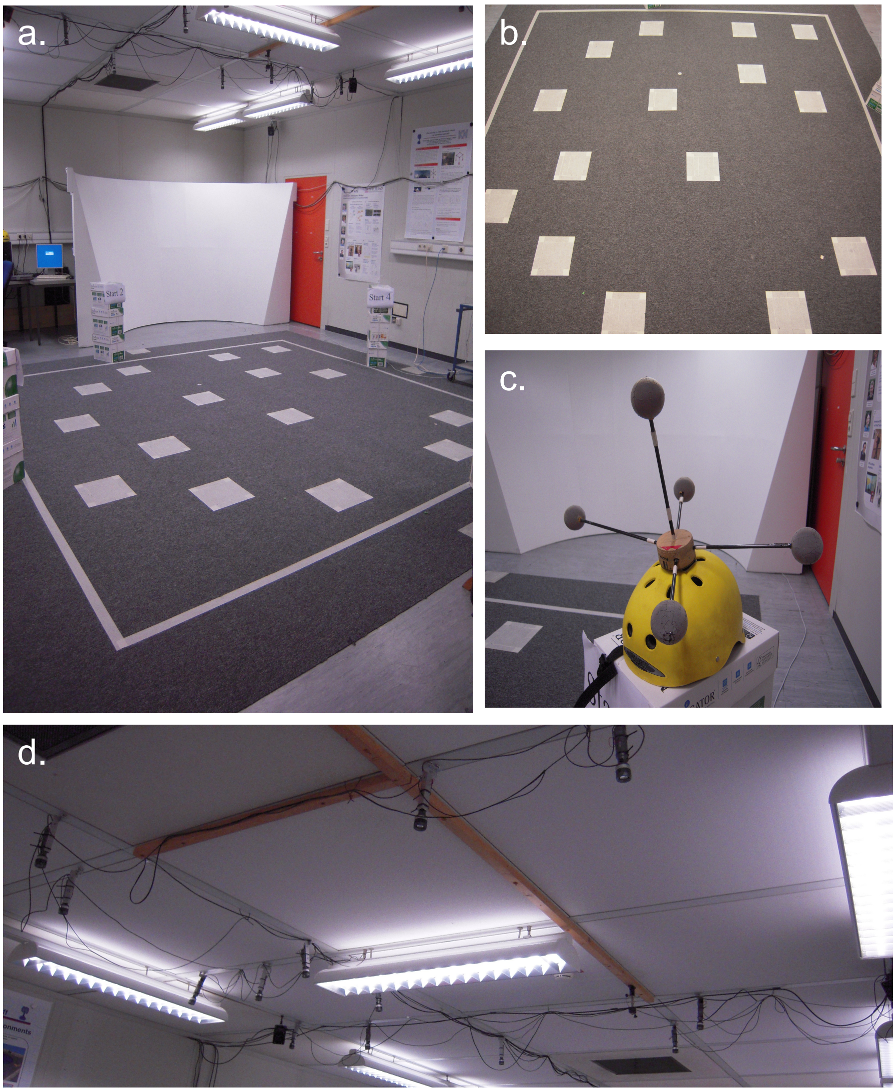


**Figure 2.1:** Experimental Room. a. Shows the room all experiments took place in. b. shows the carpet participants walked on, with the pattern from starting position 1. c. shows the helmet subjects were wearing when walking. The balls on top of the helmet are engulfed in infra red light reflecting foil. This reflection is detected by the cameras, so the movement is recorded. d. shows the flashlight construction on the ceiling. The flashlights are arranged in a way that they shine directly on the fields of the pattern displayed in b.

tium(R)M, 1.73 GHz, 1,00 GB RAM, Screen: NVIDIA Quadro FX Go 1400, 1680x1050, 32 Bit, 60Hz).

On the floor of the experimental room sat a 5m x 5m carpet as shown in figure 2.1 b. On the carpet 15 white squares were positioned right beneath the 15 flashlights, so the white squares could be lit by the flashlights. The flashlight construction on the ceiling is presented in figure 2.1 d. The squares were distributed in a 4m x 4m area which was outlined with white stripes. In the middle of each side was a starting position marked as starting point with the words “Start 1” up to “Start 4”. These signs were sticking to an about 1.10 m high rack. On top of this rack the laptop could be positioned. The squares were arranged in a way that no apparent pattern could be detected. There was an attempt to limit the amount of geometric figures that could be deducted from the arrangements of the squares. The same pattern was used on the computer screen. It would always turn, so that the starting position was on the bottom part of the screen to mimic the view on the field (figure 2.1 a.,b.).

When walking the participants had to wear a helmet on top of which a target with five balls was attached (see figure 2.1 c.). They were also wearing over-shoes with a ball on each shoe. These balls were engulfed in infrared-light reflecting foil. The light they reflected was recorded by six infrared cameras positioned in the four corners of the room and in the middle, facing the carpet area. These cameras belonged to the ARTrack/Dtrack from A.R.T. GmbH Weilheim, Germany and ran with DTrack version 1.22.2.

The computer attached to the cameras recorded the movement of the participants. With this the position and also the facing direction of the subjects was traced in a frequency of 60 Hz. With this position, walking speed and rotation could be calculated. The computer controlling the flashlights was connected to them via a binary transitor connected with a parallel port. So every flashlight could be turned on individually. The software used was MatLab (R2013a (8.1.0.604), 32-bit(win32), Feb. 15, 2013). All programs were written by Andrea Röser and only minimally adjusted after the first four participants. The last computer was used only by the participants. It also had MatLab (R2011b(7.13.0.564), 32-bin(win32), August 14, 2011 ) running for the experiment SS. The PTA task was also conducted on this computer using ”Computerized Perspective-Taking Ability (PTA) Test” software by MM Virtual Designs LLC and Rutgers University.

The laptop, participants carried with them and placed it on top of the racks by the starting positions during experiment two and three. It had Matlab (R2013a (8.1.0.604), 32-bit(win32), Feb. 15, 2013) on it. Via a wireless connection it was connected to the computer controlling the motion tracker, so that the laptop could start and stop the recording the movements of the participants.

### 2.2.2 Programs

For the experiments four different programs were used.

There was also an additional program just for the pre-test. The program used in experiment 1, the screen/screen condition (SS) showed the pattern of squares on a computer screen. The sequences were presented by highlighting one spare at a time for 1 second. Participants were asked to reproduce the sequence by clicking in the right fields after all had been shown. There was no feedback whether they clicked in the correct field, only when participants missed the field and clicked in the free space all squares would light up red.

In experiment 2, the screen/floor condition (SF) participants were using the laptop on which they were shown the sequence, which they had to reproduce by walking on the carpet with the helmet on. Their movement was recorded.

In experiment 3, the floor/screen condition (FS) the flashlights were used to light up the squares on the floor and thus present the sequence. Participants had to reproduce it on the laptop which they positioned at every starting position.

In experiment 4, the floor/floor condition (FF) participants saw the sequence light up on the floor and also had reproduce it on the floor walking to the squares that had just lit up.

### 2.2.3 Levels

Each experiment had six levels. Each level had four trials, that makes a total of 24 trials per experiment. In every level subject started from every starting position, which in SF, FF and FS meant that participants had to move to a different position for each trial in a level. For SS, SF and FS the pattern of squares displayed on the monitor was turned so that the starting position was always on the bottom of the screen, and therefore subjects viewing direction. In level 1 participants had to memorise and reproduce sequences of the length 3, in level 2 of the length 4 and so on untill level 6 in which they had to memorise and reproduce sequences of the length 8.

### 2.2.4 Routes

There were four different blocks of routes, one for each experiment. They were contributed equally between the subjects so that each route was used about equally often in each experiment. Block 1.1 and 1.2 consisted of the same 24 routes in which the order within each level was changed, to limit learning effects. Block 2.1 and 2.2 were made up of 24 new routes and again only differed in order of route presentation within a level. Figure 2.2 is an example of such routes. Here the first level of block 1.1 is presented. The total distance of a route was kept fairly constant in order to ensure that no effects of length or distance would appear.

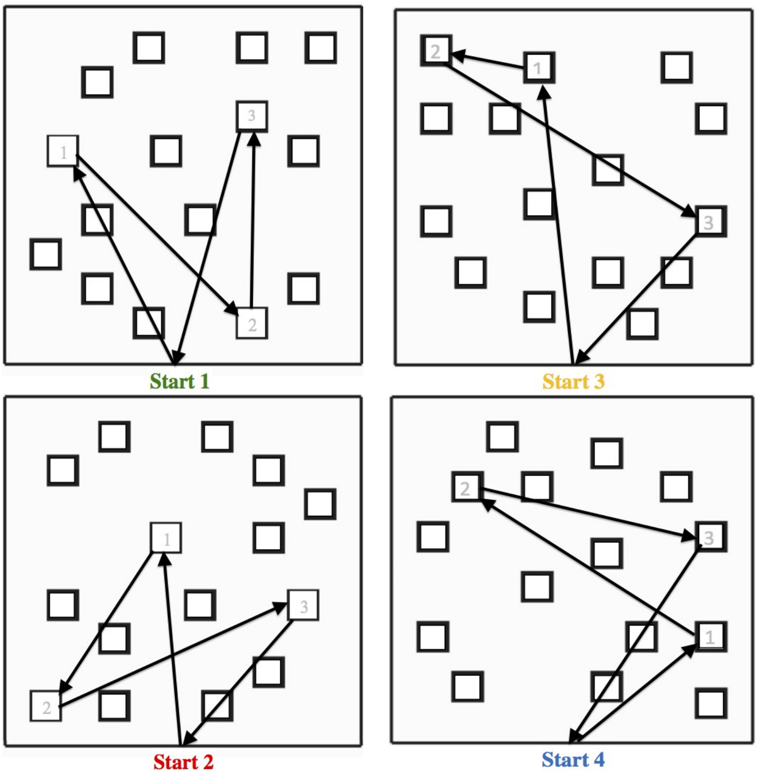


**Figure 2.2:** Example of routes. This figure shows the routes of the first level of block 1.1. First subjects started from start 1, then start 3, then start 2 and finally start 4. Each route consisted of three fields. If participants were watching the sequence on a computer screen the starting position would be presented on the bottom.

## 2.3 Procedure

### 2.3.1 General procedure

Participants received a friendly greeting and were given a brief instruction on what they should do. They signed a consent form, and filled out a short personal information sheet stating their full name, age, gender and their study course.

After this they were instructed to put on the helmet and the over-shoes. The experimenter asked them to walk a five square long sequence on the floor which would be presented to them on the screen of the laptop. This was supposedly done to get a first measurement and check if everything was working.

Actually the pre-test was used to measure the walking speed of the subject, which was later integrated by the experimenter into the programs so that no faster clicking reproduction was possible than walking reproduction.

They started at start position one and looked at the laptop while the sequence was showing. The pattern on the laptop screen was the same as on the floor. The sequence was displayed by highlighting a green circle in the squares which were part of the sequence, one square at a time. After all five squares were marked with the circle the participant could start walking. After having completed the sequence they were instructed to return to their starting position and press space. This stopped the measuring of the motion tracking.

After the pre-test participants were asked to do the PTA task which would take about ten minutes. In the PTA task participants were shown a map with five landmarks (such as church, harbour, school, etc.). In the middle of the landmarks was a head looking in the direction of one of the landmarks. Participants had then to imagine they were the person displayed on the screen facing the same way. Then they were asked to point in the direction of on of the landmarks by clicking on an arrors displayed beneath the picture. There were eight different arrors. On pointing to the front, one to the back, two to each side and the last four were the angeled ones, so front-right, front-left, back-right and back-left.

During the time it took the participants to perform the PTA task the experimenter calculated the walking speed of the subject during the pre-test. This speed was then included in the programs on the computers. Subjects were unaware of this.

Then the actual experimental block started. Participants were first instructed in and then performed one of the four experiments. All the experiments had six levels with four trials each. Each trial in a level started from a different starting position. Depending on the experiment the participant had either to view the sequences on the computer screen or on the floor. They also had to repeat the sequence either on the floor with actual walking or on the screen clicking on the squares. The clicking could only be done in the same speed the participant walked during the pre-test.

After the first experiment participants took a short break before being instructed in and performing the second experiment. This concluded the first session

The next session was held between one and eight days after the first session. In the second session participants would be instructed and perform the other two experiments which they had yet not performed. After completing all experiments they were given a questionnaire.

The order in which participants would do the experiments was balanced so that each experiment appeared equally often at each position. I also tried to make sure that the two same experiments would not always follow one another, but with only 15 subject a complete balance could not be achieved.

### 2.3.2 Procedure experiment SS

The experiment SS, was the screen/screen condition in which participants saw the sequence of fields on the screen and also had to reproduce them on the screen.

They were seated in front of the computers. First they were presented with a practice trial in which three squares were marked after one another with a green circle. After all three squares had been marked the participants read the instructions on the screen which told them to reproduce the sequence by clicking in the fields. When the subject clicked into a square the cursor would vanished. This was done to limit the reproduction time. The individual walking speed from the pre-test was integrated into the program so that it would take equally long to click in the fields as it would if walking between those fields. After that amount of time the cursor reappeared and the next field could be clicked upon.

When all fields were done, instructions were shown on the screen telling the subject to begin the experiment with space. Before each trial the number of fields that would be presented was shown. Every fourth trial the next level would begin and the sequence would be one field longer. After trial 24 the programm stopped and the subject notified the experimenter.

### 2.3.3 Procedure experiment SF

In this experiment subjects were presented with the sequence on the screen of the laptop and reproduced it by walking on the fields on the carpet.

Participants were wearing the helmet with the target on top and also the over-shoes with the balls on top, so that their movements could be recorded. They carried the laptop to every starting position where they positioned it on top of the rack. When having done so, they started viewing the sequence by pressing space. Once they did so the motion-tracking started. After the sequence was shown, participants started walking. When they finished with all the fields they returned to their starting position and pressed space. This made the motion-tracking stop. Then they could read the instructions which stated the next starting position and also the amount of fields with which they would be presented with. So participants picked up the laptop and repeated this procedure for all trials. Again they started with a practice trial and then completed the 24 experimental trials.

### 2.3.4 Procedure experiment FS

Experiment FS was the floor/screen condition in which participants saw the sequence on the floor and had to reproduce it on the laptop.

Again participants were carrying the laptop to the starting position they were instructed with. When being ready they gave the experimenter a sign, who then started the sequence display on the floor via the flashlights. This was done in a half dark room, so it was absolutely clear which field was lit up. After the last flashlight went out, the participant could start the reproduction by clicking space. Again the reproduction speed was limited by the walking speed from the pre-test. When the participant had clicked on the last field, he was instructed to move to the next starting position and also told how many fields would be presented to him in the next trial. As in all experiments there was first a practice trial followed by the 24 trials.

### 2.3.5 Procedure experiment FF

The experiment FF, was the floor/floor condition in which participants viewed the sequence on the floor and also reproduced it on the floor.

Subjectes were wearing the helmet and the over-shoes. Instructions were given by the experimenter, who also started the sequence-display. The experimenter told the participant the starting positions and the length of the sequences. Once the participant was ready the experimenter started the sequence and the motion-tracking. After the last flashlight went out the participant started walking. When the subject returned to his starting position, the experimenter stopped the motion tracking and told the participant where to go next and how long the next sequence would be. Again one practice trial and 24 experimental trials were conducted.

# Chapter 3

# Analysis and Results

## 3.1 Data reconstruction

Data was analysed with Matlab (R2012b(8.0.0.783, 64-bit(maci64), August 22, 2012). Data-handling was the same for the experiments SS and FS, and for experiments SF and FF. The later two were analyzed with the motion-tracking data, the former two were analyzed only with the data from the click-responses, becaue the reproduction of these experiments was done at a computer. This also means that for SS and FS especially performance was important, whereas for FS and FF additionally to performance also walking speed and amount of rotations were relevant.

### 3.1.1 SF and FF

In experiments SF and FF subjects position, the x- and y-coordinates in the room and their rotation around the z-axis were used for analysis.

The first step was the calculation of the walking speed in meters per second for each trial. For this resting time on a field were excluded and the mean of walking speed for all the parts of a trial was calculated.

The next step was the determination of the route the participants took, in order to compare it to the route they were instructed to walk. A field was counted as being part of the route if a participant stood on it longer than 0.3 seconds. If there were more fields that were stood upon for that amount of time than the route was supposed to be long, then those fields with the shortest resting time were excluded. This was done for all 15 subjects for all the 24 trials in both experiments. After this, one participant had to be excluded, since his data could not be transformed into any routes. Hence for the rest of the analysis this participant was excluded for all the experiments.

**Table 3.1:** Matrix of data of participant mg for the experiment SF. Each row is a trial. The first four trials are level 1, the next four level 2 and so on. The first column states the trial number. PRW is Perfromance right wrong, PAF is Performance Amount of Fields, PLS is Performance longest Sequence, Start. P. is the starting position of the longest sequence, no. LS is the number of longest sequences, speed is the average walking speed in meters per second, parts is the number of part routes where a part route is the leg between two fields, rotation is the total rotation in degree. In the last row speed has the value 200. This is the marking of a trial that was excluded due to measuring difficulties.

| mg | PRW | PAF | PLS | Start. P. | no. LS | speed [m/s] | parts | rotation[degree] |
|---|---|---|---|---|---|---|---|---|
| trial 1 | 1 | 3 | 3 | 1 | 1 | 0.897 | 4 | 864.41 |
| trial 2 | 1 | 3 | 3 | 1 | 1 | 0.861 | 4 | 1209.63 |
| trial 3 | 1 | 3 | 3 | 1 | 1 | 0.968 | 4 | 1635.39 |
| trial 4 | 1 | 3 | 3 | 1 | 1 | 0.933 | 4 | 684.13 |
| trial 5 | 0 | 3 | 2 | 3 | 1 | 0.742 | 5 | 1110.38 |
| trial 6 | 1 | 4 | 4 | 1 | 1 | 0.923 | 5 | 1217.24 |
| trial 7 | 1 | 4 | 4 | 1 | 1 | 0.724 | 5 | 829.16 |
| trial 8 | 1 | 4 | 4 | 1 | 1 | 0.864 | 5 | 1200.55 |
| trial 9 | 1 | 5 | 5 | 1 | 1 | 0.843 | 6 | 1623.62 |
| trial 10 | 0 | 4 | 2 | 1 | 1 | 0.741 | 6 | 1238.58 |
| trial 11 | 1 | 5 | 5 | 1 | 1 | 0.843 | 6 | 1775.71 |
| trial 12 | 0 | 4 | 3 | 1 | 1 | 0.901 | 6 | 1820.55 |
| trial 13 | 0 | 5 | 4 | 1 | 1 | 0.816 | 7 | 1294.31 |
| trial 14 | 0 | 5 | 4 | 1 | 1 | 0.727 | 7 | 1615.83 |
| trial 15 | 1 | 6 | 6 | 1 | 1 | 0.814 | 7 | 1178.07 |
| trial 16 | 1 | 6 | 6 | 1 | 1 | 0.755 | 7 | 1247.66 |
| trial 17 | 0 | 6 | 4 | 4 | 1 | 0.784 | 8 | 1791.32 |
| trial 18 | 0 | 6 | 4 | 1 | 1 | 0.946 | 8 | 2463.30 |
| trial 19 | 0 | 6 | 1 | 3.666 | 6 | 0.774 | 8 | 1019.02 |
| trial 20 | 0 | 4 | 2 | 1 | 1 | 0.776 | 8 | 1780.22 |
| trial 21 | 0 | 6 | 3 | 1 | 1 | 0.774 | 9 | 1525.63 |
| trial 22 | 0 | 8 | 4 | 5 | 1 | 0.761 | 9 | 1545.98 |
| trial 23 | 0 | 5 | 2 | 1 | 1 | 0.692 | 9 | 1832.50 |
| trial 24 | 0 | 0 | 0 | 1 | 1 | 200 | 0 | 0 |

A first measure of performance (Performance Right Wrong (PRW)) was calculated which stated whether a route was completely right (1) or wrong (0). Looking at these results, there did not seem to be a big difference in performance especially in the higher levels. So two alternative measurements of performance were introduced. The first alternative performance measurement was the amount of fields that were supposed to be in the route. So if the route was [3 8 15] and the participant walked [3 7 4] he would have a performance of one, if the participant walked [15 3 9] he would have a performance of two and so on. This Performance will be referred to as Perfomance Amount of Fields (PAF). The last measure of Performance was Performance Longest Sequence (PLS), which stated the longest part-sequence of a route. So if the participant was supposed to walk [15 6 8 9 2] and actually walked [15 6 8 2 9] PLS would be three. If he walked [15 9 2 8 3] PLS would be two. Also the starting position of this longest sequence was calculated. If there were two or more same long sequences, the mean of their position was used. Also the number of longest sequences was recorded.

Since there were some measuring difficulties, some trials were excluded from analysis. The total of not used trials in FF is six, in SF it is 16. The maximum number of excluded trials in a level was seven in level 6 of SF, this is also based on the fact that the first four participants had only three trials in level 6, due to an unfortunate programming error.

Finally the rotation was calculated for each trial. This was done by analysing the rotation around the z-axis.

For each participant and each experiment a matrix was constructed. These matrices consisted of 9 columns stating the Performance Right Wrong, the Performance Amount of Fields, the Performance Longest Sequence, the starting position of this longest sequence, the number of longest sequences, walking speed, amount of routes between fields and total rotation within a trial were recorded. So for SF and FF matrices of the size 24x8 were constructed.

Such a matrix is shown in table 3.1 of participant mg for the experiment SF. Please also note that in the last row of this matrix the walking speed is 200 and all other cells in this row are 0. This is the marking for a trial that did not measure well enough to calculate a route from it. Those trials were excluded.

### 3.1.2 SS and FS

For the first data conversion of SS and FS the routes were identified and the three performance measurements were applied. So if a participant was shown the sequence [3 9 6 14 11] and he clicked [3 6 14 9 5] PRW = 0, PAF = 4 and PLS = 2.

After the first transformation for each participant and for each experiment a matrix was constructed.

For SS and FS these matrices consisted of five columns stating the Performance Right Wrong, the Performance Amount of Fields, the Performance Longest Sequence, the starting position of this longest sequence and the number of longest sequences. So matrices for SS and FS were of the size 24x5.

## 3.2 Evaluation

For the evaluations of differences unbalanced, one-factorial ANOVAs for within-subject were used. This was done, because all experiments were done by all 14 participants. All ANOVAs are comparing mean values of the concerned groups. Since there was a lot of data it was decided to first focus only on comparing one factor at a time and later do a correlation analysis. For this correlation analysis the classic Pearson-correlation was evaluated. Later also the Spearman-correlation was calculated. Reasons for that will be explained below.

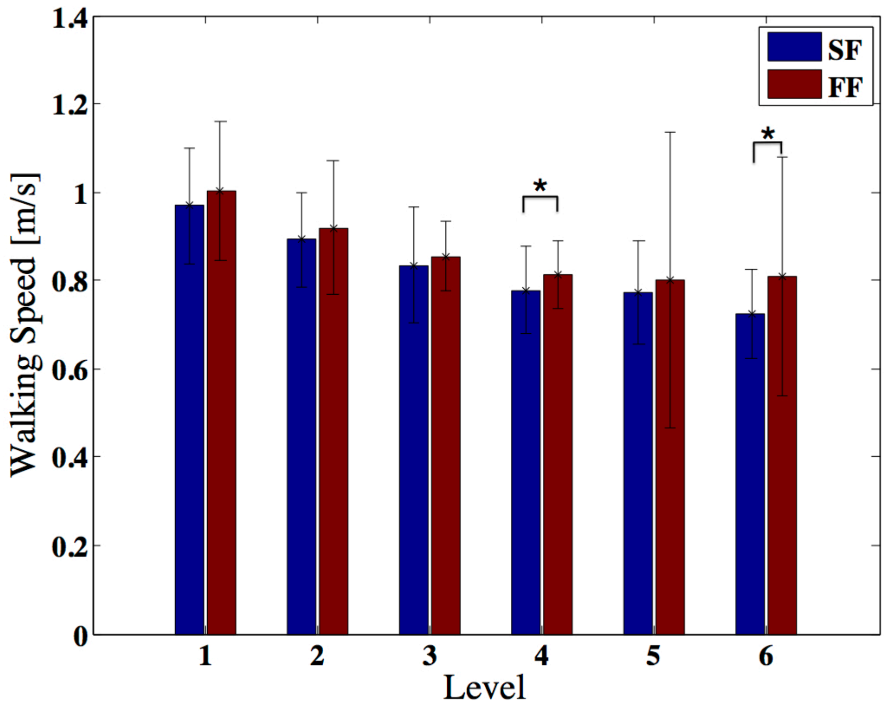


**Figure 3.1:** Display of walking Speed for each Level and experiment.This figure shows the mean walking speed per level in the experiments SF and FF. The blue bars present mean walking speeds in experiment SF, the red ones in experiment FF. Significant differences are reached in level 4 and 6. Shown is also the SD.

### 3.2.1 Walking speed

Walking speed was only available in SF and FF, so first a comparison between the two was made evaluating whether or not the two experiments differed in their walking speed. Interestingly, when comparing the walking speed of SF and FF a significant difference ($F(1) = 6.67$, $p < 0.05$) can be found. Looking closer at the levels only level 4 ($F(1) = 4.74$, $p < 0.05$) and level 6 ($F(1) = 4.1$, $p < 0.05$) reach significance in difference of walking speed for experiments SF and FF. Figure 3.1 illustrates these differences.

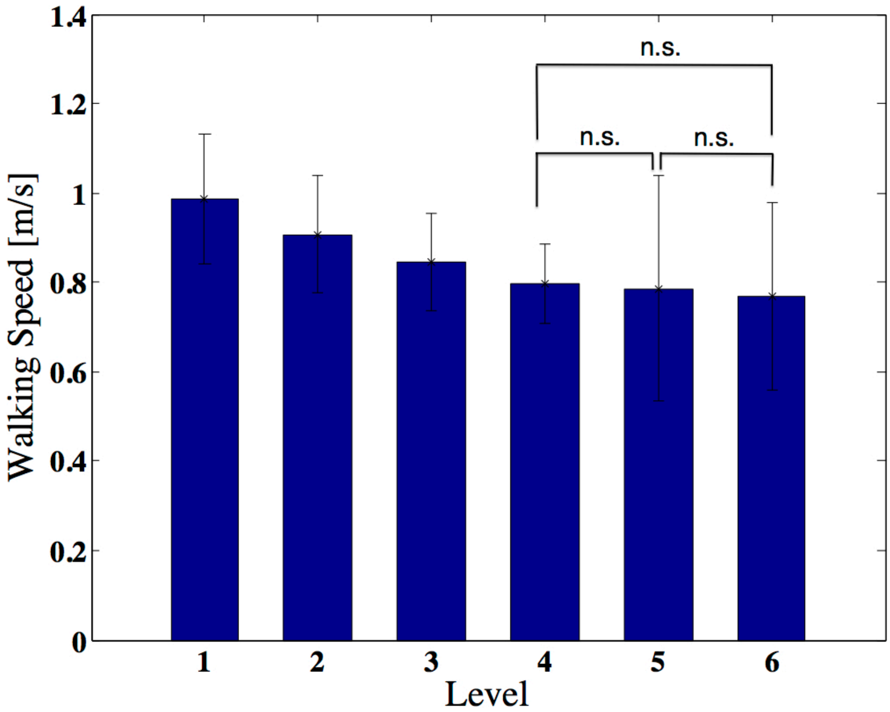


**Figure 3.2:** Diagram of walking speed development over the levels. This figure shows the development of the walking speed per level taking data from both experiments SF and FF. SD is included in the figure. All levels exept for level-pairs 4/5, 4/6 and 5/6 show a significant difference in walking speed.

What also seemed interesting was the development of walking speed during an experiment. The results are presented in figure 3.2. Again analysis has been done with one-factorial, unbalanced ANOVAs comparing the mean values of the walking speed for each two levels. All of these reach significance ($p < 0.05$) exept comparing Levels 4 and 5, 4 and 6 and 5 and 6. These comparisons and the one between level 3 and 5 are the only ones that don't reach a high significance ($p < 0.01$).

Again an ANOVA was used this time not analyzing any differences between the experiments but between those trials that were completely right and those,

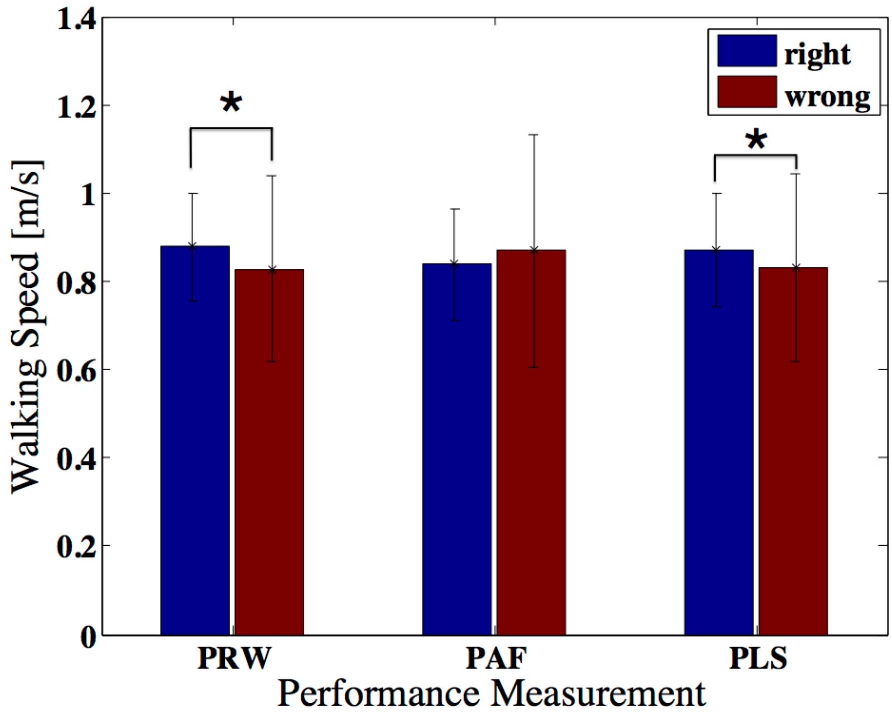


**Figure 3.3:** Diagram of walking speed according to performance. This figure shows the walking speed of trials that achieved more than 80 % in their performance measurement and those that did not. The ones with more than 80% are displayed in red, the others in blue. SD are displayed.

that were not. It was found that a significant ( $F(1) = 12.12$, $p$ <0,01) difference existed, but participants were walking slower, when they made no mistakes. The other two performance measurements were checked as well with the same result: participants were significantly faster when making mistakes than when achieving more than 80% in the performance score. These results can be seen in figure 3.3.

Since this finding may depend on the difficulty of the task, the levels were looked at individually. But as can be seen in table 3.2 there were no significant differences in walking speed between those trials where no errors were made and those in which errors were made.

**Table 3.2:** Table that shows p-values of one-factorial unbalanced ANOVAs comparing the walking speed of trials that were completely right with those, that were not for experiment FF. Each column is a level. No values become significant.

| PLS for FF | Level 1 | Level 2 | Level 3 | Level 4 | Level 5 | Level 6 |
|---|---|---|---|---|---|---|
| p-value | 0,506 | 0,108 | 0,829 | 0,812 | 0,559 | 0,879 |

### 3.2.2 Questionnaire

**Table 3.3:** This table shows the most important answers of the questionaire. The first column states the questions, the second the answers. The first three questions are answered with the mean value the participants gave on a scale from one to seven. The fourth and fifth questions are answered with all the different answers participants gave and the number how often they were given. The last question states the order of the experiments from hard to easy and the average rank participants gave this experiment.

| Question | Answer |
|---|---|
| Did you have fun? | 5.866 |
| How motivated were you? | 6.066 |
| How hard did you find the experiment? | 5.400 |
| Which sequences were the easiest? | Those with a geometric form (11x),<br>those with small distances (13x),<br>those with a small rotation degree (1x) |
| Did you have a strategy? | Dividing up the sequence into smaller ones (5x),<br>find geometric figures (7x),<br>walking facing only one direction (2x),<br>using hands to trace the sequence (2x),<br>naming fields(1x) |
| Put the experiments in an order<br>from easy to hard. | SS (1.166), FF (2.133), FS (2.700), SF (4.000) |

All participants answered a short questionnaire with ten questions after the completion of the last experiment. The most interesting questions and answers are displayed in table 3.3. Participants rated the difficulty of the experiment on a scale from one to seven with a 5.4, their motivation with a 6.066 and the fun they had with a 5.866.

Generally they found those sequences easiest that had a geometric form and small distances between fields. One subject also said that sequences in which he didn't have to rotate a lot were easier. All subjects exept one had some sort of strategy. Most searched for geometric figures or divided the longer sequences into smaller ones. One subject even named the fields and remembered a string of words. Participants also stated that the easiest experiment was SS, then FF, then FS and the hardest experiment was SF.

### 3.2.3 Level differences in performance

After this first reorganization of data performance measurements were transformed from a total number into percentage. This was done in order to compare the levels with one another. For each experiment and for each performance measurement a matrix was created in which the p-values for an unbalanced, one-factorial ANOVA with repeated measurement, within-subjects

**Table 3.4:** This table shows p-values of one-factorial unbalanced ANOVAs between two levels for the performance measurement PRW for the experiment FF. Each column and each row represents a level each cell contains the p-value of the ANOVA between those levels with the null-hypothesis that the mean values of PRW in those levels is the same. The p-value states the probability with which the null-hypothesis is right.

| PRW for FF | Level 1 | Level 2 | Level 3 | Level 4 | Level 5 | Level 6 |
|---|---|---|---|---|---|---|
| Level 1 | 1 | 0.259 | 0.008 | 4.76e-04 | 1.71e-07 | 3.99e-13 |
| Level 2 | 0.259 | 1 | 0.126 | 0.017 | 4.50e-05 | 1.54e-09 |
| Level 3 | 0.008 | 0.126 | 1 | 0.394 | 0.012 | 9.54e-06 |
| Level 4 | 4.76e-04 | 0.017 | 0.394 | 1 | 0.100 | 3.73e-04 |
| Level 5 | 1.71e-07 | 4.50e-05 | 0.012 | 0.100 | 1 | 0.050 |
| Level 6 | 3.99e-13 | 1.54e-09 | 9.54e-06 | 3.73e-04 | 0.050 | 1 |

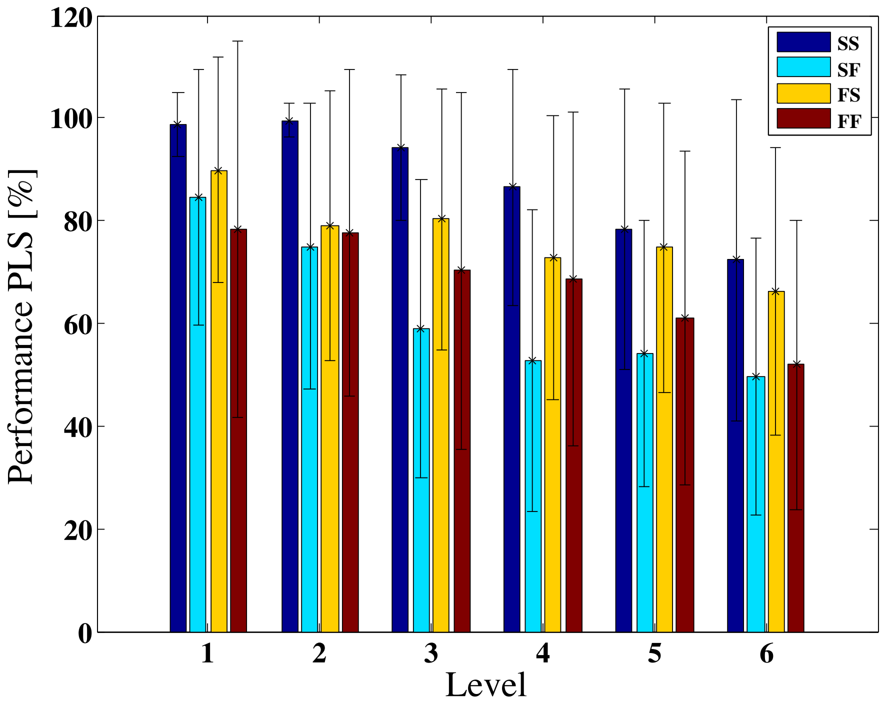


**Figure 3.4:** Comparison of PLS Performance over all levels and all conditions. Here the performance PLS is displayed per level and per experiment. The x-axis shows the levels, the y-axis the performance PLS. The dark blue bars are experiment SS, light blue is SF, yellow is FS and red is FF. n = 14.

**Table 3.5:** This table shows p-values of one-factorial unbalanced ANOVAs always between two levels for the performance measurement PAF for experiment FF. Each column and each row represent the levels each cell contains the p-value of the ANOVA between those levels with the null-hypothesis that the mean values of PRW in those levels is the same. The p-value states the probability with which the null-hypothesis is right.

| PAF for FF | Level 1 | Level 2 | Level 3 | Level 4 | Level 5 | Level 6 |
|---|---|---|---|---|---|---|
| Level 1 | 1 | 0.604 | 0.971 | 0.875 | 0.856 | 0.703 |
| Level 2 | 0.64 | 1 | 0.526 | 0.404 | 0.624 | 0.789 |
| Level 3 | 0.971 | 0.526 | 1 | 0.891 | 0.795 | 0.6141 |
| Level 4 | 0.875 | 0.404 | 0.891 | 1 | 0.646 | 0.449 |
| Level 5 | 0.856 | 0.624 | 0.795 | 0.646 | 1 | 0.749 |
| Level 6 | 0.703 | 0.789 | 0.614 | 0.449 | 0.749 | 1 |

**Table 3.6:** This table shows p-values of one-factorial unbalanced ANOVAs always between two levels for the performance measurement PLS for experiment FF. Each column and each row represent the levels each cell contains the p-value of the ANOVA between those levels with the null-hypothesis that the mean values of PRW in those levels is the same. The p-value states the probability with which the null-hypothesis is right.

| PLS for FF | Level 1 | Level 2 | Level 3 | Level 4 | Level 5 | Level 6 |
|---|---|---|---|---|---|---|
| Level 1 | 1 | 0.913 | 0.240 | 0.138 | 0.009 | 5.87e-05 |
| Level 2 | 0.913 | 1 | 0.247 | 0.135 | 0.007 | 1.93e-05 |
| Level 3 | 0.240 | 0.247 | 1 | 0.770 | 0.142 | 0.003 |
| Level 4 | 0.138 | 0.135 | 0.770 | 1 | 0.226 | 0.005 |
| Level 5 | 0.009 | 0.007 | 0.142 | 0.226 | 1 | 0.122 |
| Level 6 | 5.87e-05 | 1.93e-05 | 0.003 | 0.005 | 0.122 | 1 |

were recorded. The h0-Hypothesis was that the performance in the different levels is the same.

These matrices were also used to have a first comparison between the different performance mearsurements. Table 3.4, table 3.5 and tabel 3.6 are examples of those matrices. As you can see in table 3.4 ten ANOVAs get significant, e.g. have a p-value under 0.05. So here the null-hypothesis is rejected and these level differ significantly in their mean of the PRW. In table 3.5 non of the p-values reaches significance, so for this performance measurement PAF all levels have the same mean. Table 3.6 contains 6 signifant differences for PLS.

Figure 3.4 shows the results of all PLS-level comparisons for all four experiments. Significant differences are not displayed since that would decrease clarity of the figure. As you can see does performance decrease in all experiments with increasing levels.

For all of these matrices and experiments the same basic pattern emerges. For PRW and PLS levels that have a big difference in sequence length have significantly different mean values, PAF has the least amount of significant differences, PRW the most and PLS the second most. This result shows that higher and lower levels differ in their difficulty.

### 3.2.4 Experiment differences in Performance

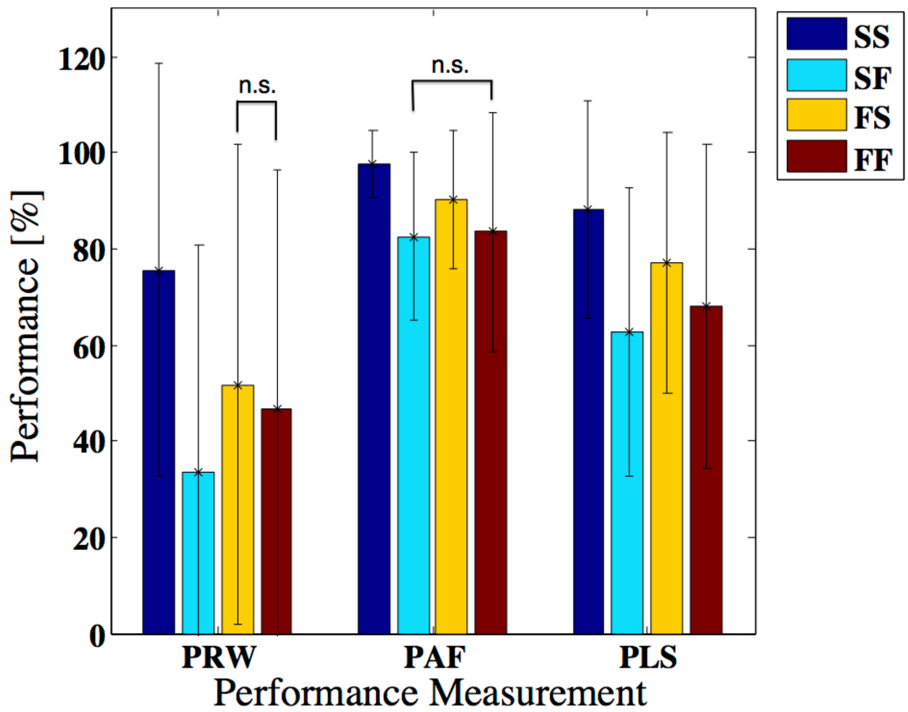


**Figure 3.5:** Comparison of performance measurements over all conditions. This figure shows the three different performance measurements for each experiment. 1 refers to the PRW, 2 refers to the PAF, 3 refers to the PLS. Significant differences for PRW are all but FS/FF. For PAF significant differences exist for all but SF/FF. For PLS all differences are significant. SD is included. n.s. stands for not significant. n = 14

In the next step performance differences between the experimental conditions were calculated. Again a one-factorial ANOVA for unbalanced data was used. A total performance difference and a performance difference per level was calculated for each of the three performance measurements. The performance differences for each level and each condition are shown in figure 3.5. All differences are significant but the ones in PRW for experiments FS and FF and in PAF for experiments SF and FF. In all three performance measurements the best performance was found for SS, when participants were viewing the sequence on the screen and also reproduced them by clicking with a mouse on the screen. Second best was FS, in which participants viewed the sequence on the floor and reproduced it clicking on the screen. Third was FF, in which participants viewed the sequence on the floor and walked. The worst was SF, in which participants saw the sequence light up on the screen and had to walk it.

On the evaluation sheet which participants filled out after having completed all the experiments, they ranked SS as the easiest, FF as the second easiest, FS as the third easiest and the most difficult one was SF. See table 3.3. Even though not all participants made the ranking like this, differences in the mean values still reach significance. So in comparison to the actual results FS and FF have swapped places. This will be discussed later.

### 3.2.5 Additional performance calculations

Another thing that was calculated was the mean of the starting position of the longest sequence. First all trials that were completely right were excluded. It was found that it was 2.124 with a standard deviation of 1.379. The number of total appearences is displayed in figure 3.6. The longest sequence started most of the times at position one but had a little rising point for position four.

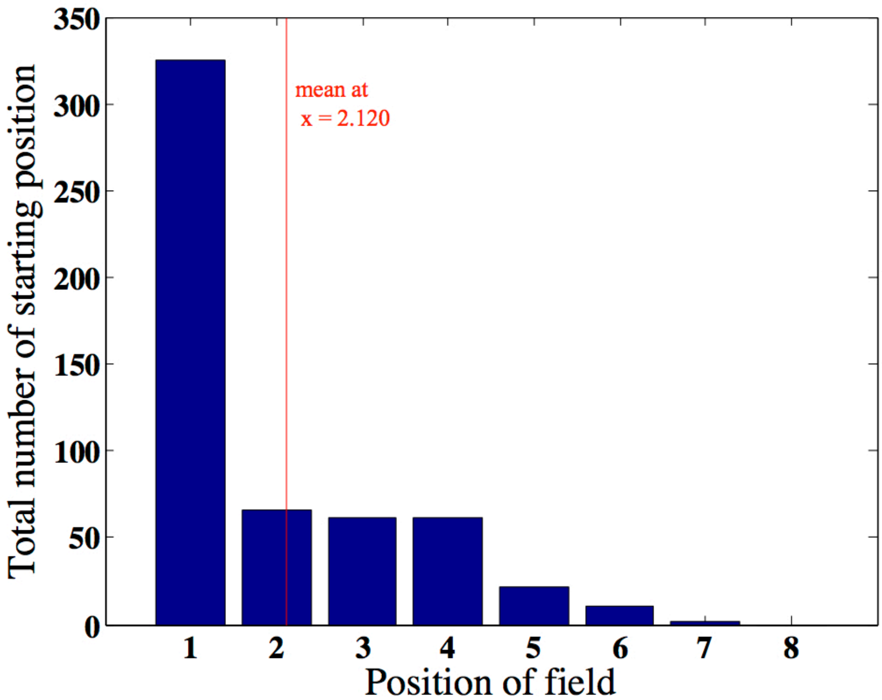


**Figure 3.6:** Position of the longest Sequence. On the x-axis the field number is displayed, on the y-axis the total number of appearences. The mean is shown at the position x = 2.120.

### 3.2.6 Rotation

First for the analysis of the rotation influence, an unbalanced one-factorial ANOVA was made to compare the two experiments SF and FF. No significant difference was found. Also when looking at the levels, no significance was found. This is shown in figure 3.7.

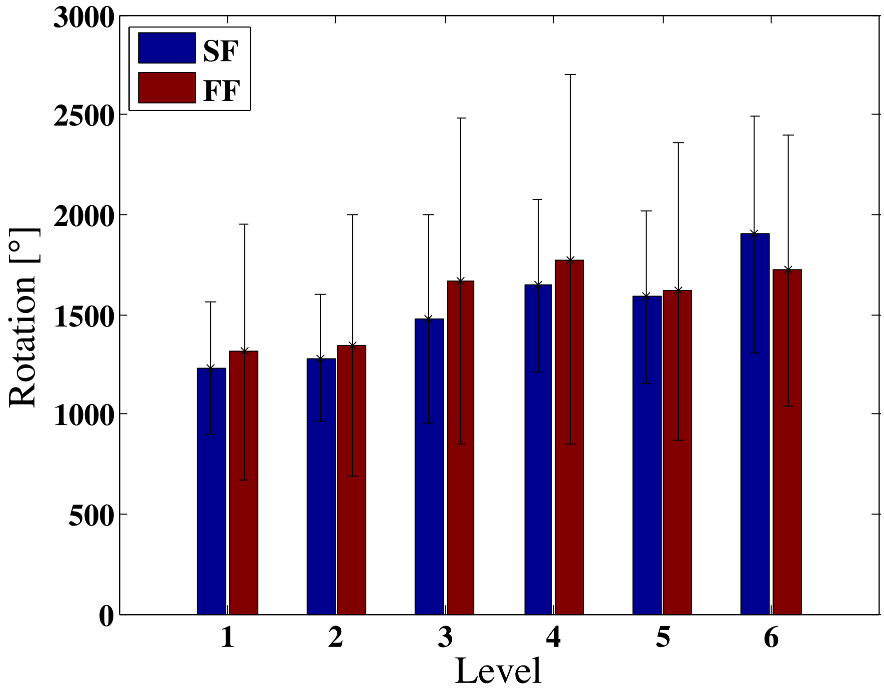


**Figure 3.7:** Total rotation for each level and both experiments SF and FF. This figure shows the mean rotation for each level and both experiments SF and FF. The blue bars are for the experiment SF, the red ones for FF. The SD is displayed. No significant differences are reached.

Looking at all trials that were performed correctly a significant difference ($F(1) = 24.51$, $p < 0.01$) in total rotation was found. Since this could also be an effect of sequence length, the levels were regarded seperately. Taking PRW as the measure to divide the trials into two groups no significance was found.

Then it was decided to use PLS the longest sequence as the measurement. This is because PLS always formed the compromise between PRW and PAF. PRW as a very strickt measurement and PAF as a quite generous one. Since the problem of very different sized groups still remained, the trials were seperated according to the median of the PLS. This was a way to make sure that both groups were of equal or close to equal size. In figure 3.8 the results of the analysis are presented. The blue bars represent the mean values for each level for the trials in the better half. A trial belonged to the better half if its PLS value was higher or equal to the median of all the trials. If its PLS value was lower, it belonged to the worse half. For levels 1 to 4 no significant difference in total rotation was found. But for level 5 ($F(1) = 5.34$, $p$ <0.05) and 6 ( $F(5.26)$,$p$ <0.05) such a significant difference was reached.

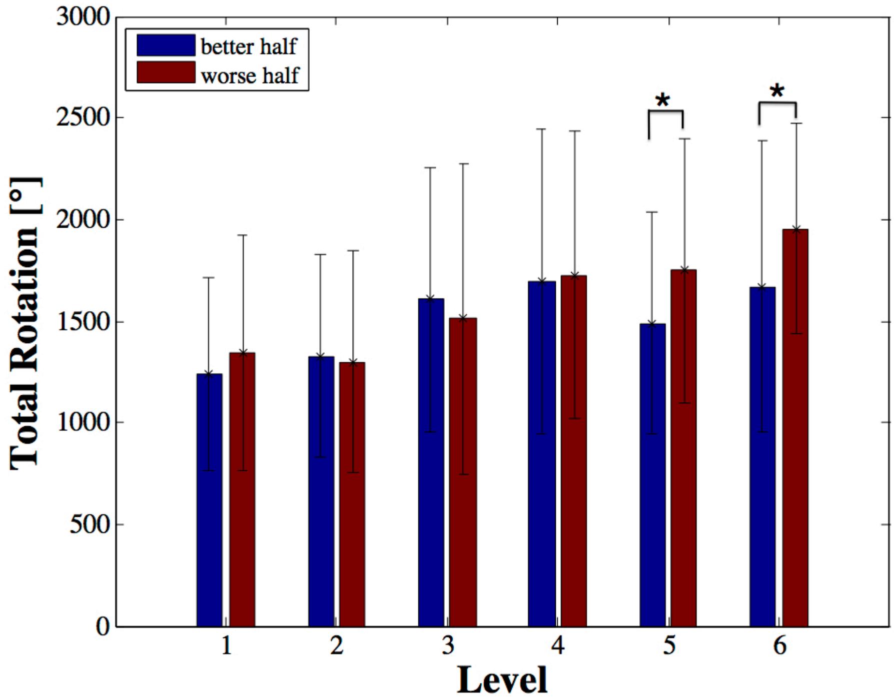


**Figure 3.8:** Comparison of total Rotation per level between trials with good performance and trials with bad performance. On the x-axis the levels are shown. The y-axis shows the total rotation. The blue bars represent the mean of rotation of those trials in the better half, the red bars of the worse half. Trials were divided into the better half if they had a better PLS than the median of the PLS for all the trials. In level 5 ($F$ (1) = 5.34,$p$ <0.05) and 6 ( $F(5.26)$, $p$ <0.05) a significant difference is reached. SD is displayed. n = 14

## 3.3 Correlations

### 3.3.1 Walking speed and performance

First a Pearson-correlation for PRW and walking speed was calculated ($r$ = 0.135, $p$ = 0,0005) showing a small positive correlation. The same was done for PAF and walking speed ($r$= -0.110, $p$ = 0.004) and PLS and walking speed($r$ =0.055, $p$ = 0.156).

Since the performance measurements show quite some differences and since it is difficult to find fitting intervals for performance differences, a Spearman-correlation or Rank-correlation was used. This correlation can be used for data that is on ordinal scale-level or higher. This means the data can be sorted, but the intervals between the objects do not matter.

In order to apply such a correlation I added another quantity which took all three performance measurements into account. The first priority was the PRW, so if a trial was completely right, it would get the highest rank possible. Second priority had PLS, so from the remaining trials those with the highest PLS scores got the next highest ranks. The third measure PAF sorted the rest of the trials, or those that were of equal size after the first two priorities. So if four trials a, b, c and d had the following scores: a = (PRW = 100%, PLS = 100%, PAF = 100%), b = (PRW = 0%, PLS = 60%, PAF = 60%), c = (PRW = 0%, PLS = 60%, PAF = 90%) and d = (PRW = 0%, PLS = 70%, PAF = 70%), they would be sorted like this: a, d, c, b. If two trials had the same scores, they also were given the same rank. A positive correlation ($r$ = 0.192, $p$ = 7.25e-07) was found.

### 3.3.2 Rotation and performance

Rotation and performance was first correlated with the Pearson-correlation. PRW and rotation correlated negatively ($r$ = -0.190, $p$ = 9,43e-07), as did PAF and rotation ($r$ = -0.078, $p$ = 0.047) and PLS and rotation ($r$=-0.195, $p$ = 5.10e-07). Even though all three performance measurements ended in a negative correlation, the problems of the informative value of these measurements remains. Therefore a Spearman-correlation using the same rank-giving method as described above was applied. A negative correlation ($r$ = -0.219, $p$ = 1.5e-08) was found. This result needs to be regarded carfully since higher levels had longer sequences, which led to more rotation and they were also more difficult. So Spearman-correlations for each level were calculated. Results are shown in table 3.7.

**Table 3.7:** This table shows the results of the spearman-correlations between performance and rotation. Ranks were giving according to priorties. First priority had PRW, second priority PLS, third priority PAF. The correlation was calculated for each level.

| Level | correlation-coefficient | p-value |
|---|---|---|
| Level 1 | -0.103 | 0.288 |
| Level 2 | -0.001 | 0.989 |
| Level 3 | 0.041 | 0.666 |
| Level 4 | -0.078 | 0.420 |
| Level 5 | -0.263 | 0.005 |
| Level 6 | -0.237 | 0.016 |

### 3.3.3 PTA task and performance

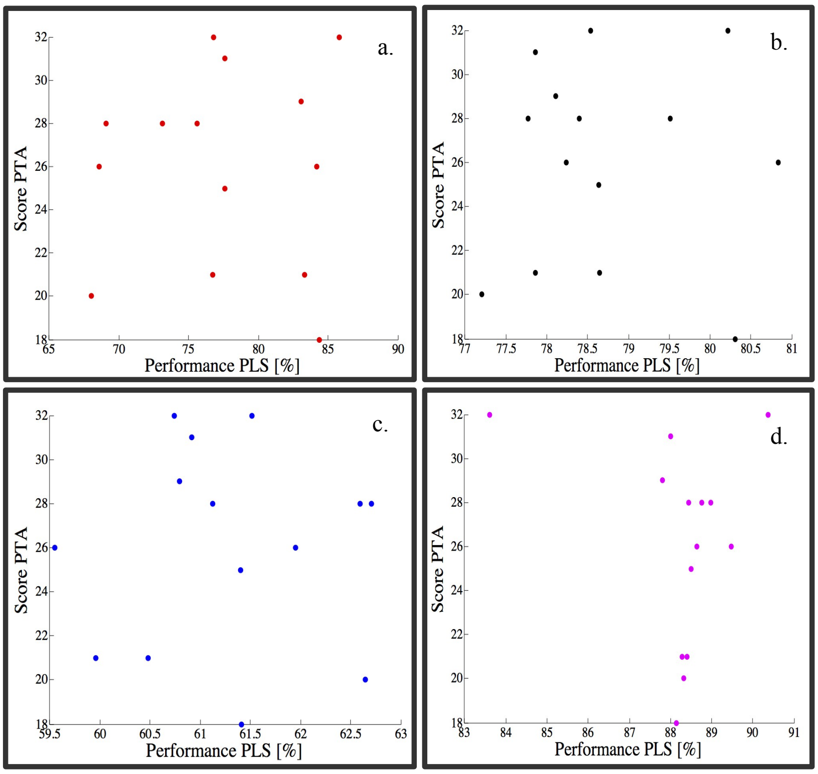


**Figure 3.9:** Scatter-plots of PTA scores and PLS for all four experiments. In this figure four scatter-plots are presented. On the x-axis is the performance score of PLS, on the y-axis the score of the pta. Each dot is one of the 14 participants. a. displayes the scatter-plot for experiment FF, b. for experiment FS, c. for SF and d. for SS.

Before the first experiement all subjects performed the Perspective-Taking Ability (PTA) task. The results of each participant were correlated with their mean performance, first taking each performance measurement seperatly into account, then combining the performance measurements by simply taking their mean. For not one of these correlations significance could be reached. An example of this is given in figure 3.9. Each plot is for one experiment. On the y-axis is the score of the pta, on the x-axis the performance score of PLS. Each dot represents a participant. There is no apparent correlation.

# Chapter 4

# Discussion

## 4.1 Review of the theory

The Corsi block tapping task is a way to measure the visuospatial working memory span. It is a commonly adopted method, that can be modified in several ways like sequence length, path complexity, the medium used, learning method etc. For this study two different versions were used. One that involves a larger pattern on the floor, one where the pattern is displayed on a computer screen. Since the Corsi block tapping task consists of two parts first the learning or memorisation phase and then the reproduction phase, four different experiments were constructed to evaluate results from four possible combinations.

In 1998 Berch et al. identified many possible variable quantities of the CBT, however later studies (e.g. Busch et al. 2005) showed that mostly one quantity was responsible for performance differences: the complexity of the sequence. Performance was generally better when sequences displayed geometrical figures and had fewer path crossings.

The involvement of the working memory is apperant. Especially Baddeleys visuospatial sketchpad is important for the CBT. It is responsible for revising and storing visual and spatial information. Logie (1995) later proposed a dissociation within the visuospatial sketchpad between a passive store and an active rehearsal component which also results in the seperation of purely visual information and spatial information.

Since in this study participants also performed a walking part, cognitive processes like spatial updating may play a role when it comes to performance in the CBT.

Additionally the finding of recent studies (Yogev-Seligmann et al. 2008) which state that walking is a task which does need more cognitive resources than expected in the classical view, will play a role when looking at walking speed. These studies claim that during a dual task walking speed is slower than without a dual task.

Therefore the expected outcome was a decrease in walking speed with an increasing difficulty. It was also hypothesised that performance would differ between experiments. The last hypothesis was that a lot of rotation within a trial would correlate with a worse performance.

## 4.2 Review of main findings

We will first take a look at the results concerning the walking speed, then concerning performance and finally concerning rotation.

The first interesting finding concerning walking speed is the significant difference for experiments SF and FF. This difference exists when looking at the mean walking speeds for the whole experiments as well as for the level comparison when looking at levels 4 and 6. Participants were walking faster in the SF condition. In SF participants memorized the sequence on the screen and reproduced it on the floor. Hence after accessing their memory they would also have to translate this information onto the pattern on the floor. This finding may also result from the memorization method, the way information was stored or the way it was recalled.

The next important finding is that the walking speed generally decreased with increasing levels. This does support the first hypothesis that difficulty may be displayed in speed. Eventhough levels 4,5 and 6 do not differ significantly in their mean walking speed, the decrease is still there.

What could not be found was a negative correlation between performance and walking speed. Instead, using a Spearman-correlation, a positive correlation was found. This may be explained with the fact that when a participant did not know what field to visit next he just chose any-one field and did so without much consideration and walking fast, since he wanted to finish quickly. However since from a correlation no cause-effect relation can be deducted it would need further research to explore this relation.

An interesting finding for performance was mainly the difference in indicated difficulty and actual performance. In the questionaire participants declared that SS was the easiest, FF the second easiest, FS the third and SF the hardest experiment. The first and the last do agree with the performance findings. However, even though FF was supposedly easier, performance here was worse than in FS. And significantly so. This will be discussed in detail below.

The second finding concerning performance is that the longest sequences mostly begun with field one (trials that were completely right were excluded, which left 548 trials out of which 325 started at position 1 which is about 60 %). This shows that participants tend to remember the first fields better than the last fields. Looking at the experiments seperately led to the same results.

For rotation the most important result is that in the two highest levels the trials with a poor performance had a significantly higher rotation than those with a good performance. That this significance is only evident in the two highest levels may mean that especially for difficult sequences the amount of rotation influences performance more strongly. Also, when correlating performance and rotation a significant negative correlation is found in levels 5 and 6. This will also be discussed below.

## 4.3 Review of possible reasons for differences

### 4.3.1 The way of memorization

Logie (1995) suggested two parts of the visuospatial sketchpad: a visual cache and an inner scribe. The visual cache being responsible for the storage of the information whereas the inner scribe is responsible for the rehearsal. For the CBT this would mean that the visual cache stores the pattern and all the visual images, without further evaluating them. The inner scribe, however, rehearses this spatial information of the sequence. This would result in the by Logie proposed dissociation between visual and spatial information. So when a subject remembers the sequence he could rely on both parts to the same extend or use one or the other to a bigger extend.

The finding that experiment SF and FF differ significantly in walking speed may be an effect of differently stored or memorised information. It could be that the information is stored differently. Since in FF subjects are presented with the pattern directly on the floor they may rely more on landmarks during motion than on their mental representation in memory. In this case walking speed would be more influenced trying to produce a path through landmarks which are still visible and therefore accessible than through considering a map that is no longer visibly accessible.

Furthermore, the fact that walking speed decreases with increasing levels may result from the possibility that shorter sequences are memorized more easily or easier accessible. The proposed inner scribe may be able to rehearse a shorter sequence faster, which could cause the faster walking speed due to a stronger confidence.

This also goes hand in hand with the fact that performance decreases with increasing levels. This is the case for all four experiments.

Memorisation may play a role in the found differences because of multiple reasons. The by Logie proposed inner scribe may be able to rehearse shorter sequences more often, which could explain the better performance in the lower levels in comparison to higher levels. Also ,the decrease of walking speed with increasing sequence length may be explained with this. But not only rehearsing time could play a role. Additionally the way of storing could affect the results. As can be seen when comparing walking speed for experiments SF and FF. Even though the reproduction is the same, the way the information was memorised is different. Thus, if the information was stored exactly the same way there should not be a difference in reproduction speed.

### 4.3.2 The way of reproduction

Participants stated that the experiment FF was easier than the experiment FS. However, looking at their results, performance is significantly worse for FF than for FS. Even though FS has an incongruent memorisation and reproduction subjects still performed better. Thus, the reproduction on the floor is probably more influencial than a translation. This speaks for the possibility that spatial updating takes up a lot of mental resources. Trying to reproduce the correct sequence from ever changing view points seems to be more difficult than translating from the floor to the screen even though participants did not notice this.

Moreover, most of the times the longest sequence started at position one. This is an indicator that during reproduction the sequence is 'lost'. For the walking conditions it may be caused by the loss of orientation or the difference in view points. During the clicking conditions this may be caused by the interference of reproduction and memory. Also, the duration of the reproduction may cause this effect.

Furthermore, the negative correlation of rotation and performance for levels 5 and 6 can be explained by reproductional effects. As Rieser (1989) showed, rotation is harder than translation. So, sequences with a lot of turnes are more likely to throw participants off course than those with fewer turns. Two participants even used the strategy to turn as little as possible and therefore face in the same direction for the entire time. Even though this did not result in better performance of these two participants, it still shows that they noticed a greater confusion when turning a lot. When asking them if the strategy helped they both replied that the effort of walking sideways and backwards made it more difficult.

Reproduction may cause some of the found differences due to multiple reasons. First of all, during walking participants also had to deal with spatial updating which may take up additional cognitive resources. This could have caused the fact that even though FF is a congruent experiment performance in it was worse than in FS. Secondly, the negative correlation of rotation and performance in higher levels underlines the greater difficulty of rotations compared to translations found by Rieser. Also, the fact that the longest sequences started usually in the beginning suggests that during reproduction problems arise which may be caused by reproduction-time effects or interference of reproduction and memory.

## 4.4 Critical view on the study and outlook

This study has resulted in quite some interesting results. However, there are a couple of things that could be improved. First of all, the PTA task turned out to be not very helpful. It seems that it does not correlate at all with the results in this study, for a follow up study I would therefore exclude it.

Which might also be a good idea is to use four completely different sets of routes. Even though most participants stated on the questionnaire that they did not notice anything about the routes there could still have been learning effects. Of course there are also some problems with this since routes would have to be fairly similar and with only 15 fields to choose from, it might be difficult to produce that many similar routes.

A bigger group of participants may have also been good. With this one could better balance the route-experiment pairs.

Even though I included three different measurements of performance and analyzed everything with all three measurements they sometimes led to different results. See tables 3.4, 3.5 and 3.6. One should think about an incorporation of all three measurements similar to the one used for the Spearman-correlation when all three performance measurments were used to give a rank to each trial by sorting them after priorities. Of course unlike in the Spearman-correlation one would have to find intervals to have data on an interval-scale level at least. However for this an additional pre-test would be needed to find fitting intervals.

What might be interesting to investigate further is the walking speed. So far it was found that walking speed decreases with increasing sequence length, but it correlates positively with performance. This seems to be a contradiction. However, since the experimenter was in the room during the walking conditions, she noticed the behaviour of the participants: when not knowing the rest of a sequence participants started walking faster and choosing fields that were on their direct way back to the starting position. Only when they were torn between two fields did they linger. This did not seem to happen that often, usually once they were unsure they had completely lost orientation. Still further analysis of the walking speed may be interesting. For example, one could take a look at the walking speed participants had from the first incorrect field onwards, and the speed leading up to it.

There is also the possibility of a size effect: since the field on the floor is so much bigger than on the screen, the screen reproduction might be easier. Perhaps participants should also reproduce the sequence on the floor with for example a flashlight or a remote-controlled vehicle. That vehicle could also be wearing the motion tracking target. Its speed could be limited to walking speed. Of cause the handling of the vehicle needs to be rather easy. With this memorization could also be excluded as a reason for possible differences, since memorization would be the same for all conditions. Only reproduction would differ. Another possibility is that the sequence could be displayed once on the monitor, with reproduction on the monitor as well, and once on the floor with reproduction with the remote-controlled vehicle on the floor. This would delete the effects of spatial updating and investigate the possibility of a size effect.

In the literature on the CBT corsi-span is often compared to the digit-span. Apparently, the corsi-span does not differ when participants are asked to reproduce the sequence in the inverse order. The digit-span on the other hand does (Kessels 2008). This I find quite interesting and worth investigating further. Does this effect remains when walking? Which factors could influence it?

## 4.5 General conclusion

The three hypothesis were: 1. Walking speed will decrease with growing difficulty. 2. The performance will differ in the four experiments. 3. Routes with more rotations will be more difficult than those with smaller rotations.

Hypothesis 1 is supported by the fact that walking speed decreases with increasing sequence length. One could argue that the longer the sequence the greater a participants uncertainty. However a positive correlation of walking speed and performance was found. But as outlined above, this finding should be investigated further. Additionally, the significant difference in walking speed in experiment SF and FF might be an argument for hypothesis one.

Hypothesis 2 is supported since in nearly all comparisons of all performance measurements experiments differd significantly. Participants performed best in SS then in FS, FF and SF. From this it may be deduced that mechanisms during reproduction have a bigger influence on the performance than those used for translation.

Hypothesis 3 is supported by the fact that there is a negative correlation between rotation and performance in levels 5 and 6. Also literature states that performance is better when less rotation is involved.

Overall, there is evidence for all three hypothesis. Memorization and reproduction as well as translation between them play a role in performance. Nevertheless, there is still a lot that can by investigated.

# Chapter 5

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