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Quantification of memorization demand of block patterns in change detection

Diplomarbeit Bioinformatik

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Abstract

In this study we conducted a change detection experiment using the flicker paradigm. The first goal of this study was to investigate the difficulty to memorize different kinds of simple block patterns used as stimuli in our experiments. The second goal was to provide behavioral data from a change detection task to model the processes of degradation and consolidation concerning the information memorized.

1 Introduction

This project is intended to use a change detection trial for two reasons:
(i)to quantify the memorization demand of simple block patterns used as stimuli and
(ii)to provide data for modeling the processes of decay and consolidation in the human brain during such a trial.

1.1 Motivation

The two bases of this work are a study about the trade-offs between walking and memorization of simple block patterns for copying these patterns and the idea to model the processes in the visual working memory during change detection tasks. The first provides the idea for the stimulus material and variation within it. The latter provides the approach of a change detection task using the flicker paradigm and other relevant parameters, like stimulus and blank times.

1.1.1 Quantification of memorization demand of block patterns

In the experiments conducted by Hardiess et al. [HBM11] subjects were given the task to copy a pattern built out of LEGO ®DUPLO ®blocks. The model was shown at a model area (M), blocks were provided at a resource area (R) and the task was to rebuild the model identically at a working area (W). The participants were not allowed to carry more than one block at any time. The three areas were arranged in a triangular formation with two different distances (4.50 m and 2.25 m) between two areas as depicted in figure 1. Each area was only visible and manually accessible when standing right in front of it. The patterns were varied in the underlying construction rules for block placement, providing two different complexities as shown in figure 2.

The study shows the use of different walking strategies, categorized by the sequence of visited areas between two visits of the working area. Mainly two walking strategies were used. Firstly a low-memory strategy characterized by a visit sequence of W-M-R-W which implied the memorization of color and position of one block per visit at the model. Secondly a high-memory strategy, characterized by the sequence W-R-W in which memorized information from former model visits is used to place another block without further need for acquisition. The analysis showed different use of these strategies for each combination of distance and complexity, yielding a trade-off between acquisition and memorized pattern information. For the more complex patterns the use of the memory-intensive strategy is reduced, yielding longer walking distances. In contrast, for longer walking distances the use of the more memory-intensive strategy rises.

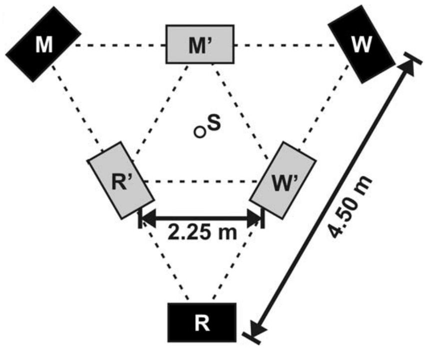

Figure 1: This figure illustrates the experimental setup used by Hardiess et al. for their experiment. It shows the three areas for the model (M/M'), the resources (R/R') and the working area (W/W') in the two different distance setups. S marks the starting point of the subject.[HBM11]

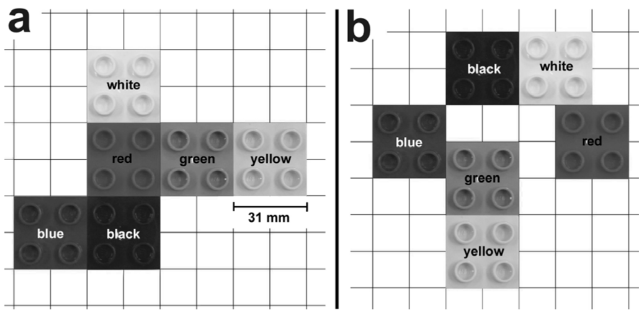

Figure 2: Model examples of the two different complexities used by Hardiess et al. (a) is a simple pattern (called easy in this work) using only full edge contacts in construction. (b) is a complex pattern using also half edge contacts and diagonal contacts in construction. [HBM11]

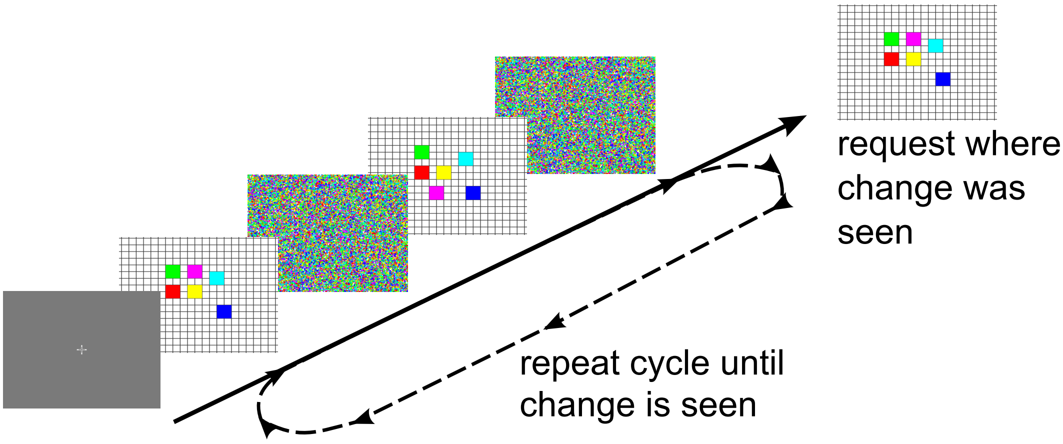

Figure 3: Exemplary display sequence of one subtrial. After a fixation cross of two seconds, the flicker, consisting of alternating presentation of stimuli and blank starts. It is kept until the subject announces the spotting of the change. Now one of the stimuli is shown to test whether the change was really perceived.

The question remained whether the assumed additional complexity of the patterns build by more complex rules really led to additional memorization demand. This question shall be investigated further by using the same kind of patterns as stimuli in a change detection experiment.

1.2 Change detection

The basic experimental setup commonly described as change detection task in visual research is quite simple. A stimulus is presented to the subject. The stimulus is then exchanged for an altered stimulus in a way that prevents the usual visual motion detection system from being utilized. The task for the subject is to detect the change. The difficulty of the task is not rooted in the marginal difference between the stimuli. Changes used are usually quite strong. The difficulty is to memorize the exact representation of one stimulus for comparison with the other one.

In our case two stimuli which differ in one detail are repeatedly presented, separated by a blank screen. This blank screen prevents the common way visual change is recognized by the human brain, by low level comparison of directly successive visual input. By using the blank screen the stimuli have to be memorized to be compared to the following stimulus after the blank screen. This is a task which is done by the visual working memory known to be limited in the capacity of storable elements [LV97]. So this change detection experiment yields an approach to quantifying the memorization demand for the stimuli by measuring the number of repetitions needed for recognition of the presented change.

1.3 Different concepts in change detection tasks

[Ren02] gives a good categorization of different approaches used in change detection experiments, according to which our approach shall be classified.

One of the first questions in a change detection experiment is how to conceal the change from motion detection mechanisms. We used a gap-contingent approach. This means that between each original and altered stimuli a mask (or blank) is shown, preventing the direct bottom-up comparison of the stimuli by the visual system. To detect the change, the changed part of the stimulus has to be memorized and represented until the presentation of the altered stimulus starts. Now remembered details may be compared with the new input in order to spot the change. Other possibilities here would have been saccade-contingent or blink-contingent which means change is applied during saccade or blinking of the eye respectively by closely monitoring the eye-movement. It is also possible to carry out the change during saccade-like shifts of the entire display (shift-contingent), while brief distractors are shown on the screen (splat-contingent), while only the changing item is briefly occluded (occlusion-contingent) or during movie-cuts (cut-contingent). Also gradual change can be used.

Regarding the repetition of change our setup is a repeated-change approach also known as the flicker paradigm [ROC97]. This means that unlike in one-shot paradigm where after one display of original and altered stimulus the altered stimulus remains and the subjects have to respond, the stimuli are presented continually with blank screen between each two stimuli. The trial proceeds until the change is spotted by the subject.

The stimulus display used in the experiments contained only colored squares on a grid and thus can be classified as simple figure. But change detection tasks can be accomplished with stimuli of arbitrary complexity. Also drawings of objects and scenes, images of objects and scenes, dynamic displays(movies) or real life interaction are in use.

The change we apply can be classified in two ways. The first possibility is a perception of property change to an object. This is the case if the pattern of blocks is perceived as one coherent object which changes its shape. If the blocks are perceived as different objects, this also could be seen as a layout change. Change of existence or semantic identity are other possible categories of change which are not applicable in this case.

Our subjects fully expect the change and should not be distracted by any other task. So in terms of observer intention we use an intentional approach rather than divided-attention or incidental.

The task for the subjects was the localization of the change rather than identification of the changed block, because even the position where the block had been in the other stimulus was counted as correct response. This includes detection of the change as a subtask.

Our response was visuomotoric. The subjects had to click on the currently presented block which had changed its position or the position the block had been in before. Hence it is explicit and not semi-explicit or implicit.

2 Methods

2.1 The change detection experiment

As stated earlier we conducted a change detection experiment using the flicker paradigm [ROC97]. As stimuli we used patterns containing colored blocks.

We systematically varied four independent variables. Two were in the scope of the flicker: the time one stimulus was presented per flicker cycle (166, 333, 666 and 1333 ms) and the time each blank appeared in between (166, 333, 666 and 1333 ms). The other two were in the scope of the stimulus: the number of blocks presented in the stimulus (6, 12 and 18) and the used set of rules to construct the stimulus (3 different rule sets, called easy, complex and hypercomplex). All variables were varied within each subject. Each combination of variables was presented once, leading to a total number of 144 trials per subject.

To eliminate any compromising effects of trial order, or make them obvious if occurring, the order of trials was pseudorandomized. The arrangement of stimuli and flicker times was made in a way that two consecutive trials did not have any variable setting in common with the help of Mix [vCD06]. Furthermore, the stimuli were assigned to their places in the pseudorandomized order in such a way, that the changing block of two consecutive trials never occurred in the same area of the screen or had the same color.

2.2 Experimental Procedure

After collecting their basic data the participants were given a printed instruction for the procedure of the experiments (figure 14). The experimental formalities were accomplished and for each participant the calibration of the eye tracking was checked and corrected if necessary. The stimuli presentation began showing three pretrials which contained each pattern size and complexity once. During the pretrials the experimenter was available beside the participant available in order to answer any questions thta might come up. The experiment began while the experimenter stayed in the room not visible for the participants but at hand for any occurring problems. The trials were split in three blocks. Before each block the eye tracking system was recalibrated. The first two blocks consisted of 48 trials each. At the end of block 3, after each subtrial was presented once, any failed subtrials were presented again until they were answered correctly. The complete experimental procedure took from 30 to 60 minutes.

Each subtrial containing one stimulus pair was initiated by a mouse click of the subject. The subtrial started with the presentation of a fixation cross for two seconds, followed by the flicker of stimuli and blank screens until the subjects stopped it by another click, once they had seen the change. If the click was applied during the presentation of a stimulus, this stimulus was shown until localization of the change by another click was completed. If the flicker was stopped during a blank presentation this last blank phase was completed before the display was switched to the next stimulus for localization. In either case the cursor was surrounded by a gray selection frame which had the size of one block. Any trials where the cursor position was inside either the currently visible changed block or the alternative changed block position were counted as correct.

2.3 Stimuli generation

The stimuli utilized in the experiment where simple block patterns derived from the experiments performed by Hardiess [HBM11] with LEGO®DUPLO®. They were generated according to a given rule set by a MATLAB®program, designed and implemented as part of this work. Each block was displayed as a square with side length 31mm.

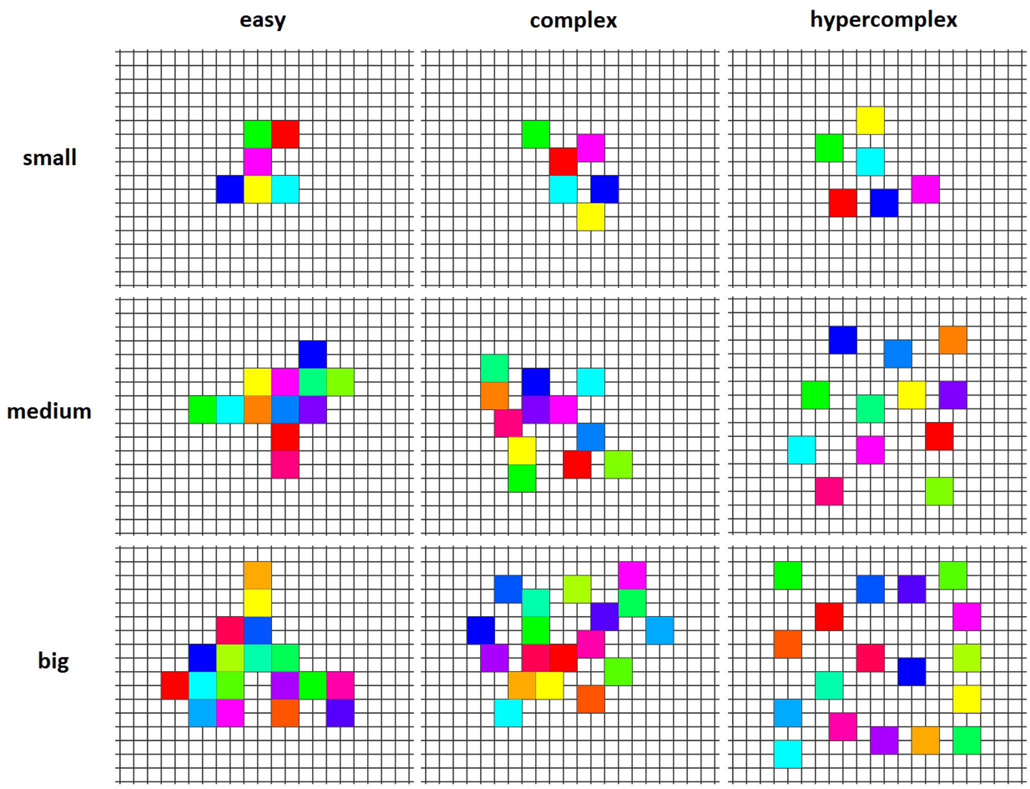

Figure 4: The 9 different types of patterns used in this experiment. The combinations of the three different difficulties (easy, complex and hypercomplex) and three different sizes (6, 12 and 18 blocks).

2.3.1 The grid

The block patterns were displayed on a grid of 21x17 white fields with separating black lines of five pixel width. Each block was placed according to the grid with its center on a crossing of two grid lines, covering four grid fields.
Only a part of the grid was available for block placement, in order to generate compact patterns and to keep the space occupied by the three different complexities on screen comparable. The space available for block placement was set to 9x9, 13x13 and 15x15 half blocks for the three different pattern sizes respectively.

2.3.2 Block placement

The placement of the blocks was done according to the rules for the different types of patterns used in [HBM11] . The first block was placed at the central position of the grid. In easy patterns every block after the first has to share at least one full edge with an already existing one, leading to full and diagonal contacts but to no half edges shared. In the complex condition every pattern of 6 blocks may display between one and two full edges, two to three half edges and one to two diagonal contacts. For patterns of 12 and 18 blocks the limits are doubled and tripled respectively. Each block has to share at least one kind of connection with another one. The hypercomplex condition does not allow any contacts between two blocks.

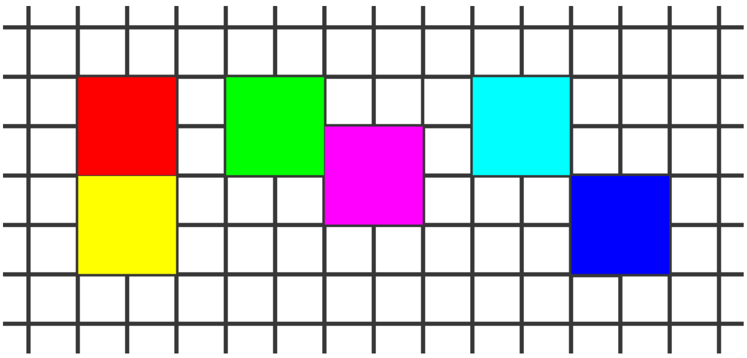

Figure 5: The 3 different types of block interactions. From left to right: full edge contact, half edge contact and diagonal contact.

2.3.3 Block color

Every pattern was generated consisting only of blocks colored differently. As colors we varied only the hue value of colors described in HSV-space. The colors were distributed with equal distances over the hue axis. Saturation and value were set to one. Note that this does not imply equality in the perceived distance of colors. Greater ease in discriminability would have been possible by adding variation in saturation or value. But this was dismissed in favor of the more colorful and thus probably more motivating simple hue variation.

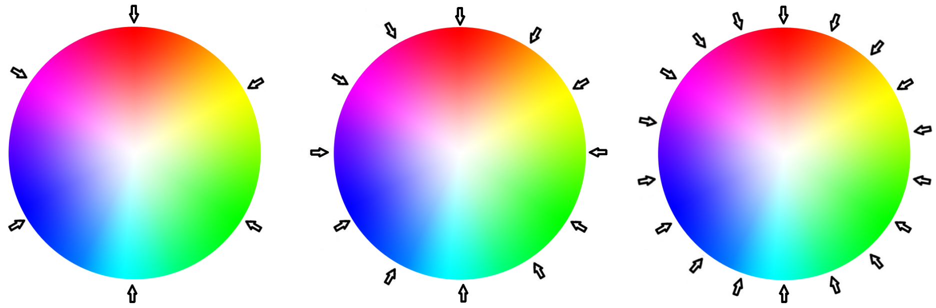

Figure 6: These three color wheels depict the relation between hue and saturation in the HSV color space, with value set to one. The hue describes the angle of a point in the circle with zero degrees at the top in the red area. The saturation describes the distance of a color from the center on a scale between zero and one. Setting saturation to one means we took only colors from the edge of the circle. The arrows mark from left to right the colors we chose for 6, 12 and 18 blocks in display, which were taken in equal distance within the hue dimension for each number of blocks. Saturation and value were constantly kept at one.

2.3.4 Change

The only change type used in our experiment was a change of the position of one block. This was due to the observation in [HBM11] that this was the most emergent kind of error in the block copying task. After generating a pattern according to the rules stated above, a block was chosen randomly and inserted back into the pattern at a position which led to a pattern which stuck to the rules the original was generated with. This implies that two associated patterns of the easy and complex variant do not necessarily share the same amount of contacts in each case. This also yields the preservation of the connectedness of these pattern variants. To make the change relevant, only position changes of at least 4, 6 or 7 grid length were possible for the different pattern sizes.

After generating an excess of stimuli pairs, those used for the experiment were chosen manually aiming for an equal distribution of colors in the blocks affected by the change and compact structured whose global shape was not affected by the change.

2.4 The blank

To prevent prolonged stimulus presentation due to after images we used 9 different randomly generated colorful blanks. Each was created by placing 40.000 circles of diameter between 5 and 15 pixel at random position on screen. The color of each

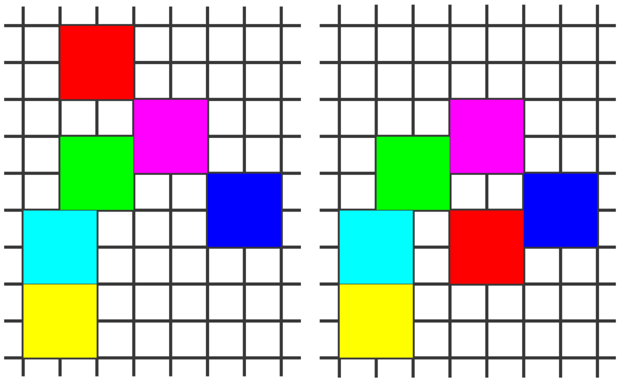

Figure 7: Example of a change used for these experiments. The red square moves from top left to the center of the pattern. Rules for complex patterns are still met, including connectivity. All other blocks retain their position.

circle was chosen randomly from the set of 18 colors used for the big block patterns as presented in figure 8 .

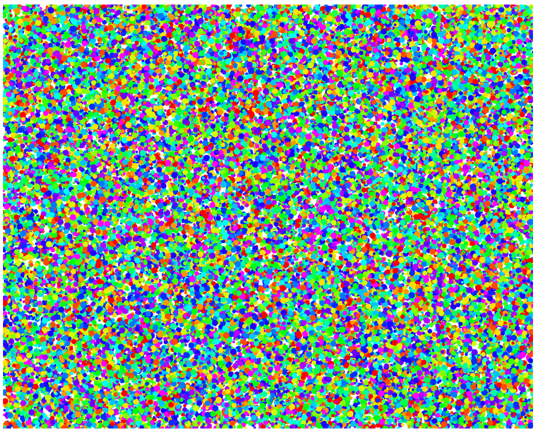

Figure 8: Example of one blank screen used in the change detection trial. It consists of 40.000 randomly placed circle in 18 different colors.

2.5 Apparatus

The experiment was conducted using an IBM-compatible computer with a 19 inch TFT screen with 60 Hz refresh frequency and a screen resolution of 1280 x 1024 pixel. The participants' responses were collected via a standard mouse and an eye-tracker. The pattern generation and the trial itself were implemented in MATLAB.

2.6 Participants

24 students aged between 19 and 36 (mean 26) formerly unknown to the experimenter took part in the experiments. 12 of them where male and 12 female. No color vision deficiencies where reported. All of them were recruited by an e-mail to all students of the University of Tübingen. All participants were paid for taking part in the experiment and gave informed written consent.

3 Results

3.1 Main effects

All 24 subjects finished the experiment. For 20 of them eye tracking data could be obtained. The data of one subject was removed from further analysis.

We measured the number of stimulus presentations until the subjects stopped the flicker. All results are based upon this data. We conducted a 4-way repeated measures ANOVA. Greenhouse-Geisser adjusted p-values were used due to violated sphericity. The results are shown in table 1. For post-hoc analysis Bonferroni correction was used. All four main effects were significant. Regarding the pattern size a clear correlation of increasing difficulty for growing pattern size can be seen(figure reffig:boxplotPatternSize). Post-hoc analysis showed that differences between all conditions were significant ($p < .001$). Also in stimulus duration an obvious relation of falling difficulty for increasing stimulus duration can be seen in figure 11. Post-hoc analysis showed significant differences between all conditions as well ($p < .001$). For the other two main effects the results are not that obvious. The post-hoc analysis showed that the easy patterns are really easier than complex and hypercomplex patterns ($p <. 001$). The difference between the complex and the hypercomplex patterns is not significant. For the different blank time conditions only the shortest differed significantly from the other three($p < .05$).

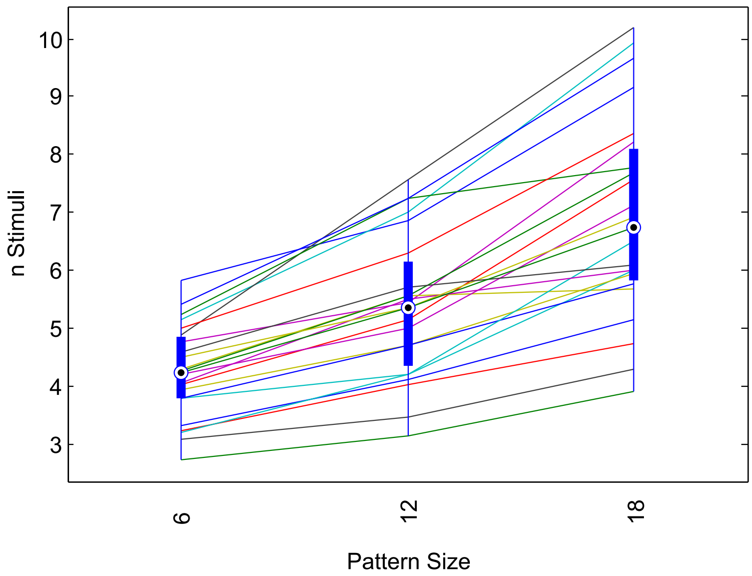

Figure 9: Boxplot of the mean number of stimuli presentations for each subject. Separated by pattern sizes. The line chart in the back shows the distribution for one subject per line. Already on subject level consistent rise of difficulty for increasing pattern size can be seen.

Table 1: Results of the repeated measures ANOVA. Assumption of sphericity was violated for all values. Greenhouse-Geisser adjusted p-values were used. *p <. 05 **p < 0.01 ***p < 0.001

Source	F
Size	107.64 ***
Stimulus Time	160.92 ***
Blank Time	10.77 ***
Complexity	21.42 ***
Size x Stimulus Time	39.27 ***
Size x Blank Time	1.32
Size x Complexity	4.94 **
Stimulus Time x Complexity	6.36 **
Blank Time x Complexity	7.05 ***
Stimulus Time x Blank Time	15.02 ***
Size x Stimulus Time x Complexity	4.13 **
Size x Blank Time x Complexity	7.06 ***
Stimulus Time x Blank Time x Complexity	4.1 **
Size x Stimulus Time x Blank Time	4.05 **
Size x Stimulus Time x Blank Time x Complexity	7.25 ***

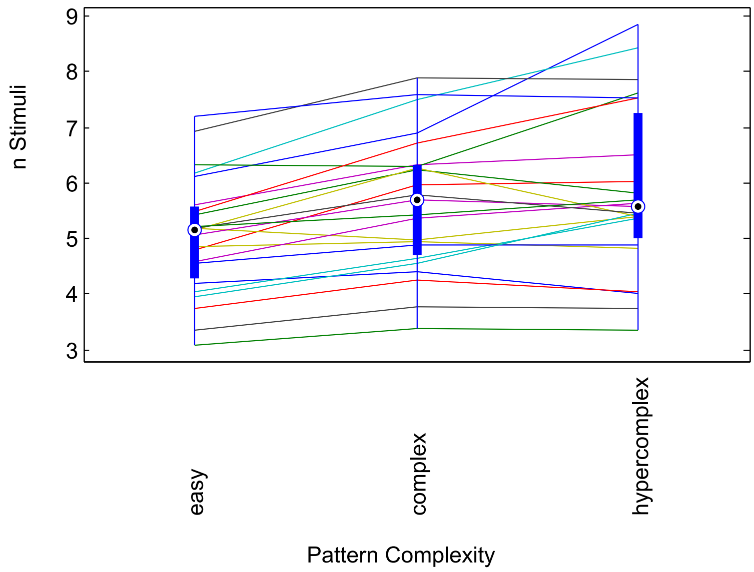

Figure 10: Boxplot of the mean number of stimuli presentations for each subject. Separated by pattern complexity. The line chart in the back shows the distribution for one subject per line. Post-hoc tests showed that the easy pattern conditions were really easier than complex and hypercomplex patterns. The difference between complex and hypercomplex is not significant.

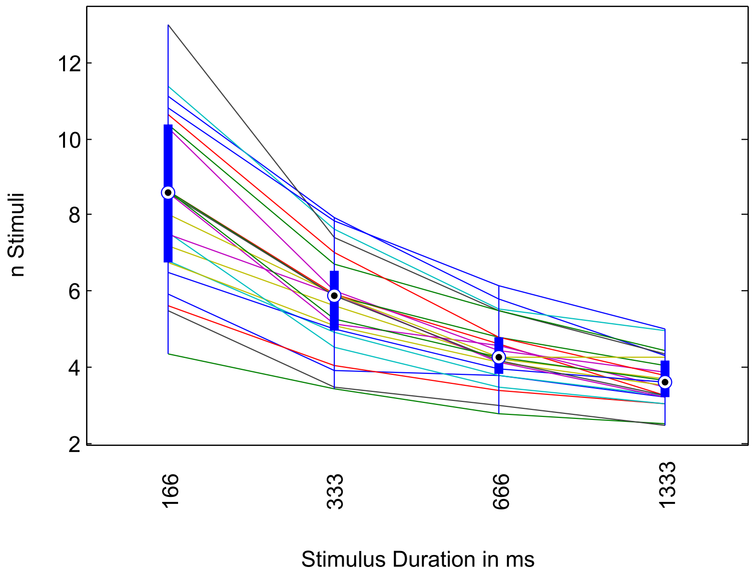

Figure 11: Boxplot of the mean number of stimuli presentations for each subject. Separated by stimulus time. The line chart in the back shows the distribution for one subject per line. Already on subject level nearly consistent decrease of difficulty for increasing stimulus time can be seen.

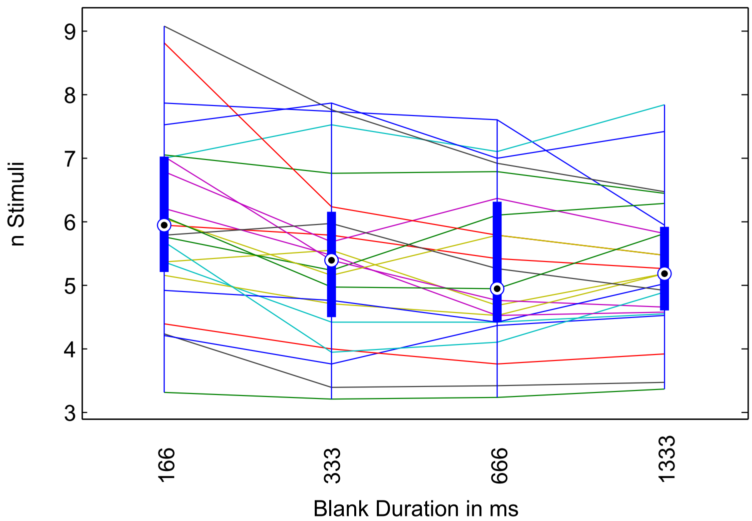

Figure 12: Boxplot of the mean number of stimuli presentations for each subject. Separated by blank time. The line chart in the back shows the distribution for one subject per line. Post-hoc tests showed that, compared to the other three conditions, only the 166 milliseconds condition is significantly different.

3.2 Two-way interactions

Five of the six possible two-way interactions reached significance level. Only the combination of pattern size and blank time did not. Plots for the other interactions are shown in figure 13. The significances of interaction between pattern size and stimulus time is produced by the much higher rise in difficulty for the shortest stimulus time (166 ms) in comparison with the three other conditions for higher pattern sizes (figure 13a). For the combination of pattern complexity and pattern size the lower slope of the easy condition compared to the nearly parallel complex and hypercomplex condition yields the effect (figure 13b). The stimulus time interaction with pattern complexities is fairly mixed. For 333 and 1333 ms stimulus time a nearly parallel slight increase in difficulty over the different complexities is visible. The significance of the main effect for different pattern complexities is mostly a result of the shortest stimulus time condition (166 ms). Here a large rise in difficulty for complex patterns in comparison with the easy condition is visible. Complex and hypercomplex condition are almost on an equal level (figure 13c). For the easy complexity-condition the major influence of blank time is a decrease for the 666 ms condition. The other blank durations show nearly the same level. Complex and hypercomplex condition are nearly parallel for all conditions except for 666 ms with hypercomplex slightly below complex. In the case of 666 ms the hypercomplex rises above the complex condition (figure 13d). For the longest stimulus duration (1333 ms) the blank has nearly no effect on the difficulty of the task. Only the longest blank time yields a slight increase in difficulty. For 666 ms of stimulus presentation the blank time causes mostly a reduced difficulty in the 666 ms condition. The short stimulus times are effected in opposite direction by the blank time conditions. With the combination of shortest stimulus and blank time the subjects needed the highest number of stimuli to recognize the change, whereas longer blank times led to fewer iterations. However, 666 ms of blank display was still harder than the alternative conditions. For 333 ms of stimulus presentation the effect of blank duration mainly shows a rise for 333 ms and a decay for 666 ms in comparison with the other two conditions (figure 13e).

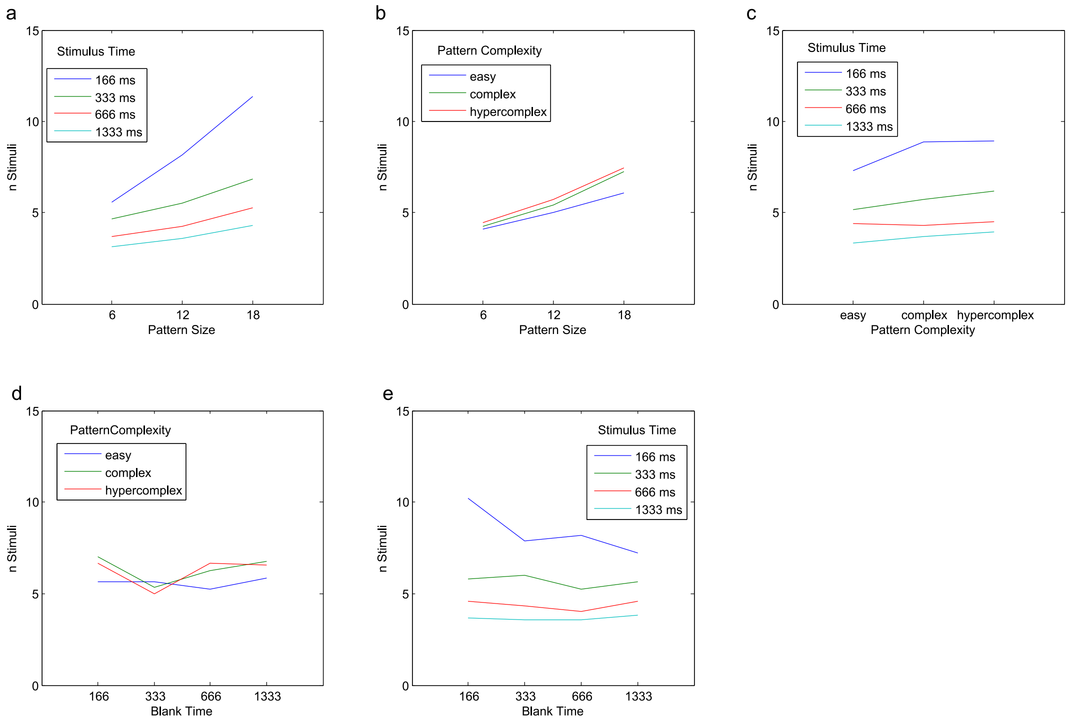

Figure 13: Plots for all significant two-way interactions. a) shows the interaction between pattern size and stimulus time, b) shows the interaction between pattern size and complexity, c) shows the interaction between pattern complexity and stimulus time, d) shows the interaction between blank time and pattern complexity, e) shows the interaction between blank time and stimulus time.

4 Discussion

The original goals of this work were only partly achieved. The change detection experiment was designed and conducted as planned. A customizable pattern generator was implemented, reusable for any further experiments using this kind of block patterns. The results regarding the quantification of the block patterns were only partly what we expected. For the size of the patterns increased memorization demand for a greater number of blocks could be shown. In terms of pattern complexity the patterns generated with the easy rule-set proved to be easier to memorize than the complex or hypercomplex ones as expected. But no significant difference between complex and hypercomplex patterns could be found. This might be due to the limited space each pattern was generated on. The intent to keep the on-screen pattern size comparable it resulted in hypercomplex patterns with only few possible positions within these boundary where the position change could occur. It is possible that this boundary was perceived because of the positioning of the blocks at this border. This may have led to a dramatic simplification of the task because not every single block in the hypercomplex condition had to be memorized but only the white spaces where a whole block could fit in without forming any contacts (compare figure 4). The great variety in single subject performances between complex and hypercomplex condition (see figure 10) might be due to some subjects using this strategy and others not.

The modeling of the achieved data primarily intended to be part of this work was not conducted due to lack of time. But first results looked promising.

A Appendix

A.1 Experiment instruction

Versuchsanleitung: Change Detection - Experiment

Vielen Dank für deine Teilnahme an diesem Versuch!

Der folgende Versuch testet die Schwierigkeit von verschiedenen Mustern über Change Detection. Es geht hier darum, den Unterschied eines Musters innerhalb zweier aufeinander folgender Bilder zu entdecken. Dieser Unterschied wird immer die Änderung der Position **eines** Steines im Muster sein (Abb. 1).

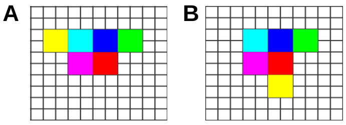

Abb 1: Hier sind die zwei aufeinanderfolgenden Bilder eines Musters im Versuch gezeigt. Die Positionsänderung bezieht sich auf den gelben Stein. A) Muster vor der Positionsänderung des Steines, B) Muster nach der Positionsänderung.

Jeder Versuchsdurchgang besteht aus drei Teilen:

(I) Er beginnt mit einem Fixationskreuz welches für 2 Sekunden gezeigt wird und welches du **möglichst genau fixieren** sollst solange bis es nach den 2 Sekunden verschwindet.

(II) Nach dem Fixationskreuz kommt der eigentliche Stimulus. Hier wird dir ein Muster mit farbigen Blöcken gezeigt (Abb. 1). Unmittelbar darauf verschwindet das Muster und wird dir kurz darauf wieder gezeigt. Nun hat jedoch **ein** Stein im Muster seine Position gewechselt. Wieder kurz darauf siehst du das erste Muster erneut (also mit der alten Position des Steines). Die beiden Muster wechseln so lange, bis du die Änderung erkannt hast.

Sobald du die Änderung bemerkt hast, **klicke sofort** mit der **linken Maustaste**!

(III) Nach dem Klicken der Maustaste wird das jeweilige Muster dauerhaft angezeigt und du sollst im Muster eine der beiden möglichen Positionen des Blocks (der seine Position verändert) anklicken. Dazu erscheint im Muster ein weißer Auswahlrahmen den du mit der Maus bewegen kannst

Wenn du auf der Position bist, **klicke** mit der **linken Maustaste**!

Bevor das eigentliche Experiment startet, werden dir **3 Probedurchgänge** gezeigt, um dich mit der Aufgabe und den verschiedenen Mustern vertraut zu machen. Dabei wird dir mit blauen Rahmen angezeigt, wo die Änderung zwischen den Bildern stattfindet. Das sind dann die Bereiche, die im Versuch als korrekte Antwort zählen.

Der Versuch ist in **3 Blöcke mit je etwa 48** Durchgängen unterteilt, wobei du nach jedem Block eine Rückmeldung erhältst, wie viele Durchgänge du schon absolviert und wie viele du davon richtig beantwortet hast. Ein neuer Block startet sobald du die linke Maustaste drückst. Du kannst also zwischen zwei Abschnitten eine Pause machen, wenn du möchtest.
Während des gesamten Versuchs werden deine Augenbewegungen mit einem Eye-Tracker aufgezeichnet. Während des Versuchs solltest du deinen Kopf auf der Kinnstütze möglichst ruhig halten. Deine Augen kannst du frei bewegen.

Falls du noch Fragen hast, wende dich bitte an den Versuchsleiter.

VIEL SPASS!!!

Figure 14: Experiment instruction

A.2 Erklärung der Urheberschaft

Hiermit versichere ich, dass ich die vorliegende Arbeit selbständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel verwendet habe. Diese Diplomarbeit wurde in gleicher oder ähnlicher Form in keinem anderen Studiengang als Prüfungsleistung vorgelegt.

Tübingen, den 15. Oktober, 2012 Unterschrift

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