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Overt vs. covert retention strategies
eye movements in a spatial Corsi task

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Abstract

How is visuo-spatial information retained over short periods of time? In the literature, evidence for the involvement of the oculomotor system, covert shifts of attention as well as the central executive can be found. We carried out an eye-tracking experiment with a within-subject design based on the spatio-temporal Corsi block-tapping task (CBTT) to investigate this question. The task had three phases: the encoding, the retention (10 seconds) and the retrieval. The experimental manipulation took place during the retention: in condition A a free strategy choice was possible, in condition B a forced fixation on the centre was introduced and in condition C a spatial secondary task disrupted the retention process for the main task. We propose that all of the following rehearsal strategies are used in the CBTT: I) overt external (relying on eye movements), II) covert external (relying on covert shifts of attention) and III) internal (relying on mental processes, e.g. mental imagery). Every participant has an individual preference for one strategy, resulting from an individual, cost-optimising trade-off process between internal and external processes necessary (see Hardiess and Mallot, 2015). In order to investigate the covert external strategy, we propose an experimental design utilising the pupillary light reflex to track covert shifts of attention and the variable PSC_{diff} quantifying them (similarly to Unsworth and Robison, 2017). Consistently with our hypothesis, we observed a wide range in the extent of eye movements and two fundamentally different strategy types achieving similar performance: strategy type 1, not relying on eye movements (either covert external or internal) and strategy type 2, dependent on eye movements (overt external). We found that the preference for a certain strategy, as measured by the exploration extent, remained stable over all three conditions as well as over the encoding and retention phase of condition A. Consulting the proposed variable PSC_{diff}, we found evidence for both covert external and internal strategy within strategy type 1. However, more data is necessary for a statistically significant distinction.

Contents

1 Introduction

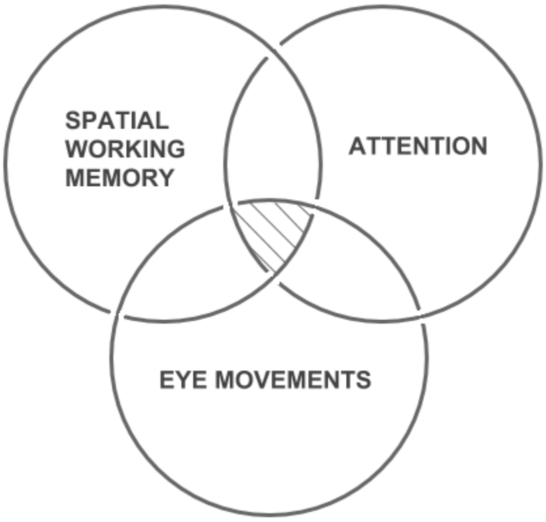


Figure 1: Theoretical classification of our study at the overlap of the processes spatial working memory, attention and eye movements.

How we do humans memorise visuo-spatial information over short periods of time? This was the fundamental question we wanted to investigate with this study. Our experiment was based on the Corsi block-tapping task, a classic experimental paradigm, that assesses the spatial working memory in a non-verbal way. To comprehend the theoretical background of our experiment, three processes and their interactions have to be understood: the spatial working memory, attention, and eye movements. In the Corsi task especially, but also in everyday life, these three processes are deeply intertwined (see figure 1 for a visualisation). In the following, we would like to clarify these processes and their interactions in light of our research purpose and present the current study in the end.

1.1 Corsi block-tapping task (CBBT)

As mentioned before, our research interest lay in retention of visuo-spatial information. More specifically, we wanted to identify and better understand different strategies used to do so in the so called Corsi task. The Corsi block-tapping task examines the visuo-spatial, temporal short term memory in a simple, elegant way. Corsi originally used the non-verbal CBTT along with a verbal task as double dissociation between the effects of left and right temporal-lobe lesions (Corsi, 1972). In the original set-up from the seventies, participants were presented nine different blocks lying on a table. The examiner tapped on an increasing amount of blocks in a randomised order. After a short pause, in which the participants had to remember the sequence, they had to reproduce it by tapping on the right blocks in the right order. These three subsequent phases are generally called *encoding*, *retention* and *retrieval*. The block-tapping sequence length was increased, until the participant's performance suffered.

The participants have to memorise which blocks have been tapped on. Doesn't that make this a visual task? The acquisition of the to-be-remembered information is realised with visual input of course, but as the blocks look all the same, considering the retention of information the Corsi task targets spatial rather than visual memory. To solve the task correctly the participants do not only have to remember which blocks (spatial component), but also in which order (temporal component) they have been tapped on. Targeting spatial as well as temporal memory in a non-verbal way has made the Corsi task one of the most popular tasks in clinical and neuropsychological research. As analogue to Hebb's digit span, assessing numerical verbal memory performance (Hebb, 1961), Corsi proposed a "spatial span" for non-verbal spatial memory. It was determined, by counting the number of block sequences which were tapped in correct order (today the scoring is often realised with different, more complex procedures. See section 2.4.2 for more details on Corsi span scoring in our experiment). Nowadays, it is known as Corsi span and is still considered the standard for spatial short-term memory assessment (Berch, Krikorian, & Huha, 1998). In the late eighties, the CBBT started to be adapted to computerised, digital formats. In our experiment also, the blocks were represented by ten squares distributed on a computer screen. An increasing number of squares lit up in green to indicate the Corsi sequence to be remembered. After the retention phase, the participants reproduced the sequence by clicking into the squares with a computer mouse. Instead of auditory feedback by the examiner, they were given immediate visual feedback about the correctness of their choice, by the squares lighting up in either green or red.

1.2 Attention

Our brain has to constantly deal with external input (visual, auditory, sensory,...) as well as internal processes (e.g. thoughts, memory retrieving,...) of all kinds. The cost of cortical computation is high and the brain has limited capacity as well as energy available to process information (Carrasco, 2011). It is only able to manage this huge amount of perceivable information by concentrating on the aspects that are of importance and filtering out the rest. Without the selective process of *attention* we would not be able to function properly. The relation between attention and consciousness is quite complex. But, simply put, what we pay attention to, we become aware of. The verbal expressions "to attract sb.'s attention" versus "to direct one's attention to sth." reflect a common distinction of types of attention also made in psychology. Attention can be "caught" by an unexpected or distinctive stimulus and is then called exogenous or bottom-up attention. The term "bottom-up" implies that we have no conscious control over this process. It is passive, reflexive. A sudden, rapid movement towards us or an unforeseen, loud sound will automatically catch our attention, whether we want it or not. On the other hand, we can deliberately direct our attention to stimuli that are of interest for us. Here we speak of endogenous or top-down attention, an active, voluntary act (Bear, Connors, & Paradiso, 2007).

1.3 Attention and eye movements

1.3.1 Overt visual attention (eye movements)

Exogenous as well as endogenous attention is a process happening across all sensory modalities. However, visual attention is the modality that has been researched most extensively. One of the reasons for this is that we have relatively easy access to information that allows us to draw conclusions about the current location of visual attention: the eye movements (compared to auditory attention for example). In order to obtain visual information beyond our visual field, we obviously need to perform eye movements. But even within our visual field, we perform quick, simultaneous eye movements (saccades), to examine details with a higher resolution. This is because the human eye only renders sharp, detailed colour vision (foveal vision) on a small patch of the retina called fovea centralis and therefore has to be constantly relocated. The term *overt attention* is used, when the location of visual attention is also the location of gaze, i.e. when visual attention and eye movements are in synchrony. In an experimental set-up using a computer screen, the centre of retinal vision (where the gaze rests) can be traced with an eye tracker in real-time. In such a set-up the participants do not have to verbally report the location of their vision, making a study a lot more reliable and allowing research on subjects that are not able to verbally report in the first place, like animals or human infants. Using eye tracking, it was found that gaze prioritises locations with high information content. Dwell time can even be considered a function of information value of specific features of an object, giving valuable information about cognitive processes happening (Laeng, Bloem, D'Ascenzo, & Tommasi, 2014).

1.3.2 Covert visual attention

However, our visual attention not always lies where our gaze does. Human adults, infants as well as non-human primates are also capable of shifting their visual attention to their visual periphery, while maintaining fixation with their eyes on another spot. In this case, the location of vision differs from the location of visual attention. This is then called *covert attention*. We are able to orient our visual attention towards information relevant to our goals, even if this information lies in our visual periphery and we currently cannot (yet) perform eye movements to move it to the centre of vision. Covert attention improves our perceptual performance in many common visual tasks like detection, discrimination and localization (Carrasco, 2011) and is therefore a useful tool. Within covert visual attention, the distinction between endogenous and exogenous attention can also be made. The use of covert attention helps us to monitor our environment in an energy-efficient way, as we do not have to constantly perform eye movements to acquire new information from the periphery. This becomes useful in several everyday situations, like crossing the street for example. Covert attention will inform us about sudden, salient stimuli in the periphery, like an approaching car, even before we directly look at it (an example for exogenous covert attention). In other situations we might want to deliberately inhibit eye movements in order to hinder another person from knowing where our visual attention lays (an example for endogenous covert attention). Such a situation could be a sporting competition, a fight or even a conversation. If it later becomes necessary to move a stimulus from the periphery into central vision, covert attention helps to prepare and facilitate these subsequent eye movements (Carrasco, 2011).

1.4 Attention and spatial working memory

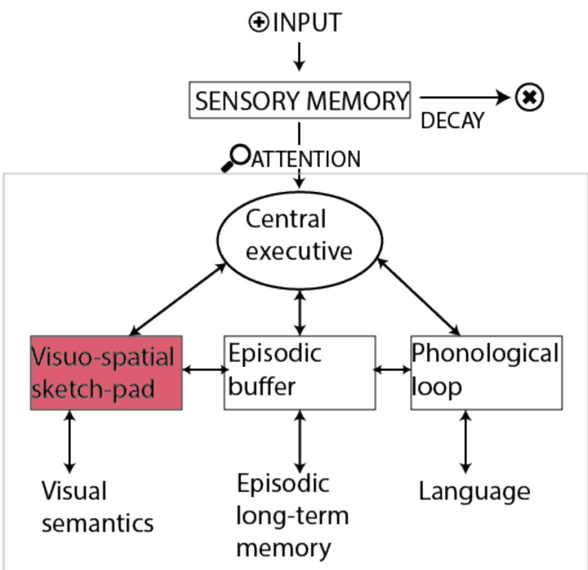


Figure 2: Multicomponent working memory model by Baddeley and Hitch (1974). Redrawn from https://www.simplypsychology.org/-working%20memory.html

As mentioned before, our study focused on retention of visuo-spatial information. More specifically, retention of visuo-spatial information in the working memory (WM). The working memory is responsible for short-term storage of limited information for goal-driven processing. Complex mental arithmetic targets the working memory, for example. The working memory has to retain partial results for later processing, otherwise the final result cannot be calculated. Compared to long-term memory, the working memory has a very limited capacity. Miller proposed the "magical number seven plus or minus two" as limit for the amount of meaningful units of information ("chunks") that can be stored for short-term processing (Miller, 1956).

But how do attention and spatial working memory interact? Baddeley proposed, that the rehearsal of information, refreshes traces in immediate memory that otherwise decay over time (as cited in Smyth and Scholey, 1994). This is why endogenous attention directed to the to-be-remembered information is crucial for goal-driven consolidation of short-term memory. In their multicomponent working memory model from 1974 (see figure 2) Baddeley and Hitch proposed two passive, perceptual stores, the “visuo-spatial sketchpad” and the “phonological loop”. These two components of WM are used for independent, short-term retention of visuo-spatial and auditory verbal information, respectively. Without rehearsal, the information there rapidly decays. Compatible with this idea of a visuo-spatial sketchpad, is a theory proposed by Smyth and Scholey. Like in our experiment, they used a Corsi task to target the visuo-spatial WM and asked the participants to do concurrent tasks causing shifts of spatial attention in the retention interval. They concluded that maintenance in visuo-spatial immediate memory is based on shifts of spatial attention (Smyth & Scholey, 1994). A similar theory was proposed by Awh, Jonides, and Reuter-Lorenz (1998). They identified selective spatial attention as rehearsal mechanism for spatial WM and offered an explanation on the neurological level of how shifts of spatial attention to memorised locations improve the accuracy of spatial information retention: Frontal and parietal mechanisms, responsible for the internal allocation of attention, enhance activation of sites in the extrastriate occipital cortex, which in turn result in reinforced activation of location-specific representations.

Somewhat contradictory to these two theories are findings by Klauer and Stegmaier (1997). They investigated inference in serial spatial memory and draw the conclusion of a central executive involvement in the rehearsal process of spatial memory. Ten years later, in 2007, Rudkin, Pearson, and Logie found that a Corsi task is more impaired by a non-spatial central executive task (random number generation) than a spatial task (matrix pattern task), also indicating that the central executive rather than spatial attention is involved in retention of spatial information.

1.4.1 Covert attention and spatial working memory

As explained before, visuo-spatial attention can be shifted without performing actual eye movements. Godijn and Theeuwes (2012) investigated the use of covert spatial attention shifts with a task requiring the retention of a sequence of serially presented spatial locations of six digits. In fact, they found that overt shifts of attention, including eye movements, did not offer any benefit over covert shifts in this task.

In order to investigate covert spatial attention, we can use a task demanding shifts of spatial attention for information retention while at the same time the experimental set-up disrupts or completely inhibits eye movements during retention (as did Godijn and Theeuwes). We then assume that the participants switch to strategies including covert shifts of attention. But in the absence of eye movements, how can we verify if there are really covert shifts of attention happening and not other internal mental processes? Unsworth and Robison (2017) proposed a method for doing so, using the *pupillary light reflex* (PLR). They performed a change detection task on a screen with a dark and a bright side. Even with their eyes fixating on the neutral middle, the participants' pupil dilated when their attention was cued to the dark and restricted when cued to the bright side of the screen, indicating that the PLR reflected covert shifts of spatial attention.

1.5 Eye movements and spatial working memory

Contrasting the theories that the visuo-spatial working memory (VSWM) relies on shifts of covert attention, there is also an influential theory stating that the VSWM relies on the activation of the oculomotor system instead. This theory proposes that spatial locations are encoded as the goals of potential eye movements. The consolidation of spatial information is realised by the rehearsal process of covertly planning saccades to the to-be-remembered locations. During the recall, the retained saccade plans activate the oculomotor system and lead to the selection of correct locations (Pearson, Ball, & Smith, 2014). Using the so-called "abducted eye paradigm" in a Corsi task Pearson et al. (2014) prevented oculomotor preparation during the encoding and maintenance of spatial information and indeed found a significant reduction of spatial memory span. They concluded that the oculomotor system contributes to the maintenance of spatial information independently from processes of covert attention.

If the oculomotor system contributes to spatial information maintenance, forced, counter-intuitive eye movements should impair rather than improve performance. Following this logic, de Vito, Buonocore, Bonnefon, and Della Sala (2014) asked participants to perform visual and spatial imagery tasks concurrently with smooth pursuit eye movements. Considering mental imagery, they concluded that eye movements serve the spatial component to a bigger extent than the visual component, as the disruptive effect of concurrent eye movements was stronger on spatial than visual imagery.

1.6 Eye movements, attention and spatial working memory

Summarising, there is (partially contradictory) evidence for the involvement of all of the following processes during encoding and/or retention of visuo-spatial information: eye movements (or rather the oculomotor system in general) (Laeng et al., 2014; Pearson et al., 2014), covert attention shifts (Godijn & Theeuwes, 2012; Unsworth & Robison, 2017; Smyth & Scholey, 1994; Awh et al., 1998), as well as central executive processes (Klauer & Stegmaier, 1997; Rudkin et al., 2007). Considering the CBBT these three processes can be classified in two categories: *internal* and *external* strategies. The internal strategy relies on purely cognitive processes. The external strategy on the other side, externalises the given task by utilising their environment rather than solely their cognition for maintenance of the to-be-remembered spatial information. This can be realised by processes of rehearsal, e.g. retracing the sequence or revisiting salient points, with either overt eye movements or covert spatial attention shifts.

In a comparable visuo-spatial paradigm requiring external as well as internal strategy use, Hardiess and Mallot investigated the cost-optimising trade-off between the two strategies. In a comparative visual search task they observed that each participant had an individual trade-off strategy between the external process of acquisition (relying on gaze shifts) and the internal process of memorisation (relying on WM) (Hardiess & Mallot, 2015).

The use of internal and external strategies in the CBBT was investigated by Walter in 2016. During the retention in the three different conditions, different secondary tasks were given. In the first condition there was no secondary task and therefore the preferred strategy could be chosen freely. In the second condition a visual secondary task was given in order to impair external strategies, while in the third condition a visuo-spatial secondary task was assumed to impair external as well as internal strategies. She concluded that both internal and external strategies are used. Furthermore, there seems to be a stable individual preference for one of the strategies.

1.7 The current study

In the current study we would like to investigate more closely the differentiation between strategies using eye movements (overt external strategy) and strategies that do not depend on eye movements (covert external and internal strategy). Furthermore, we would like to propose an instrument to identify covert shifts of attention in the CBTT in the absence of eye movements. Similarly to Unsworth and Robison (2017) we employed bright and dark backgrounds in order to use the pupillary light reflex as indicator for covert shifts of attention (see section 2.4.2 for more details on the proposed variable PSC_{diff}).

We adopted the fundamental experimental design used by Walter (2016) (CBTT monitored by an eye tracker, three different conditions), but adapted the secondary tasks during retention, in order to better control for confounding factors. Condition A was still used to determine the preferred strategy, as there was no secondary task limiting any of the three assumed strategies. During the retention of condition B, Walter asked the participants to click on a square appearing in a small grid in the centre of the screen for three times. However, it seems that this secondary task is too easily solved and that in the meantime between the secondary stimuli presentations the participants can still engage in their preferred retention strategy. We therefore introduced a forced fixation on the fixation cross in the centre during the whole retention phase of condition B, almost completely inhibiting eye movements. In condition C we used a slightly adapted version of the visuo-spatial secondary task used by Walter, in order to interfere with the visuo-spatial retention process for the main task, may it be external or internal.

1.7.1 Our hypotheses

So we assume that the retention of spatial information demands the allocation of spatial attention (overt or covert) or eventually other internal mental processes like mental imagery for example. Therefore, we expect to find three different strategies used: I) overt external strategy (using eye movements), II) covert external strategy (using covert shifts of attention) and III) internal strategy (using solely mental processes).

We assume that every participant i) has an individual preference for a certain strategy, but also that ii) strategy changes to an alternative strategy can happen as an adaptation to different conditions or longer sequence lengths.

In condition A we expect i) a wide range in the extent of eye movements (i.e. a wide range of covert/internal and external strategy use) and ii) a stable strategy choice between encoding and retention.

In condition B we expect i) participants with a covert or internal strategy to maintain their performance, while ii) participants with an overt strategy show a performance loss (if not able to switch strategy).

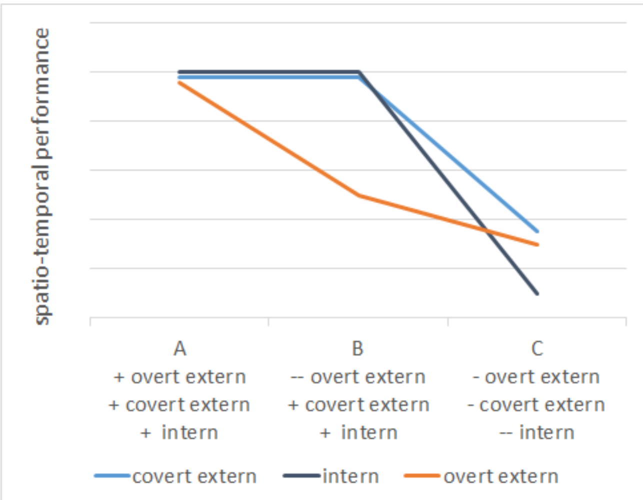


Figure 3: Hypothesis for the course of performance of the three suggested strategies over the conditions. Under the respective condition the intended experimental manipulation for each strategy is indicated: (+) strategy usable, (-) strategy impaired, (- -) strategy strongly impaired.

In condition C we expect that i) all participants show a decrease in performance, but that ii) participants with an internal strategy are most impaired by the secondary task (see figure 3 for a visualisation of our hypotheses considering the visuo-spatial performance).

Considering the pupil size change we expect that i) PSC_{diff} is biggest in participants with a covert external strategy (as they perform covert shifts of attention) and that ii) participants with an internal strategy show the smallest PSC_{diff}.

2 Methods

2.1 Participants

Seventeen volunteers participated in the study. In three cases the experiment had to be aborted due to problems with the eye tracker, yielding a final total number of 14 participants (6 male, $M = 20.64, SD = 1.26$, all right-handed). All participants were from the University of Tübingen and received written confirmation of experiment participation as a reward. All of them had normal or corrected-to-normal vision. The experiment adhered to the Code of Ethics of the World Medical Association (Declaration of Helsinki) and a written informed consent for the participation as well as the storage and evaluation of their data was obtained from each volunteer prior to participation.

2.2 Setting and apparatus

The experiment took place in a windowless room. The light setting in the room was kept constant over all participants. The experiment was conducted on a computer running on Windows 10 from Microsoft. The monitor measured 37.6×30.1 cm (1280×1024 pixels) and was set on 70% brightness. The head position of the participants was kept constant with a headrest attached to the desk, 50 cm from the monitor. The experiment was coded in Matlab (MathWorks, 2017b) with use of the Psychtoolbox-3 (Kleiner et al., 2007).

Figure 4: Monocular eye tracker used. The infra-red camera is mounted in the centre below the screen. Image taken from http://www.eyegaze.com

2.2.1 The eye tracker

The eye movements of the participants were tracked in a non-invasive way with a monocular eye tracker from the brand EyeGaze. An infra-red light is sent out to the eye and the system then computes a 3D-model of the eyeball using the reflection of this light in the cornea as a reference point. This technique is called Pupil Center Corneal Reflection (PCCR). [1] The eye tracker works with a sampling rate of 60 Hertz (60 measurements per second). It logs, among other things, the position of the eyeball

[1]http://assistivetechnologyblog.com/2016/08/eye-tracking-101-how-does-it-work.html

in space, its gaze point in pixels, as well as the pupil diameter in millimetres. The equipment provided by EyeGaze includes a 1280 x 1024 pixel monitor, an infra-red camera mounted below the screen (see figure 4) as well as the software which constantly writes the tracker's calculated data into a log file and allows access of the data in real time.

2.3 Procedure

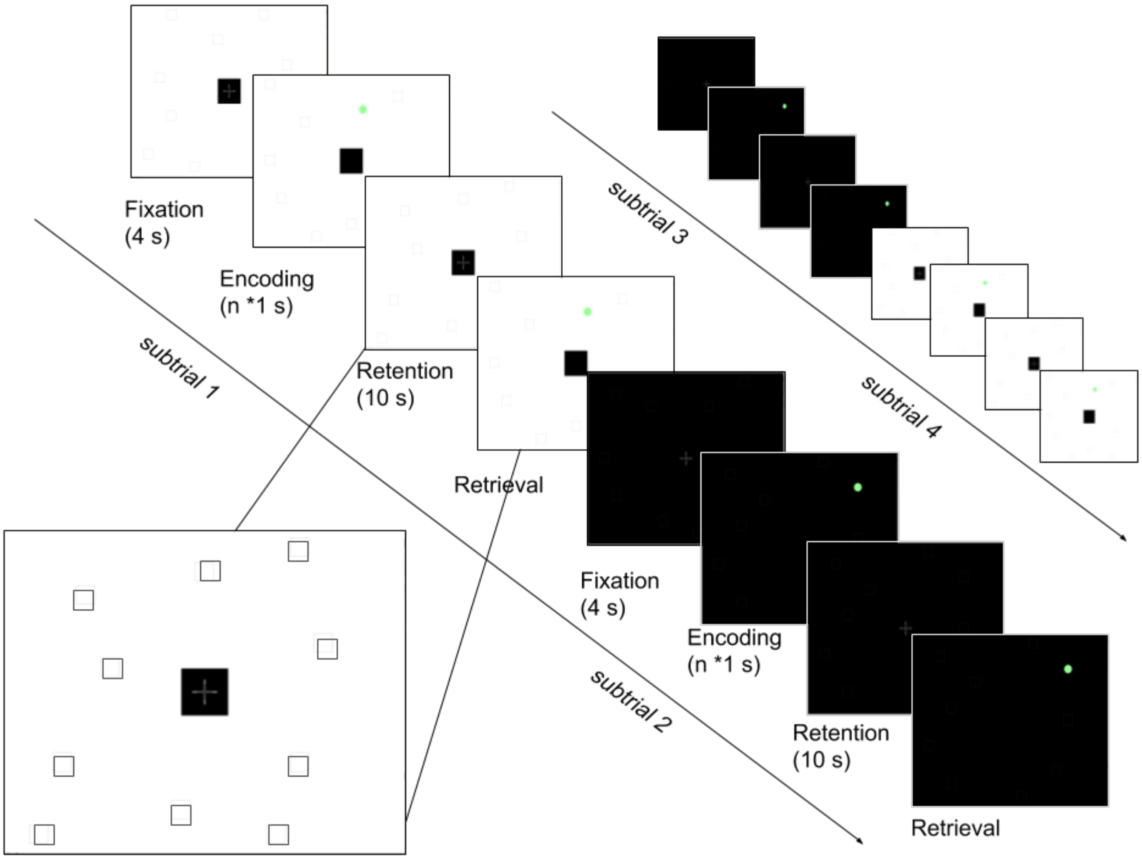


Figure 5: Schematic procedure of subtrial one (white background) and subtrial two (black background). Subtrial three and four (pictured in the back) were structured the same way, whereas subtrial three had a black and subtrial four a white background to control for a possible effect of the order of background colour. Every subtrial consisted of a fixation cross phase, an encoding phase, a retention phase and a retrieval phase and took (in total) approximately between 20 and 30 seconds. In the bottom left corner an enlarged display of the screen during the retention of condition B is displayed.

The participants were welcomed by the investigator and led to the experimental room. The procedure was explained in detail and they were informed that they could interrupt the experiment at any time without giving reasons. Those willing to participate then signed an informed consent. After this, the investigator tested if the participant was suitable for the eye tracking with the Eye-Gaze eye tracker (see section

2.2.1). In order to do so, they were seated in front of the computer and their head placed on the headrest. The investigator checked whether the eye tracker was getting a viable image of the right eye and a calibration was performed. The calibration consisted of nine points appearing at different locations of the screen. The participants had to follow these points with their gaze while the eye tracker system checked and updated its 3D-model for their eye positions. One participant was not compatible with the tracker and had to be excluded. Next, the experimental procedure was explained to the participants and they were given time to ask questions. They then absolved a training block consisting of six trials (3 conditions x 2 subtrials x 1 sequence length) with a Corsi sequence length consisting of two stimuli, that was otherwise identical to the main experiment. If the participant concluded the training block successfully, the main experiment started.

The experimental design was a variation of the Corsi block-tapping task (see section 1.1). It started with a sequence length of three stimuli, assuming that sequence length one and two are too trivial to make significant mistakes once the experimental procedure has been understood. The experiment consisted of three blocks, consisting of two trials with consecutive sequence lengths. Before each block, an eye tracker calibration was performed and the participants were given the opportunity to take a break if desired. If a person failed in more than two of the four subtrials of a certain condition/sequence length combination, this condition was excluded in the following sequence length within a block. This was done in order to keep the total time of the experiment short and spare the participants frustration. In total, the experiment took about one hour per participant.

The three different conditions were presented in a pseudo-randomised, fixed order over the six trials to rule out possible effects of order (see table 1). Every combination of a condition and sequence length was repeated four times, i.e. consisted of four subtrials. The order of background colour for the four subtrials was white-black-black-white in all trials (see figure 5). This yielded two pairs of the different background conditions, one with the order white-black (subtrial 1 and 2) and the other black-white (subtrial 3 and 4). This enabled us to rule out effects of the order of background presentation in data analysis.

Every subtrial consisted of four different phases: the fixation, the encoding, the retention and the retrieval phase (see figure 5). Situated in the centre of the screen was a grey fixation cross (80×80 pixels, 2.35×2.35 cm) on top of a black window (150×150 pixels, 4.41×4.41 cm). During phases of the experiment where the participants were not required to fixate in the middle (encoding, retention condition A and C, retrieval), the fixation cross vanished, indicating to them the freedom to move their gaze. In the

Block	Training	1st	2nd	3rd
Sequence length	2	3, 4	5, 6	7, 8
Order of conditions	(A C B)	(A C B C B A)	(B A C A C B)	(C B A B A C)
Number of subtrials	2	4	4	4

Table 1: Tabular overview of sequence length, order of conditions (A, B and C) and number of subtrials in the training sequence and the three experimental blocks

subtrials with a white background (1 and 4) the window behind the fixation cross was still black, ensuring that the observed central image during fixation was the same for both backgrounds even if the brightness was not.

There were five different default patterns consisting of ten squares evenly distributed over the screen in the space around the fixation window. The pattern changed at the beginning of a new subtrial and was used over all four phases of the subtrial. The choice of pattern was randomised but fixed, meaning every participant saw the same pattern during the same subtrials. The squares measured 60×60 pixels (1.76×1.76 cm). For the two different backgrounds, the squares were outlined in different shades of grey (white background: rgb(210, 210, 210), black background: rgb(45, 45, 45)), leading to a similar perceived contrast between them and both backgrounds.

The Corsi sequences displayed were also pseudo-randomised, but fixed. It was hard-coded, which sequence appeared in which particular subtrial. The sequences were not generated completely randomly in order to minimise the so called path-length-effect as a confounding variable. The complexity of a to-be-remembered spatial sequence significantly affects the retrieval performance of participants (Parmentier, Elford, & Maybery, 2005). As factors of spatial temporal complexity the number of path crossings, path lengths, and angles have to be considered. The path length depends on the sequence length, of course, but what is meant here is that even for the same number of stimuli (the same sequence length) the resulting total distance of the path between them can vary tremendously. The predefined routes covered a maximum of the screen and all had similar numbers of path crossings for a certain sequence length. However, if a person failed to maintain fixation during the retention phase in condition B, a randomised sequence was generated to prevent repeated display of the same sequence. 17.6% (26 out of 148) of the correctly solved subtrials had such a truly random sequence. In none of these sequences was clustering of the stimuli observed, therefore none had to be excluded from later evaluation.

2.3.1 Different conditions

The experimental manipulation took place in the retention phase, where in the different conditions, different secondary tasks were demanded. As mentioned before, there were three conditions, i.e. three different secondary tasks. The experiment had a within-subject-design, meaning that every participant underwent all three conditions. The current sequence length as well as condition was shortly displayed before every trial. For the order of the conditions consult table 1.

Condition A: no secondary task

In this condition there was no secondary task or eye movement restriction and the participants were free to use their preferred retention strategy (internal or external). This condition was later used to determine participants' preferred strategy tendencies.

Condition B: forced fixation on the centre

Here the participants were told to maintain their gaze on the middle of the fixation cross during the 10 seconds retention. According to our hypothesis, this disrupts overt external strategies, but still allows mental representations or covert attention shifts as strategy. Due to the inaccuracy of the eye tracker and unconscious mini saccades that can hardly be oppressed, a tolerance window of 200×200 pixels (5.88×5.88 cm) around the screen centre was implemented. If the eye tracker computed a gazepoint coordinate outside this tolerance window, a warning message was displayed and the subtrial was repeated with a randomly generated sequence of given length. For two participants, gazepoint coordinates outside of the tolerance window were constantly computed and the experiment had to be aborted.

Condition C: spatial secondary task

The aim in this condition was to disrupt internal (mental representations and covert attention shifts) as well as external strategies (overt attention shifts). To do so, we asked the participants to perform a secondary visuo-spatial task, which requires similar brain regions as the main task, as well as eye movements to be solved. During the retention interval, a grid with 5×5 squares was displayed in the area of the fixation window (150×150 pixels, 4.41×4.41 cm) in the centre of the screen. After an onset delay of one second, three different squares were marked with a grey filling and displayed for two seconds. After a delay of 1.5 seconds the participants had to report these three positions by clicking at their former positions within the grid. For the same reasons as explained above for the Corsi sequences (see section 2.3), we had to ensure that the different randomly generated patterns of three positions had similar levels of difficulty to remember, and that no coincidental clusters form. In order to do so, we divided the grid in three levels: the upper level (squares 1 - 8), the middle level (squares 9 - 17) and the bottom level (squares 18 - 25). For each level at a random position within it, a square was marked. In the middle position (square 13) a small fixation cross was depicted and it was excluded as possible position for a stimuli. If a participant made more than one error in this task, a message asking for more accuracy was displayed at the end of the subtrial. The number of correct clicks in the secondary was logged, but there were no other direct consequences for them. However, in the correct subtrials included in the final data evaluation no participant made more than one error. If a person reacted quickly, the secondary task covered about six out of the ten seconds of retention phase, still allowing them to use their preferred retention strategy in the remaining time. If and to what extent this happened was not extractable from the final data.

2.4 Analyses

The basis for the final analysis was firstly the log file generated by the eye tracking system. The variables used for analysis were the sample index, the boolean variable "Eye Found", the computed gazepoint coordinates on the screen X and Y, the measured pupil diameter, and a numeric marker variable, indicating the phase within a trial (1: fixation, 2: encoding, 3: retention, 4: retrieval).

Secondly, we consulted the protocol file generated by the Matlab program. For every block/condition combination, one file was generated, yielding in total nine files (3 blocks x 3 conditions) per participant. For every single subtrial it contained the participant's acronym, the current sequence length, the current subtrial number, the number of correct clicks within a subtrial, the number of correct subtrials within a sequence length, and a variable k ($1 \geq k \geq 5$) indicating which pattern was deployed. The last ten numbers specified the Corsi sequence displayed in the form of a permutation from one to ten. 'One' indicated the left-most square, 'two' the square second from the left and so forth to 'ten' (the right-most square). As there were no squares placed directly beneath one another, this guaranteed an unambiguous assignment of squares for all patterns.

2.4.1 Data processing

When looking into the eye tracker log files, we noticed that the eye tracker systematically miscalculated the pupil diameter when the EyeFound variable in three subsequent measurements read '101' or '010'. It is mechanically impossible for the human eye to change its pupil diameter on such a large scale in such a short time interval, as calculated by the eye tracker in these cases. We cleared the data of these outliers by replacing the three pupil diameter measurements in such a constellation with the last plausible one before it. Furthermore, we smoothed the pupil diameter over a time window of 100 ms. At the measurement frequency of 60 Hertz, that corresponded to six data points. In the smoothed data set, each data point was replaced by the mean of the six subsequent data points.

From the protocol files, only the correct subtrials (number of correct clicks = sequence length) were further considered. For every participant these correct subtrials were aggregated in one separate file for every condition, yielding 42 files (14 evaluable participants x 3 conditions).

2.4.2 Dependent variables

Corsi span (CS)

The Corsi span is a measure for the spatio-temporal working memory performance proposed by Corsi (1972). The bigger the Corsi span of a person, the better their performance in the spatio-temporal Corsi task. For the calculation we used a formula adapted from lle Lépine, Parrouillet, and Camos (2005). The advantage of this method of Corsi span calculation is that the span is weighted according to the sequence length and divided by the number of subtrials. A correctly solved subtrial with a long sequence length will have more impact on the final Corsi span than a subtrial with a short sequence length. The Corsi span was calculated separately for every participant and every condition with the following formula:

$$\text{Corsi span} = \frac{\sum_{i=1}^{8} (\#\text{correct subtrials}(i) \cdot i)}{4}$$

$$i = \text{sequence length}; 3 \geq \text{Corsi span} \geq 36$$

The maximum Corsi span theoretically achievable is therefore $\frac{\sum_{i=1}^{8}(4 \cdot i)}{4} = 36$. As we assumed, that with sequence length one and two, our task was too trivial to make significant mistakes, the initial sequence length was set to three. Due to this, we added $\sum_{i=1}^{2} (4 \cdot i) = 12$ to the calculated enumerator to compensate for the missing subtrials with sequence length one and two in the final Corsi span. The minimum Corsi span achievable in our set-up was therefore $\frac{12}{4} = 3$.

Exploration extent (EE)

The aim of this measure is to quantify the use of the externalising strategy during the encoding and the retention phase of the Corsi task. It was adopted from Walter (2016). In the encoding phase, it reflects the extent to which the participant performed overt eye movements to the locations of presented stimuli to acquire the necessary visual information about the to-be-remembered Corsi sequence. In the retention phase, the measure reflects the extent to which the participant used oculomotor repetition (the retracing of the presented sequence with overt eye movements) as a memory strategy. In both cases, the basic idea is that the exploration extent indicates to what extent the fixations were located at the centre of the screen (all fixations at centre: EE = 0) or at the position of stimuli presented (all fixations at stimuli: EE = 1).

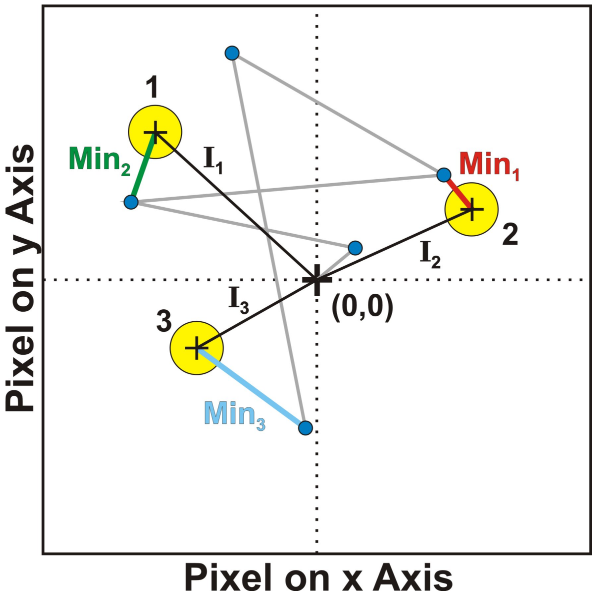


Figure 6: Example of a exploration extent calculation with a sequence length of three. The three yellow dots represent stimuli of the Corsi sequence, the five blue dots fixations of the gaze trajectory and I_1, I_2, I_3 the euclidean distances from stimulus to centre. Graph kindly provided by Dr. Hardiess

During fixations, the eye stops to scrutinize a part of the visual field. These typically have a duration of at least 100 ms (Salvucci & Goldberg, 2000). For the analysis of the exploration extent, the fixations realised during the task had to be extracted from the raw data. This was done by a Matlab program provisioned by Dr. Hardiess. It checked, whether the calculated eye position stayed constant for at least seven measurement points. At the measurement rate of 60 Hertz, that corresponds to a little more than 100 ms, the time span used to distinguish a fixation from saccades.

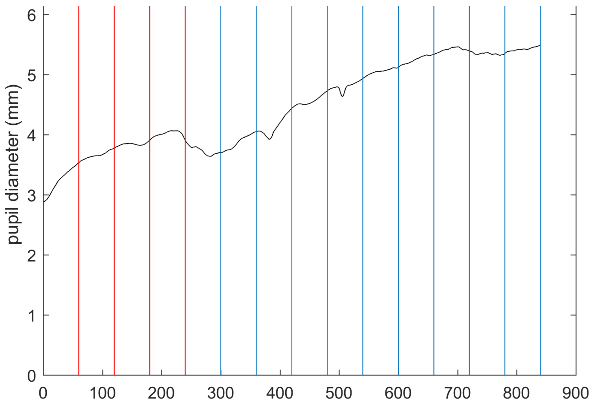
Basis for the calculation of the exploration extent was the sum of euclidean distances between the nearest fixations and the presented stimuli. In order to determine these, a distance matrix of the stimuli and the realised fixations was set up. It contained the euclidean distances between each stimuli (in the rows) and fixation (in the columns) in pixels. Firstly, the global minimum was determined and the value assigned to its corresponding stimuli. The other values in the row of this stimuli and the column of this fixation respectively, were not further considered and therefore deleted. In the resulting matrix again the global minimum was searched and its value assigned as minimum distance to its corresponding stimuli, the other entries in its row and column were deleted. In this manner, for every stimulus the closest fixation and the resulting minimal distance from fixation to stimuli was determined. In the cases where there were less fixations than stimuli, the number of searched minima was reduced to the number of fixations. In the example displayed in figure 6, the determined minimal distances are Min_1, Min_2 and Min_3. These distances were summed up to determine the overall distance from closest fixations to stimuli: Dist $= \sum_{n=1}^{SL}(Min_n)$. The smaller this value, the nearer the fixation was to the stimuli, i.e. the participant made a lot of stimuli driven eye movements, indicating the use of an externalising strategy.

In order to enable comparisons over different sequence lengths, the calculated distance had to be normalised. In order to realise this, the distance covered (*Dist*) had to be divided by the maximum distance for the given Corsi sequence (*maxDist*). Participants with a low extent of externalising strategy tend to maintain their gaze on the centre of screen (Walter, 2016). This is why the maximum distance was determined by summing the euclidean distances from the stimuli to the centre: maxDist $= \sum_{n=1}^{SL}(I_n)$. See I_1, I_2 and I_3 in figure 6 for a visualisation of this measure. The formula below provides the final normalised measure for the exploration extent in percent, i.e. the quantification of external strategy use during encoding and retention.

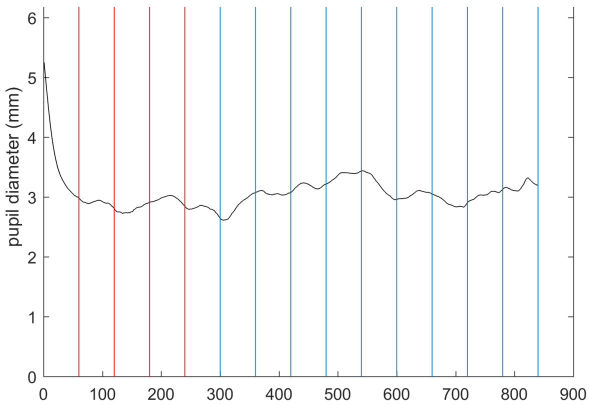
$$
\begin{aligned}
\mathrm{EE} &= 1 - \frac{\mathrm{Dist}}{\mathrm{maxDist}} \\
&= 1 - \frac{\sum_{n=1}^{SL}(Min_n)}{\sum_{n=1}^{SL}(I_n)} \\
& n = \text{number of stimuli}; 1 \geq n \geq \text{sequence length (SL)} \\
& \mathrm{EE} \in [0,1] : \text{all fixations at centre: EE=0; all fixations at stimuli: EE=1}
\end{aligned}
$$

Pupil size change (PSC) and pupil size change difference (PSC_{diff})

Unsworth and Robison (2017) demonstrated a correlation between the pupil size and covert shifts of attention to bright and dark backgrounds, respectively. In order to investigate this effect, we designed our experiment with four subtrials each trial - two with a white and two with a black background (see figure 5). The order of background condition was white-black-black-white for all trials. For every trial, this experimental design yielded two pairs of subtrials, one in the order white-black and one in the order black-white. This enabled us to rule out confounding effects of the background order. The two background conditions (black and white) had different brightness levels. During the fixation phase in the beginning the eye adapts to the current brightness by adjusting the pupil size. At the transition from a bright to a dark background (subtrial 2) the pupil quickly dilates, while at the transition from dark to bright (subtrial 4) the pupil constricts (see figure 7 (a) and (b)). As also found by Chen (2014), we observed that around two seconds after the luminance change, the pupil diameter change slows down and gradually reaches a more or less stable state after three seconds. For this reason, we used the averaged last 60 measurement points of the fixation phase as baseline, rather than the mean over the entire four seconds. By subtracting the given baseline pupil diameter on a subtrial-by-subtrial basis for each participant, we performed a baseline correction similar to Unsworth and Robison (2017). The pupil size change (PSC) therefore indicates the change of pupil diameter over time when compared to the according fixation



(a) subtr. 2 (white to black)



(b) subtr. 4 (black to white)

Figure 7: Exemplary course of pupil diameter in millimetres over the fixation and retention phase (sequence length 5, condition A). The distance between two vertical lines corresponds to one second (60 measurement points). The red lines mark the fixation phase (first 4 seconds), the blue ones the retention phase (10 seconds).

baseline during the retention phase of condition B.

$$PSC(n,t) = PS_t - b_n$$
$$PS_t = \text{pupil size in mm at point in time } t \text{ during subtrial } n$$
$$b_n = \text{pupil size baseline in mm for subtrial } n$$

The aim of the variable PSC_{diff} is to determine, whether during the retention phase in condition B, covert shifts of attention from the centre to the former positions of stimuli in the periphery were performed. As shown by Unsworth and Robison this can be done by comparing the baseline corrected pupil change in the conditions with a dark and a bright background. Under the assumption that the use of covert attention shifts as strategy remains stable over the four subtrials of a certain sequence length, we subtracted the pupil size change of subtrials with white background from subtrials with black background. In order to control for confounding effects of presentation order (see figure 5) the PSC difference was calculated in the following way for each data point t:

$$PSC_{diff}(t) = \frac{(PSC(subtr2,t) - PSC(subtr1,t)) + (PSC(subtr3,t) - PSC(subtr4,t))}{2}$$

The calculated data points were averaged over every trial, i.e. sequence length, yielding the mean PSC_{diff} for every participant at a given sequence length.

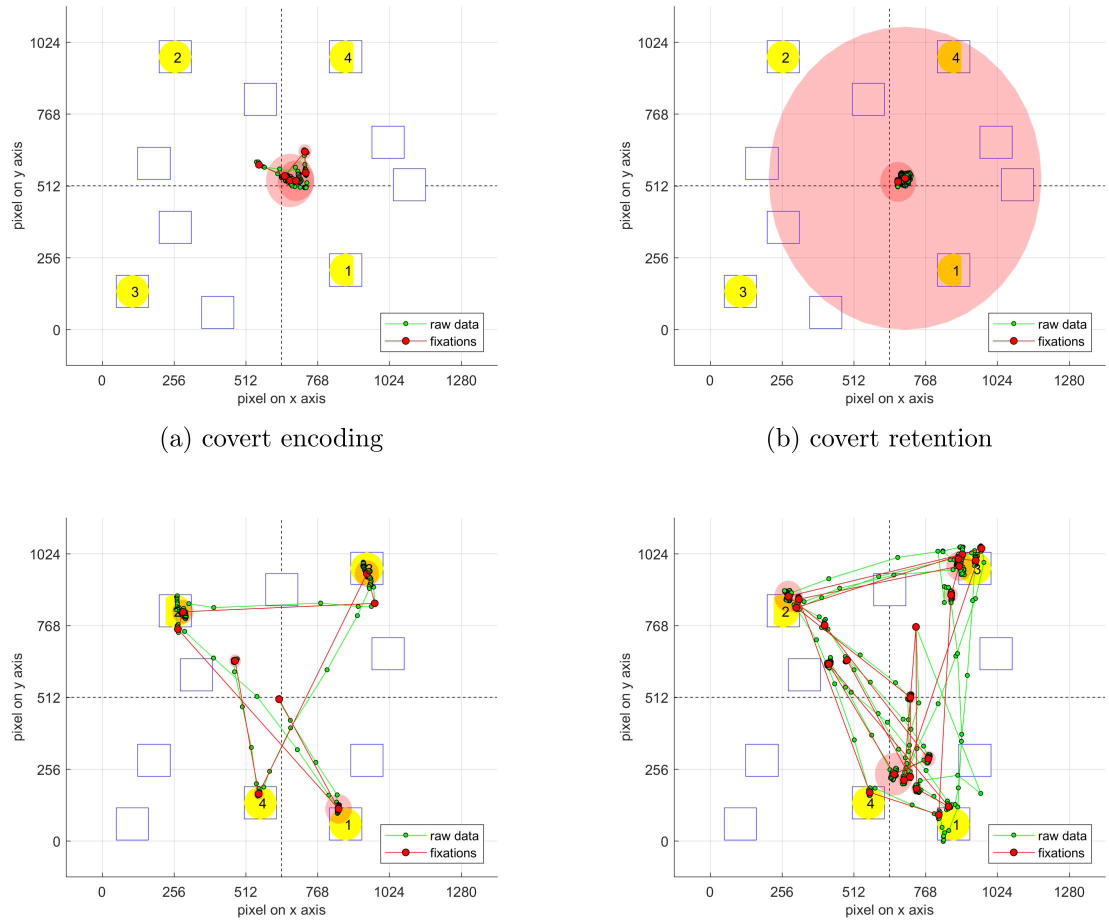
In condition B the participants are forced to maintain their gaze on the fixation cross throughout the retention phase. The fixation cross is grey on a black background in both subtrials, with white and black backgrounds. Apart from the surroundings, the central observed image should therefore be the same for both background colours. With the baseline correction, the pupil size adaptation due to the different luminance of the backgrounds should be excluded from the PSC calculated. In the subtrials with the same sequence length, the cognitive load is assumed to be constant and therefore there should be no pupil size changes due to cognitive load changes (see Chen, 2014). In summary, it is assumed that a large positive PSC_{diff} can only be explained with covert shifts of attention to the periphery, leading to a pupil constriction in subtrials with a white background and pupil dilation in subtrials with a black background as other confounding influences on the pupil size are eliminated from the calculation. The bigger this difference, the bigger the extent of covert shifts of attention used as retention strategy.

2.4.3 Statistics

The tests for statistical significance were run on SPSS Statistics (IBM, 2015, version 23.0). It was tested with a significance level of 5% ($\alpha = .05$). Before performing an ANOVA with repeated measures, the homogeneity of variances was tested with Mauchly's test for sphericity. As we could not assume a normal distribution for our data, the statistical significance of correlations was tested with the non-parametric Spearman's rank correlation test. If multiple comparisons had to be performed, a Bonferroni correction was applied in order to prevent a type I error inflation.

3 Results

3.1 Analysis of scanpath



(a) covert encoding (b) covert retention

(c) overt encoding (d) overt retention

Figure 8: Two exemplary scanpaths in condition A (free strategy choice). The x and y axis indicate the position on the screen used in the experiment (in pixels). The yellow circles and the corresponding number indicate the Corsi sequence presented to the participants. The sequence length was four in both subtrials displayed. The green dots indicate raw data points calculated by the eye tracker. The red dots indicate extracted fixations. The red translucent circles around every fixation specify its relative duration. In the first row, a participant (VP08) with a covert strategy in encoding (a) as well as retention (b) is displayed. In contrast, in (c) and (d) a participant (VP12) with an overt external strategy can be seen.

In figure 8 the exemplary scanpaths of two different participants are shown. The graphs display the eye movements the participants performed, while solving the task for a sequence length of four in condition A (no eye movement restrictions and therefore a free strategy choice). In the first column, the eye movements over the four seconds of encoding are displayed, in the second column the ten seconds of retention of the respective subtrial. The participant in the first row rested his gaze in the middle of the screen in both encoding and retention. This indicates that he used his peripheral rather than foveal vision for information acquisition during encoding. The participant in the second row performed extensive eye movements in both encoding and retention. During retention he retraced the to-be-remembered Corsi sequence several times with his gaze. However, these two are rather extreme examples. In most cases the extent of eye movements, and the distance covered by them between the stimuli, varied over the subtrials and laid between these two cases.

3.2 Analysis of Corsi span (CS)

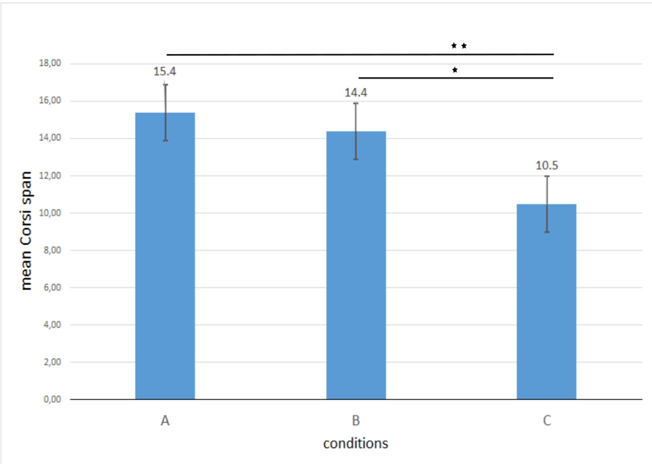


Figure 9: Mean Corsi span of all 14 participants in the three conditions A ($M = 15.39, SD = 6.62$), B ($M = 14.39, SD = 5.65$) and C ($M = 10.46, SD = 3.90$). The differences between A and C and between B and C were statistically significant. Error bars indicate the standard deviation.

Here the spatio-temporal performance of participants, measured by the Corsi span (see 2.4.2), was analysed. This analysis examined the influence of the different conditions on the Corsi span. The mean Corsi span decreased with increasing restriction of possible strategies (see figure 9). In condition A, the participants achieved a mean Corsi span of 15.4, in condition B the mean Corsi span was 14.4 and in condition C the Corsi span further decreased sharply to 10.5. To examine the effect of the factor condition, a one-way ANOVA with repeated measures was performed, which confirmed a statistically significant influence of condition on the Corsi span ($F(2, 26) = 11.88, p < .001, \eta_p^2 = 0.48$). The post-hoc analysis showed significant differences between condition A and C ($p = .006$) and condition B and C ($p = .011$), but no significant difference between A and B ($p = .65$) (see figure 9).

3.3 Individual differences of CS between conditions (strategy types)

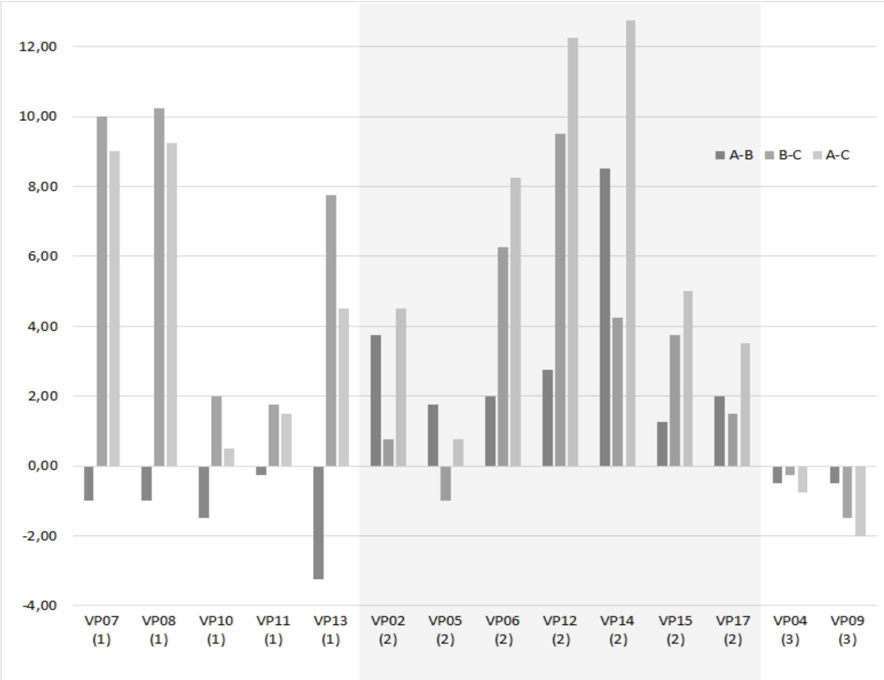


Figure 10: Corsi span difference between conditions (A-B, B-C, A-C) for all participants. On the basis of the pattern displayed, they were divided in three groups of different presumed retention strategies. The five on the left (bright background, type 1) bettered their performance in B, indicating a covert/internal strategy. The seven in the middle (grey background, type 2) were impaired in B, indicating an overt strategy. The pattern displayed by the last two (bright background, type 3) cannot be explained with our theoretical framework.

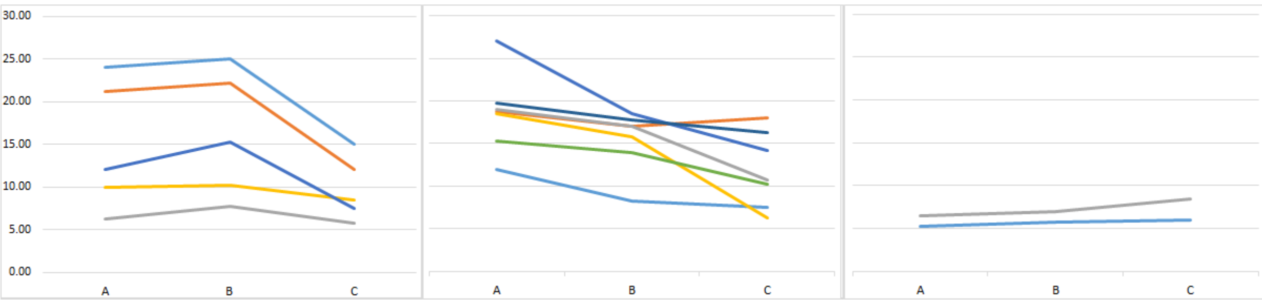
Here we examined, how the individual performance of participants was affected by the different conditions. The secondary tasks in the different conditions were designed to disrupt different strategies to different extents. This is why the individual differences of Corsi span between conditions A and B, B and C and A and C hold valuable information about the preferred strategy. For participants with a covert internal or covert external strategy, we expected no decline in performance between condition A and B (A-B ≈ 0), whereas a participant with a overt external strategy should present a reduction of Corsi span here (A-B > 0). We expected a performance impairment for all participants in condition C, compared to condition B as well as A (B-C > 0; A-C > 0). The magnitude of these differences correlates with the overall performance (the bigger the Corsi spans achieved, the bigger the differences in general. See figure 10). Aside from the magnitude, the algebraic sign of the difference was of primary interest for us: a positive difference meaning a performance impairment in the latter condition, a negative difference an improvement.

type	pattern	strategy	#
1	$(- + +)$	covert ext. internal	5
2	$(+ + +)$ $(+ - +)$	overt ext.	6 1
3	$(- - -)$	?	2

Table 2: Overview of the strategy types found. In the column *pattern* the algebraic sign of the Corsi span differences between different conditions is displayed (A-B B-C A-C). *Strategy* indicates the presumed preferred retention strategy. # displays the number of participants found with this pattern.

We found four different patterns of Corsi span change over conditions (for an overview see table 2). Five participants had a better performance in condition B than in A, and a worse performance in C than in A or B. In the following they will be assigned to "strategy type 1". Six participants demonstrated a decline in performance in all three comparisons. A single participant (VP05, see figure 10) demonstrated a decline from A to B and from A to C, but a slightly better performance in C than in B. As the first difference (A-B) is positive, meaning a decline of performance in B compared to A, this participant was nevertheless assigned to "strategy type 2", along with the other six participants with a positive A-B difference. Completely contrary to our hypothesis, two participants demonstrated a negative difference for A-B, B-C, and A-C. This means they could better their performance, even though the strategy restrictions imposed by the secondary tasks became greater.

In figure 11 the course of Corsi span over the factor condition for the strategy types 1 (a), 2 (b) and 3 (c) are displayed. As can be seen, the course of type 1 corresponded to our predictions made for participants using a covert strategy, while the course of type 2 corresponded to our predictions for the use of an overt externalising strategy (see figure 3 for our prediction of Corsi span course). The rising course of type 3 could not be explained by our hypotheses.



(a) type 1 (b) type 2 (c) type 3

Figure 11: Corsi span over the three conditions for the three strategy types: (a) type 1 (5 participants), (b) type 2 (7 participants), (c) type 3 (2 participants). The courses of type 1 and 2 correspond to our predictions for a covert and an overt strategy, respectively (see figure 3 for comparison).

3.3.1 Comparison of performance between strategy types

Here we further analysed, whether the assignment of a covert/internal strategy to type 1 and an overt strategy to type 2 is plausible. What should be kept in mind is that all analyses considering the strategy types had an extremely small n (as our overall number of only fourteen participants was further divided) and therefore a generally weak statistical power. As indicator for overall performance the Corsi span achieved in condition A was used, as on average the best performance was achieved here (see figure 9). As can be seen in figure 12, participants of type 1 achieved a mean Corsi span of 14.7 ($M = 14.7, SD = 6.19$), type 2 a mean of 18.6 ($M = 18.61, SD = 4.60$) and type 3 a mean of 5.9 ($M = 5.88, SD = 0.88$). A one-way ANOVA confirmed a statistical significant influence of the factor "strategy type" on the overall performance ($F(2, 18) = 14.97, p < .001$). Post-hoc tests revealed a statistical significant difference between type 1 and 3 ($p = .005$) and type 2 and 3 ($p < .001$), but not between type 1 and 2 ($p = .355$).

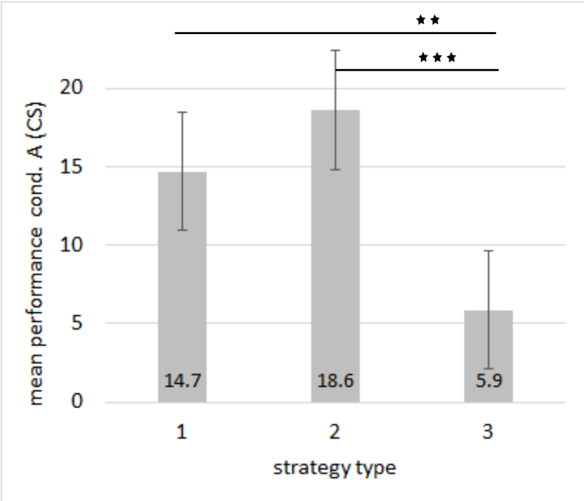


Figure 12: Comparison of mean performance (Corsi span) in condition A between the different strategy types. The two participants of type 3 had the worst performance. The difference between type 3 and type 1 was statistical significant ($p < .01$) as well as the difference between type 3 and type 2 ($p < .001$). Error bars indicate standard deviation.

3.3.2 Comparison of exploration extent between strategy type 1 and 2

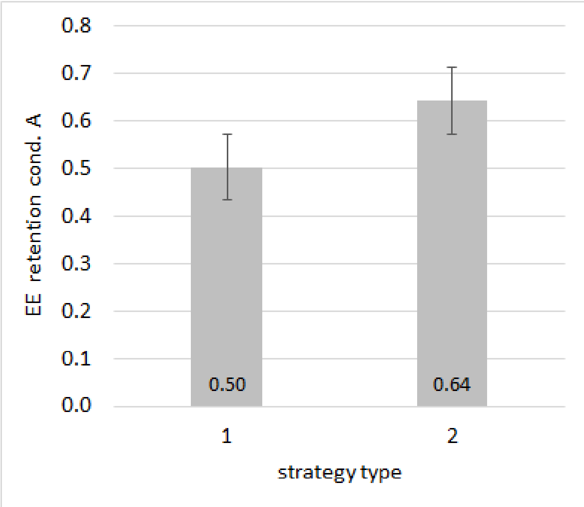


Figure 13: Comparison of exploration extent (retention condition A) between the different strategy types. The mean exploration extent of type 2 was 64% (SD = 18%) whereas type 1 had a mean of 50% (SD = 10%). The difference was not statistically significant, as a t-test for independent probes confirmed (p = .09). Error bars indicate standard deviation.

As indicator for a tendency towards an externalising strategy, the exploration extent (EE) during the retention of condition A was analysed (see section 2.4.2 for more analyses of the exploration extent). In general, the exploration extent was expected to be bigger in strategy type 2 (overt external) than in type 1 (covert external or internal). As can be seen in figure 13, the mean exploration extent of the seven participants of type 2 was indeed bigger (64%) than the mean of the five participants assigned to type 1 (50%). The difference was not statistically significant by conventional standards as a t-test for independent probes confirmed (type 1: $M = .50, SD = .10$, type 2: $M = .64, SD = .18$, $p = .092$).

3.3.3 Continuous strategy assignment

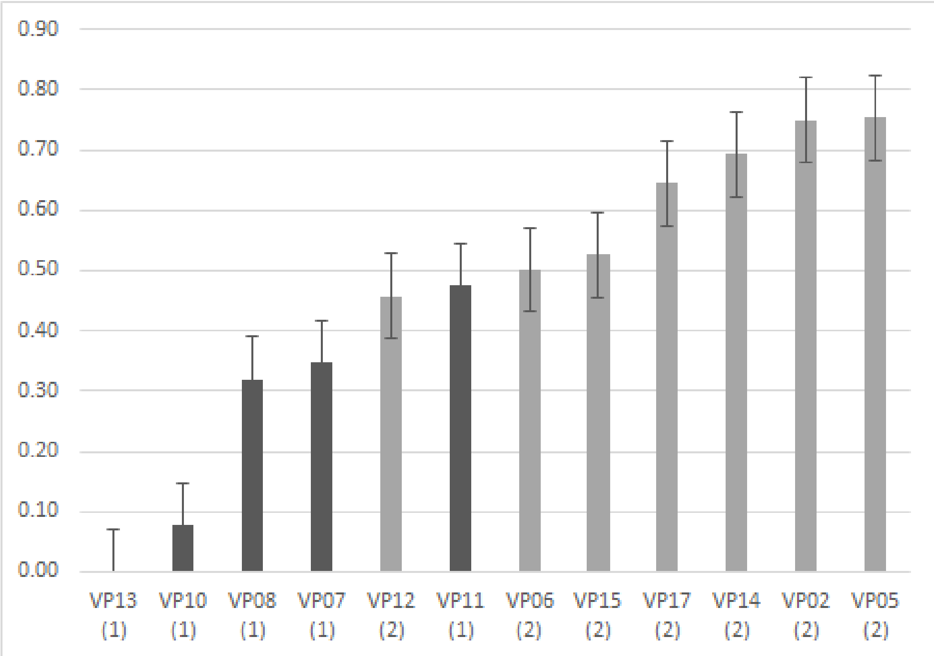


Figure 14: Continuous assignment to overt strategy in %. Participants of strategy type 1 (in dualistic assignment: covert or internal) are displayed in dark grey, participants of strategy type 2 (overt) in light grey. The strategy type is also indicated in parentheses below the participant. Spearman's rank correlation test confirmed a statistical significant correlation between continuous and dualistic strategy assignment ($r_s(12) = .808, p = .001$). Error bars indicate standard deviation.

As an alternative to the dualistic assignment to either strategy type 1 or 2, we wanted to find a continuous measure for the extent of overt strategy usage. In order to do so, the performance in condition A was determined as $x_A = 100\%$ for all participants. Then, the relative performance in percent in condition B and C compared to condition A was calculated ($x_B = \frac{B(CS)}{A(CS)}, x_C = \frac{C(CS)}{A(CS)}$). The calculated values were normalised between 0 and 1 using the following formula:

$$f(x) = \frac{x - min_x}{max_x - min_x}$$

Instead of concrete difference values as a percentage (that could happen to be $> 100\%$), the participant(s) with the smallest difference was assigned 0% and the one(s) with the biggest difference 100%. The values $f(x)$ in percent indicate the magnitude in relation to the differences achieved by the other participants. In the next step, the normalised difference between condition A and B was divided by the total normalised difference:

$$s(\text{participant } i) = \frac{f(x_A) - f(x_B)}{(f(x_B) - f(x_C)) + (f(x_A) - f(x_B))}$$

S now indicates the relative performance loss from condition A to B compared to the total performance loss for every participant (in relation to the other participants). A high value indicates the use of an overt strategy, while a small value indicates a covert or internal strategy. Spearman's rank correlation test confirmed a statistical significant correlation between the concrete strategy assignment (type 1, type 2) and the s value (continuous assignment) ($r_s(12) = .808, p = .001$). As the two procedures were strongly correlated, and analysis based on the continuous strategy assignment yielded no significant advantage over the use of the dualistic assignment (at least for our n of 14), the continuous assignment was not considered in the following data analysis.

3.4 Analysis of exploration extent (EE)

The exploration extent was used to determine the extent to which participants performed eye movements to the position of stimuli in the retention as well as the encoding phase (see section 2.4.2). A high exploration extent was used as an indicator for a preferred overt external strategy for retention of spatio-temporal information, whereas a low exploration extent indicated a preference for covert or internalising retention strategies.

3.4.1 Correlation between EE in encoding and retention phase of cond. A

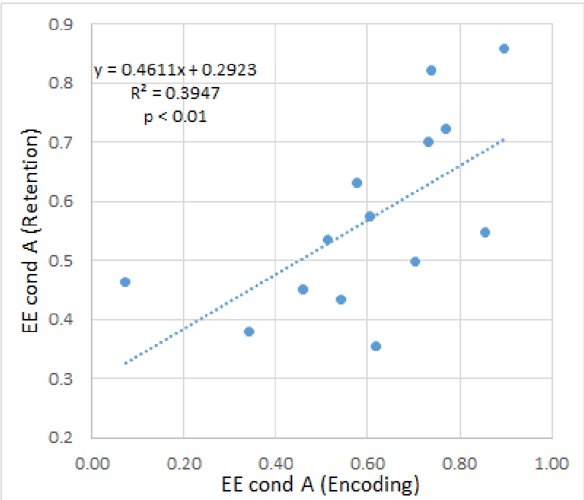


Figure 15: Correlation between the exploration extent in the encoding and the retention phase of condition A (free strategy choice) for all 14 participants. The dotted trend line indicates a positive linear relation. Spearman's rank correlation test confirmed a statistical significant correlation ($p < .01$)

In figure 15 the correlation between the exploration extent in the encoding and the retention phase of condition A is displayed for all participants. As can be seen, there is a positive linear relation with a slope of roughly 0.5 ($m = 0.46, c = 0.29, R^2 = .39$). This means if a participant performed little eye movements during the encoding, his exploration extent in the retention phase is also likely to be low. On the other hand, a participant with a high exploration extent in encoding, will probably also display a high exploration extent in retention. Spearman's rank correlation test confirmed a statistically significant correlation ($r_s(14) = .697, p = .006$). As can also be seen in figure 15, the range of exploration extent observed for condition A was fairly large, ranging between approximately 10% and 90% for encoding and approximately 35% and 85% for retention.

3.4.2 Robustness of EE during encoding over all three conditions

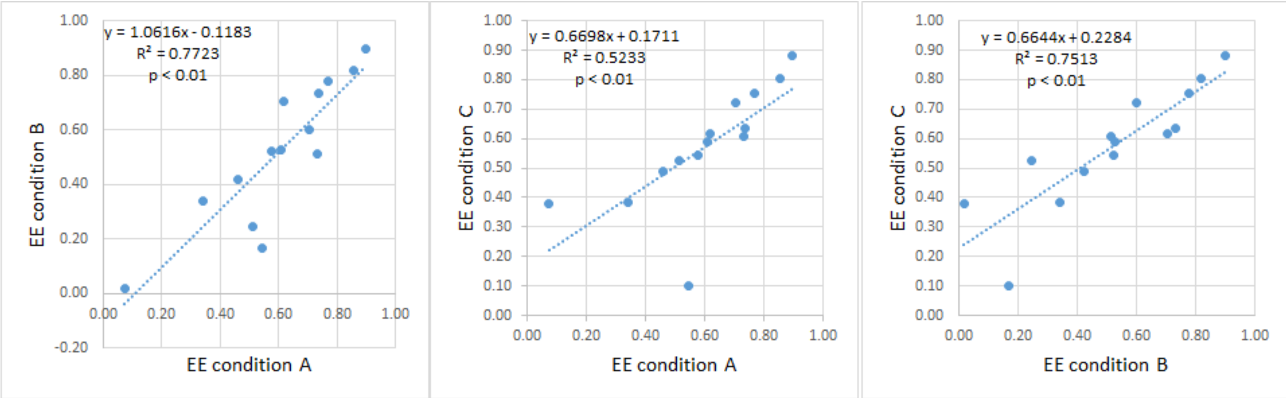


Figure 16: Correlation of exploration extent during encoding between condition A and B (on the left), A and C (in the middle), as well as B and C (on the right). The dotted trend line indicates the linear relation. Spearman's rank correlation test confirmed a statistical significant correlation ($p < .001$) for all three relations.

In figure 16 the exploration extent during encoding of condition A is plotted against the exploration extent of condition B. As can be seen, the correlation is again positive, has a slope of nearly exactly 1 and an y-intercept near zero ($m = 1.06, c = 0.12, R^2 = .77$). This means the participants tended to have roughly the same exploration extent in the encoding phase of both conditions A and B. The linear relations between condition A and C, as well as between condition B and C have both a positive slope of roughly 0.7 and an y-intercept of circa 0.2 (A and C: $m = 0.67, c = 0.17, R^2 = .52$; B and C: $m = 0.66, c = 0.23, R^2 = .75$). Spearman's rank correlation test confirmed statistical significance for all three correlations (A and B: $r_s(14) = .912, p < .001$; B and C: $r_s(14) = .956, p < .001$, A and C: $r_s(14) = .934, p < .001$).

3.4.3 Correlation between EE in retention phase of cond. A and B

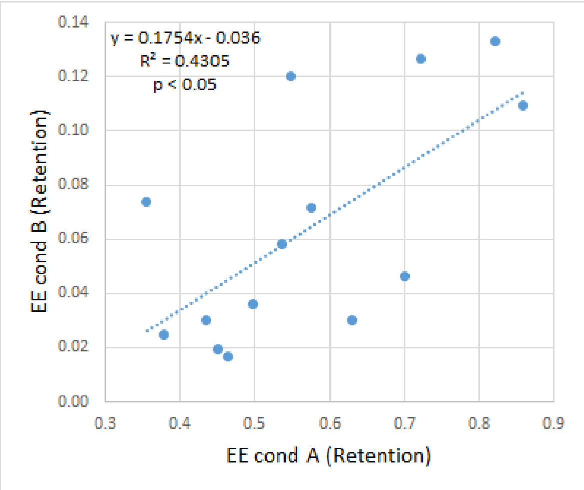


Figure 17: Correlation between the exploration extent in the retention phase of condition A (no eye movement restrictions) and B (forced fixation on the centre). The dotted trend line indicates a linear relation. Spearman's rank correlation tests conducted confirmed a statistical significant correlation ($p < .05$)

As explained in section 2.3.1, the aim of the experimental manipulation in the retention phase of condition B was to force the participants to maintain fixation on the centre of the fixation cross for the ten seconds of retention. For several reasons (technical as well as oculomotor), it was not possible to inhibit eye movements completely (resulting in EE=0 for all participants). However, for our objective in this condition, this was not necessary. The average exploration extent during retention of condition B was 6%. Compared to the average of condition A (57%), this value indicates that the eye movement constraint functioned adequately. In figure 17 the exploration extent during the retention phase of condition A is plotted against condition B. As can be seen, the EE in condition A (no eye movement restriction) varies between 35% and 86%. The EE in condition B (forced fixation on centre) varies between 2% and 13%. Interestingly, both values have a positive, linear relation ($m = 0.17, c = -0.04, R^2 = .43$). Spearman's rank correlation test confirmed statistical significance for this correlation ($r_s(14) = .607, p = .021$).

3.4.4 Correlation between EE during encoding of cond. B and CS difference between cond. A and B

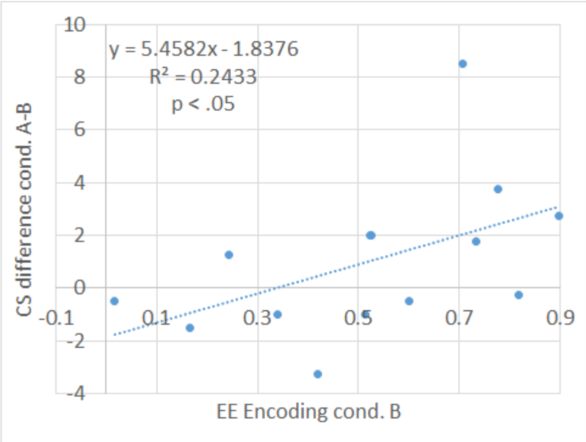


Figure 18: Correlation between the exploration extent during encoding of condition B (there were no eye movement restrictions during encoding) and the performance change between condition A and B (CS(A)-CS(B)). The dotted line indicates the linear relation. Spearman's rank correlation test confirmed a statistical significant correlation ($r_s(14) = .648, p = .012$)

As shown in section 3.4.2, participants tend to have a stable exploration extent during encoding over the different conditions, not adapting their acquisition strategy to the subsequent retention condition. In figure 18, the exploration extent during encoding of condition B is plotted against the performance difference between condition A and B. There is a positive linear relation between the two parameters ($m = 5.46, c = -1.84, R^2 = .24$). This means that the higher the EE during encoding, the higher the performance loss in condition B (forced fixation) compared to condition A (free strategy choice). In other words, the lower the exploration extent, the smaller or even negative the difference between Corsi span of condition A - B. Spearman's rank correlation test confirmed statistical significance for this correlation ($r_s(14) = .648, p = .012$).

3.5 Analysis of pupil size change differences (PSC_{diff})

The pupil size change difference was calculated comparing the pupil size changes of subtrials with a white background to those with a black background (see section 2.4.2 for details of the calculation). For the analysis, we only considered sequence length three, four and five. Too many participants struggled with longer sequence lengths in condition B, yielding too little data points for meaningful analyses.

3.5.1 PSC differences over different sequence lengths

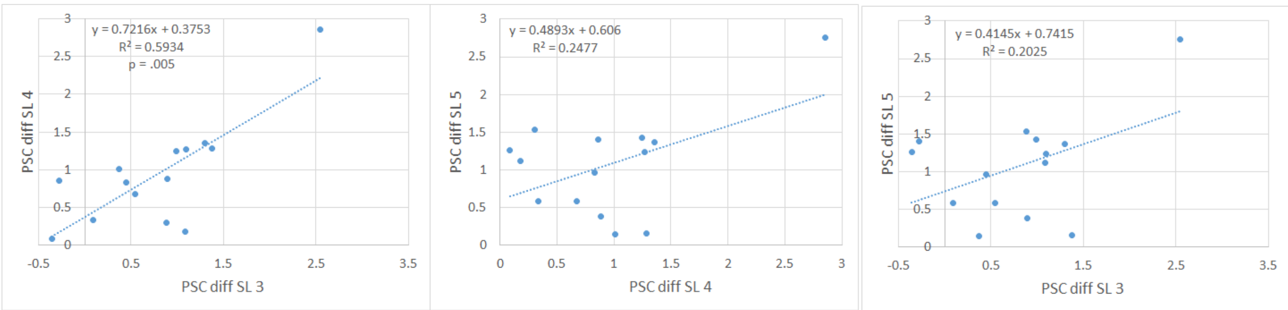
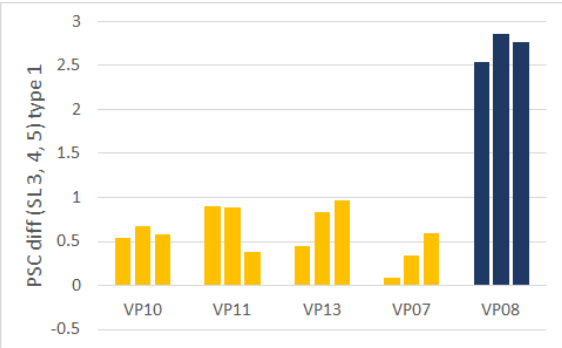


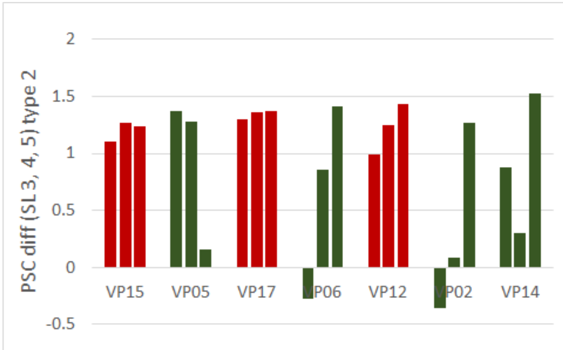
Figure 19: Correlation between the PSC_{diff} (in millimetres) for the sequence lengths three and four (left), four and five (middle) and three and five (right). All three have a positive linear relation (indicated by the blue dotted line). However, only the correlation between sequence length three and four is statistical significant as Spearman's rank correlation test confirmed ($r_s(14) = .701, p = .005$).

In figure 19, the correlation between the pupil size change differences between the different sequence lengths is displayed. The correlation between sequence length three and four was statistically significant as Spearman's rank correlation test confirmed ($r_s(14) = .701, p = .005$). The correlation between sequence length four and five, as well as the correlation between sequence length three and five had a linear, positive relation, although no statistically significant correlation ($p > .05$). Thirteen participants displayed PSC_{diffs} between roughly -0.4 and 1.4 mm for sequence length three and between 0.1 and 1.5 mm for sequence length four and five. One participant consistently showed a notably higher PSC_{diff} of about 2.5 mm for sequence length three and about 2.8 mm for sequence length four and five.

3.5.2 Individual PSC differences and strategy types



(a) PSC_{diffs} (SL 3,4,5) of strategy type 1



(b) PSC_{diffs} (SL 3,4,5) of strategy type 2

Figure 20: Individual pupil size changes in millimetres over sequence length three, four and five of participants of strategy type 1 (a) and strategy type 2 (b). The different colours indicate different patterns of PSC_{diff} over the three sequence lengths found (yellow: all $PSC_{diffs} < 1.0$ mm, blue: all $PSC_{diffs} > 2.5$ mm, red: $1.0 \geq$ all $PSC_{diffs} \geq 1.4$ mm, green: at least one $-0.4 \leq PSC_{diff} \leq 0.3$ and at least one $PSC_{diff} > 1.2$ mm). In figure (a) the colour yellow indicates the supposed internal strategy users, while blue indicates the use of a covert external strategy ($PSC_{diff} > 2.5$ mm).

In order to identify participants with a covert external strategy, we analysed the individual PSC_{diffs} over sequence length three, four and five. From sequence length six on, there were not enough data points for a meaningful analysis. The assignment of participants into strategy type 1 (covert external and internal) and strategy type 2 (overt external) made in section 3.3 was taken as a basis. The two participants of strategy type 3 were not considered. Due to their comparatively short Corsi span and unaccountable performance pattern over conditions there was no meaningful prediction to be made and tested at this point. Generally it should be kept in mind that the analysis done in the following is merely descriptive, as there is too little data for inferential statistical analyses.

Within the five participants of strategy type 1, two distinctive patterns of PSC differences could be distinguished. Four participants displayed PSC_{diffs} smaller than one millimetre for all three sequence lengths considered, while a single participant displayed a PSC_{diff} consistently above 2.5 mm (see figure 20 (a), yellow and blue bars). Within the seven participants of strategy type 2, again two different patterns could be distinguished. Three participants displayed PSC_{diffs} constantly between 1.0 and 1.4 mm. The other four participants displayed no such stable PSC_{diff} over all three sequence lengths (see figure 20 (b), red and green bars). During at least one sequence length they displayed a PSC_{diff} above one millimetre, while during at least one other sequence length the PSC_{diff} was close to zero ($-0.4 \leq PSC_{diff} \leq 0.3$ mm).

4 Discussion

4.1 Scanpath

We observed strikingly different examples of scanpaths performed by participants during both encoding and retention (see section 3.1). The two extreme cases presented in figure 8 are a strong indicator that these two participants relied on two fundamentally different strategies for both encoding and retention, resulting in such different scanpaths. Generally, some of the participants (the participant in the second row of figure 8 for example) tended to invest a lot of energy in eye movements as an external acquisition or retention tool. Following Hardiess and Mallot's idea of an individual cost-optimising trade-off discussed in section 1.6, this means they spent less energy on internal, mental maintenance strategies. On the other hand, participants like the one in the first row of figure 8 spent practically no energy on external strategies, therefore leaving more energy resources for either covert attention shifts or internal mental processes, such as mental imagery. These findings are in line with Walter (2016), who also found similar scanpaths ranging between nearly motionless fixation on the centre and constant retracing of stimuli locations.

4.2 Corsi span

Our experimental design is supposed to impair specific strategies in specific conditions. The analysis of Corsi span over conditions therefore indicates whether the intended experimental manipulation worked as expected. According to our hypothesis, the performance should be the best in condition A for all participants. The forced fixation in condition B should disturb only the participants using overt eye movements as retention strategy, leading to a performance decrease for only them. Condition C should negatively affect all participants, as the spatial secondary task competes with the resources necessary for the main task. The observed mean Corsi spans of all participants over conditions complied with our hypothesis, and indicated a robust experimental design for our research purpose. The best mean performance was found in condition A. In condition B the performance was slightly worse than in A, although not statistically significantly. In condition C, the mean Corsi span was, as expected, statistically significantly worse than in conditions A and C.

4.3 Strategy types

The individual performance differences between the different conditions were taken as indicators for the preferred retention strategy of the corresponding participant (see section 3.3). The classification in strategy types was based on the observed performance change pattern over conditions, given that our experimental design inhibited different strategies to a different extent over conditions. In the following the analyses performed will be discussed in order to verify a plausible assignment. Godijn and Theeuwes (2012) demonstrated that overt shifts of attention (including eye movements) do not provide an advantage over covert attention shifts in a task requiring the retention of spatial locations. Therefore, we expected a similar performance of participants with both an overt or covert external strategy. When the preferred strategy could be used (condition A) there should be no systematic performance differences between the strategy types, but only differences due to individual factors related to the participants themselves, their cognitive abilities or physiological condition for example. The performance of participants of strategy type 1 was not affected by the restriction of eye movements, therefore we expect participants with a covert external and participants with a internal strategy to be assigned to this type. The performance of participants of strategy type 2 decreased with the eye movement restriction in condition B, and we therefore expected participants with an overt external strategy to be assigned here. The observed performance pattern of strategy type 3 cannot be explained by our theoretical framework. However, a lack of concentration or motivation during the Corsi block-tapping task, leading to an overall worse performance compared to the others, might be an explanation for the performance pattern found here. For the reasons explained above, we expected the performance to be nearly the same for strategy type 1 and 2, although on a higher level than type 3. Indeed we found no statistically significant performance difference between strategy type 1 and 2, but a statistically significant lower performance of strategy type 3. As this is an indicator for insufficient diligence during the CBTT the two participants of type 3 were not further considered in the analysis considering the strategy types.

The second variable considered in order to evaluate the plausibility of the strategy assignment was the exploration extent. As there was no eye movement restriction during the retention phase of condition A the exploration extent performed by the participants here directly reflected their preferred strategy. This is why specifically the exploration extent during retention of condition A was consulted for the following analysis. Participants with both a covert external and internal strategy do not depend on eye movements for retention and therefore the mean exploration extent of strategy type 1 was expected to be comparatively small. Strategy type 2 had a preferred overt external strategy and we therefore expected strategy type 2 to have a bigger mean exploration extent than strategy type 1. This was indeed the case, although the difference was not statistically significant. For such a small sample size ($n = 14$) the p-value of .09 however is a good sign that the trend in the data follows the predicted direction.

In summary, the analyses performed spoke in favour of an sensible distinction made between the two strategy types. This underlying distinction between participants dependent (type 2) and independent (type 1) of eye movements was taken as a basis for further analyses. For the sake of completeness, the continuous strategy assignment was presented in the results section. As this assignment was strongly correlated with the dualistic assignment and yielded no advantage for the analysis, it was not further considered for this work. It might though be a useful tool for further analyses with more participants.

4.4 Exploration extent

The variable exploration extent (see section 2.4.2 for details) was used to determine to what extent the participants performed eye movements, as tool for information acquisition during encoding or as strategy of oculomotor rehearsal during retention.

We found a statistically significant correlation between the exploration extent during the encoding and retention of condition A. This indicates a stable strategy choice for both encoding and retention in condition A, where no strategy restrictions were imposed during retention. When free to do so, for both information acquisition and retention the same extent of eye movements, i.e. the same strategy, was used. But why is that so? In a famous experiment Godden and Baddeley (1975) let some participants learn lists of words on dry land, while others did so underwater. They then recalled the learned words either in the environmental context of encoding (on land or underwater, respectively) or out of this context. They could show that the reinstatement of the context of memory encoding leads to a better recall performance. In 2016 Röser, Hardiess, and Mallot investigated how the congruence of modality (screen or floor) of presentation and reproduction influenced the performance in a Corsi spatial sequence task. They found that reference frame transformations of information resulting from modality changes lead to a decreased performance. In a broader sense, the form of information acquisition can also be regarded as the “context” or modality of information encoding. Changing the form or strategy between encoding and retention might lead to similar negative effects for participants with an externalising strategy as described above for context and modality changes. If a participant encoded the information using overt eye movements, it is easier to retain the information retracing the stimuli with eye movements as well, while if another participant encoded the information using covert attention and his peripheral vision it is easier for him to retain the information with covert shifts of attention instead of switching to overt eye movements. Doing so, information loss due to context change or costly conversion processes of memorised information is avoided. The correlation of exploration extent during encoding and retention also is further evidence for our hypothesis of an individual, preferred strategy - that is applied during both encoding and retention whenever possible. The wide range of exploration extent found in condition A during both encoding and retention reflects the variety of eye movement involvement in the strategies used, also found by Walter in 2016.

We found a statistically significant, strong correlation of exploration extent during encoding between condition A and B, A and C, as well as B and C. These findings demonstrate a high robustness of the exploration extent over the different conditions. For the encoding phase, the participants tended to stick to their strategy independently of the condition. Participants with a high encoding exploration extent in condition A stuck to this strategy in conditions B and C, even though their overt external strategy was going to be impaired during the following retention phase. On the other hand, participants with a low exploration extent during encoding also stuck to their covert or internal strategy, independently of the fact that they were free to use external strategies in the following retention phase. This robustness in exploration extent showed the unwillingness to deviate from the preferred strategy, even when facing possible disadvantages resulting from the personal strategy. The statistically significant correlation between the exploration extent in the retention of conditions A and B, also speaks in favour of a strong, individual strategy preference and difficulties to deviate from it. Even when they were explicitly forbidden to perform eye movements, participants with a preferred external strategy scaled their exploration extent to a smaller level, but still performed eye movements. This indicates a subconscious urge to comply with the preferred external strategy. Participants with a low exploration extent during the retention of condition A on the other hand, also hardly performed any eye movements during the retention of condition B.

We observed a statistically significant correlation between the exploration extent during the encoding phase of condition B (forced fixation) and the performance change between condition A and B. The higher the exploration extent, the bigger the performance loss. The smaller the exploration extent, the smaller or even positive the Corsi span difference, respectively. This effect can also be explained with the concept of a dependence on the encoding context when retaining and/or retrieving a memory, explained above. With a very small exploration extent during encoding, it is possible to maintain this strategy for the retention, while participants with a preferred external strategy rely on eye movements during encoding and then have to perform a costly strategy switch in the subsequent retention phase, leading to a bigger performance loss compared to participants with a covert external or internal strategy.

4.5 Pupil size change differences

The variable PSC_{diff} was used to determine whether covert shifts of attention were performed during the retention of condition B in order to identify participants with a preferred covert external strategy (see section 2.4.2 for details on this variable).

From sequence length four and on, we observed a positive PSC_{diff} for all participants. This indicates that all participants performed covert attention shifts to some extent. However, this does not mean that all participants relied on covert attention shifts as retention strategy. The attention shifts could have been performed unconsciously along other strategies or the pupil size change had another confounding variable as a cause in the first place. As discussed later, the magnitude of PSC_{diff} has to be considered for a practical classification. The statistically significant correlation between the PSC_{diff} of sequence length three and four indicates that participants tended to perform covert shifts of attention to roughly the same extent in the retention phases of condition B during the first two trials with sequence length three and four. But how can we explain that the correlation between PSC_{diff} of sequence length four and five as well as three and five was not statistically significant any more? The eye movement restriction imposed during the retention phase in condition B particularly hindered participants with an overt external strategy. Independently from the preferred strategy, the task got harder with increasing sequence length. Even with the preferred strategy restricted, it might still have been possible to retain three or four stimuli in the short-term memory. With sequence length five the lower boundary of Miller's "magical number seven, plus or minus two" was reached, the limit of capacity for short-term processing (Miller, 1956). Now, participants with an external strategy might have attempted a strategy change, resulting in the diverging PSC_{diffs} compared to sequence length three.

According to our hypothesis, there should be a negative correlation between the PSC_{diff} and the performance change between condition A and B: a large PSC_{diff} indicates the use of a covert external strategy and therefore the performance should not be impaired in condition B compared to condition A. When considering all 14 participants, there was no such statistically significant relation between the PSC_{diff} and the performance change between condition A and B as Spearman's rank correlation test indicates ($p > .05$). However, as all participants displayed a PSC_{diff} to some extent, those who did not rely on covert shifts of attention as preferred retention strategy could have distorted the strength of the correlation. In order to investigate whether there really is a meaningful correlation the participants with a covert external strategy would have to be identified beforehand. In order to do so, we analysed the individual pupil size change differences.

4.5.1 Individual pupil size change differences

Participants of strategy type 1 do not rely on eye movements for their retention strategy. According to our hypothesis there are two fundamentally different ways to do so. Some participants retain the spatial information in an internal, solely mental representation, while others perform covert shifts of attention to uphold the information. Due to our experimental design, covert shifts of attention manifested themselves in pupil size change differences between the subtrials with a black and white background (PSC_{diffs}). According to our hypothesis, participants with an internal strategy display the smallest PSC_{diff}, as their strategy is the only one that does not externalise the information in some form and therefore should have the least interaction with the oculomotor system, responsible for covert shifts of attention and actual eye movements.

Within the five participants of strategy type 1 we found two very distinctive patterns of individual PSC_{diffs} over the three sequence lengths considered (see section 3.5.2). This finding is in line with our hypothesis of two different strategies used within strategy type 1: The first four participants (see yellow bars in figure 20 a) had a preferred internal strategy, while a single participant (see blue bars in figure 20 a) relied on the covert external strategy. The magnitude of PSC_{diff} of the one participant (VP08) with a supposed covert external strategy was around 2.7 mm on average. Generally the pupil light reflex (PLR) causes dilations or restrictions of the pupil in a range of about 3 mm, while pupil size changes due to cognitive load alterations only reach an effect of about 0.6 to 0.7 mm (Chen, 2014). We made use of the PLR to track covert shifts of attention as proposed by Unsworth and Robison in 2017. The observed PSC_{diffs} in our set-up were generally a lot bigger than in Unsworth and Robison's. The fact that the magnitude of PSC_{diffs} of VP08 corresponded to the one expected for a PLR is still a strong indicator that the participant was indeed performing covert shifts of attention as retention strategy. However, further data collection is crucial to verify this hypothesis as with a single subject the statistical power is far from sufficient for a statistically significant statement and VP08 could simply be an outlier. The fact that the other four participants with a supposed internal retention strategy all displayed a constant small PSC_{diff} also matches our predictions made, furthermore within strategy type 2 no other participant displayed the same pattern of constantly small PSC_{diffs}. Within the seven participants of strategy type 2, we also observed two different patterns. Within our theoretical framework this could be explained by an attempted strategy change to a covert external strategy within the first group (see red bars in figure 20 b) and with alternating, attempted strategy changes to either a more internal or a covert more externalising strategy within the second group (see green bars in figure 20 b). However, these supposed attempted strategy changes were not effective enough to maintain the performance achieved with the preferred strategy in condition A, as the performance of all participants of strategy type 2 worsened in condition B.

4.6 Summary

We assumed that the retention of spatial information demands the allocation of spatial attention (overt or covert) or other internal mental processes. Therefore, we expected to find three different strategies used: I) overt external strategy (using eye movements), II) covert external strategy (using covert shifts of attention) and III) internal strategy (using solely mental processes). We found solid evidence for the use of strategy I (overt external strategy using eye movements as an attention-based rehearsal process for spatial information retention): the evaluated scanpaths as well as the performance decline in condition B (forced fixation) compared to condition A (free strategy choice) observed in half the participants. We could also demonstrate that other participants do not require eye movements and therefore rely on either strategy II, by covertly shifting their attention, or strategy III, by retaining the information with an internal, mental process. In order to differentiate these two we proposed an experimental design making use of the PLR and the variable PSC_{diff} to track covert shifts of attention during the Corsi block-tapping task. We indeed found two fundamentally different patterns of PSC_{diffs} matching our hypotheses for strategies II (covert external) and III (internal), however more data is necessary to statistically verify these promising results.

We assumed that every participant has an individual preference for a particular strategy. This hypothesis could be confirmed. The observed robustness of the exploration extent over all three conditions demonstrates the stable preference for a certain strategy, independently of the given condition. The statistically significant correlation between the exploration extent in the retention phases of conditions A and B demonstrates not only a preference, but even a subconscious compulsion to perform eye movements in participants with a preferred overt external strategy. This individual preference for a certain strategy found in the Corsi block-tapping task can be explained with an individual, cost-optimising trade-off between internal and external processes as proposed by Hardiess and Mallot for the comparative visual search task. In a continuous process of strategy selection or adaptation each participant constantly allocates its attention and energy resources differently to achieve the best possible performance given the circumstances (sequence length, condition, cognitive and physiological state,...). For a general review of the process of *strategy selection* see Marewski and Link, 2014. More importantly, this hypothesis can explain the variety in evidence found for the involvement of various processes in visuo-spatial tasks presented in the introduction: the oculomotor system, overt eye movements, covert shifts of attention and the central executive.

The hypothesis that strategy changes to an alternative strategy can happen as an adaptation to different conditions or longer sequence lengths could not be definitely evaluated. The statistically significant correlation between the exploration extent during encoding of condition B and the performance loss in B compared to condition A shows that participants with an external strategy tend not to deviate from their preferred strategy during encoding, even if this represents a disadvantage in the following retention phase. Other observations, e.g. the PSC_{diffs}, speak in favour of attempted strategy changes happening, but rather mitigating than preventing performance loss in strategy restrictive conditions. Further analysis of the individual exploration extents and PSC_{diffs} over subtrials and increasing sequence length is necessary to conclusively answer the question of strategy changes.

As expected we observed a wide range in the extent of eye movements as well as a stable strategy choice between encoding and retention in the free strategy choice condition A. In condition B we expected participants with a covert or internal strategy to maintain their performance, while participants with an overt strategy show a performance loss. Seven participants not only maintained, but improved their performance in condition B in comparison to condition A while, as predicted, seven other participants displayed a loss of performance along with the eye movement restriction of condition B. In condition C we expected all participants to show a decrease in performance. Except the two participants of strategy type 3, all others displayed a decrease in performance in C compared to condition A. Assuming that the significantly smaller Corsi span and the unaccountable performance change pattern of these two participants is indeed due to poor concentration during the task, the first hypothesis can be regarded as confirmed. The hypothesis that participants with an internal strategy are most impaired by the secondary task in condition C could not be investigated in the course of this work due to too little data.

Considering the pupil size change we expected to observe the PSC_{diffs} in participants with a covert external strategy. Even if this is true in the one case we observed, with a single supposed covert external strategy user one cannot draw a statistically relevant conclusion. The hypothesis that participants with an internal strategy show the smallest PSC_{diff} could also not be investigated. For the testing of both hypotheses more data is necessary.

So how do we humans memorise visuo-spatial information over short periods of time? It seems that there is no universal answer to this question, true for all humans. Individual factors seem to play a lot bigger role in the strategy selection than discussed so far in the literature. To put it simple, as many things in life, it depends - on the individual, the tools and strategies available and the task at hand.

4.7 Open Issues

In subsequent experiments with a bigger number of participants, it would be advisable to introduce a lower limit of performance, i.e. only include participants in the analysis with a certain minimum performance (from Corsi span 10 upwards for example). This way it can be ensured that the participants included in the analysis solved the task with adequate diligence.

In our analysis, only the subtrials solved 100% correctly were considered. But as explained in section 1.1, the Corsi block-tapping task has a spatial (which blocks) as well as temporal (in which order) component. Consequently, errors made can be distinguished in spatial (block not in sequence) and temporal (block in sequence, but not in this order) ones. Analysing these two error types separately could yield further valuable insights about the functioning of spatio-temporal information retention.

The strategies I (overt external) and II (covert external) are well researched and documented. There are strong experimental methods to manipulate and track them. Strategy III (internal) on the other side, is hard to systematically manipulate. The inference of its existence is based on a simple procedure of exclusion: when the use of both other strategies is inhibited, the spatio-temporal performance does not drop to zero. This means there must be some other strategy still taking effect in this situation: an internal, mental strategy not relying on the oculomotor system. However, further investigation with methodically stronger manipulations than the spatial secondary task used in this experiment is necessary to better understand this process.

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5 Appendices

5.1 Declaration of consent

Probandeninformation zum Experiment

Experiment: Corsi Block Tapping Task zur Untersuchung von zeitlich räumlicher Kognition

Name des Versuchsleiters: Lílian de Sardenberg Schmid
Name des Projektleiters: Dr. Gregor Hardiess

Sie werden heute an einem Bildschirm-Experiment zur Untersuchung des räumlich-zeitlichen Arbeitsgedächtnisses teilnehmen. Dabei leuchten auf dem Bildschirm nacheinander verschieden viele Blöcke auf, deren Reihenfolge und Position Sie sich merken und wiedergeben müssen. Währenddessen werden Ihre Augenbewegungen aufgezeichnet und später ausgewertet. Das Aufzeichnen der Augenbewegungen erfolgt nicht invasiv, sondern rein passiv mittels eines am Bildschirm befestigten Eye-Trackers.

Ihre persönlichen, während dieser Studie erhobenen, Daten werden im Rahmen von wissenschaftlichen Publikationen - in anonymisierter Form - veröffentlicht und am Lehrstuhl für Kognitive Neurowissenschaft digital und anonym für 10 Jahre gespeichert.
Die Teilnahme an den Experimenten erfolgt freiwillig und kann zu jedem Zeitpunkt ohne Angabe von Gründen beendet werden, ohne dass Ihnen daraus Nachteile entstehen.

Tübingen, den ____________________ ____________________________
Unterschrift

☐ Ich möchte eine Kopie der Einverständniserklärung

Einverständniserklärung zur Teilnahme

Ich (Name der Versuchsperson in Blockschrift) ________________________________

bin schriftlich über die Studie und deren Versuchsablauf aufgeklärt worden und erkläre, dass ich volljährig bin, und bereit, an den o.g. Experimenten teilzunehmen.
Ich habe den Text der Probandeninformation und dieser Einverständniserklärung gelesen und verstanden. Aufgetretene Fragen wurden mir verständlich und vollständig beantwortet. Ich hatte ausreichend Zeit, Fragen zu stellen und mich für oder gegen eine Teilnahme zu entscheiden.
Ich erkläre mich damit einverstanden, dass meine persönlichen, während dieser Studie erhobenen Daten im Rahmen von wissenschaftlichen Publikationen - in anonymisierter Form - veröffentlicht und am Lehrstuhl für Kognitive Neurowissenschaft digital und anonym für 10 Jahre gespeichert werden.

Tübingen, den ____________________ ____________________________
Unterschrift

Figure 21: Information sheet and declaration of consent submitted for signature to the participants at the beginning of the experiment

5.2 Instruction of experimental procedure

Corsi Block Tapping Task mit 3 verschiedenen Zweitaufgaben

Lílian de Sardenberg Schmid

9. Januar 2018

Zusammenfassung

Du wirst heute an einem an einem Bildschirm-Experiment zur Untersuchung des räumlich-zeitlichen Arbeitsgedächtnisses teilnehmen. Dabei leuchten auf dem Bildschirm nacheinander verschieden viele Blöcke auf, deren Reihenfolge und Position du dir merken und wiedergeben musst. Währenddessen werden deine Augenbewegungen aufgezeichnet und später ausgewertet. Der Versuch ist in drei Blöcke unterteilt, in denen jeweils die Sequenzlänge 3 und 4, 5 und 6, 7 und 8 abgefragt wird. Zwischendrin wird der Eye Tracker neu kalibriert und du kannst eine kurze Pause machen, wenn du willst.

1 Verschiedene Bedingungen

Bei dem Experiment gibt es drei verschiedene Bedingungen, die verschiedene Zweitaufgaben mit sich bringen. Welche Bedingung die nächste ist, wird immer kurz vorher eingeblendet, zusammen mit der Länge der Corsi Sequenz, z.B. "Bedingung 1: 3". Das heißt, dass eine Corsi Sequenz der Länge 3 in Bedingung 1 auf dich wartet. Jede Kombination aus einer Bedingung und einer Sequenzlänge wird 4 mal wiederholt.

1.1 Bedingung 1: keine Zweitaufgabe

In dieser Bedingung leuchten nacheinander die Blöcke der Corsi Sequenz auf. Deren Position und Reihenfolge musst du dir merken. Bis du diese durch Klicks wiedergeben darfst, vergehen 10 Sekunden in der sogenannten Retentionsphase. In Bedingung 1 hast du hier keine Einschränkungen und darfst hinsehen wo du willst. Sobald das Zielkreuz deiner Maus aufleuchtet, darfst du die Sequenz wiedergeben.

1.2 Bedingung 2: Fixation auf das Fixationskreuz

In dieser Bedingung musst du in der Retentionsphase die ganze Zeit auf das graue Fixationskreuz in der Mitte schauen. Schaust du weg, kommt eine Fehlermeldung und du musst den Durchgang wiederholen. Sobald das Fixationskreuz in der Mitte verschwindet, darfst du durch Klicken die Sequenz die du gemerkt hast, wiedergeben.

1.3 Bedingung 3: zusätzliche Aufgabe für das räumliche Gedächtnis

In dieser Bedingung musst du in der Retentionsphase eine kleine Zweitaufgabe lösen. Dabei taucht in der Mitte ein Gitter auf, auf dem drei Vierecke erscheinen. Diese verschwinden wieder und nach einer kurzen Pause musst du ihre Position wiedergeben. Sobald das Gitter in der Mitte verschwindet, kannst du die Corsi Sequenz die du dir für die Hauptaufgabe gemerkt hast, wiedergeben.

Zu beachten

- Bitte immer genau in die Kästchen rein klicken, da der Klick sonst als falsch verwertet wird.
- Die Bedingungen tauchen in einer zufälligen Reihenfolge auf, also nicht immer unbedingt 1,2,3,...
- Sobald ein Fixationskreuz auftaucht bitte unbedingt so schnell wie möglich draufschauen und nicht wegsehen, bis es wieder verschwindet

1

Figure 22: Short written instruction of experimental procedure handed out to the participants alongside an oral explanation at the beginning of the experiment